DP2007/07

The pitfalls of estimating transactions costs from price data: evidence from trans-Atlantic gold-point arbitrage, 1886 – 1905

Andrew Coleman

April 2007

JEL classification: F15, F31

www.rbnz.govt.nz/research/discusspapers

Discussion Paper Series

ISSN 1177-7567

DP2007/07

The pitfalls of estimating transactions costs from price data: evidence from trans-Atlantic gold-point arbitrage, 1886 – 1905

Andrew Coleman[1]

Abstract

This paper argues that bilateral spatial price models do not estimate bilateral transactions costs when trade with third cities is important. The paper examines trans-Atlantic gold arbitrage during the gold standard era by assembling a database indicating when trans-Atlantic gold shipments occurred. It shows that two-way gold shipments between New York and London frequently occurred prior to 1901. However, in 1901 gold shipments to London ceased and were replaced by triangular arbitrage shipments through Paris. Consequently, New York and London gold price data cannot be used to estimate New York-London transactions costs after 1901, as no trade took place.

---

[1] The views expressed in this paper are those of the author and do not necessarily reflect the views of the Reserve Bank of New Zealand. I would like to thank Craig Brown, Neil Reddy, and Saurav Sen for assisting in the collection of the data that are the heart of this paper, and Raphael Portillo for providing useful research assistance. I would also like to thank Lawrence Officer, Galina Swartz, and seminar participants at the University of Michigan and Massey University for useful comments. A version of this paper is forthcoming in *Explorations in Economic History*. Address: Economics Department, Reserve Bank of New Zealand, 2, The Terrace, Wellington New Zealand. Email: andrew.coleman@rbnz.govt.nz.
ISSN 1177-7567

1 Introduction

In recent years several researchers have developed econometric techniques to estimate transport costs from the prices of goods in two different locations. These techniques have been based upon theories of bilateral arbitrage in which it is assumed the maximum difference between prices in two locations depends on the cost of shipping goods from one location to another. Three well known examples of these techniques include the switching regression model of Spiller and Wood (1988a), the threshold autoregression model of Obstfeld and Taylor (1997), and the technique used by Engel and Rogers (1996) in which the variances of the price differences between two cities are compared to the distance between the cities.

In this article I question the identification strategy of these papers. These techniques are appropriate only if bilateral trade between a pair of cities occurs and trade with other centres does not occur. However, if trade with a third city regularly occurs, these estimation techniques are not identified. The problem can be simply illustrated with an example. Suppose one wanted to estimate shipping costs from New York to London. If third markets were unimportant, New York would export to London when the London price exceeded the New York price by the New York−London shipping cost, and the maximum price difference between the two cities should reflect this shipping cost. In these circumstances, the bilateral price data can be used to estimate the shipping costs. If it were always profitable for Paris to import from both cities, however, this reasoning is false. Rather, New York exporters would ensure the Paris price never exceeded the New York price by much more than the New York−Paris transport cost, and London exporters would ensure the Paris price never exceeded the London price by much more than the London−Paris transport cost. Consequently, the London price would never exceed the New York price by much more than the difference between the New York−Paris and the London–Paris transport costs, and no exports from New York to London would occur. If someone used a switching regression or a threshold autoregression to estimate transport costs from London and New York price data, they would estimate the difference between New York−Paris and the London–Paris shipping costs, not the true New York−London shipping cost.

One way to circumvent this identification problem is to use trade data in

conjunction with price data. If the occasions when one city exports to another are known, the prices in the two cities on these occasions can be used to estimate transport costs. Trade data are hardly ever used for this purpose, however, because they are difficult to obtain at the same frequency as price data. Nonetheless, such data may need to be procured if bilateral transactions costs cannot be identified from bilateral threshold models.

This paper assembles a dataset covering a famous example of commodity arbitrage to demonstrate the difficulty of estimating transport costs from price data when third market effects are important. The example concerns the gold shipments between New York and London between 1885 and 1905, during the Gold Standard era. This example has been chosen partly because it has been widely studied – indeed, previous authors have used both switching regression techniques and threshold autoregression techniques to estimate transactions cost from price data – but mainly because it is possible to collect high frequency trade data to illustrate the problem. The paper establishes three main results:

(i) prior to 1901, gold exports from New York to London frequently occurred and New York−London shipping costs can be estimated from these cities' gold prices;
(ii) after 1901, New York exported gold to Paris, not London, and New York−London shipping costs cannot be estimated from these cities' gold prices;
(iii) after 1901, the maximum price of sterling in New York was not determined by the costs of direct gold arbitrage from New York to London, as traditionally understood, but by the cost of indirect or triangular arbitrage through Paris.

The change that occurred in 1901 can be traced to a change in the operating procedures of the Bank of France. Prior to 1900, the Bank of France sold foreign gold at a premium to the official rate, which raised the average price of sterling paper in Paris. In 1900 the Bank of France stopped charging this premium, which caused the average price of sterling in Paris to fall sharply, often to the point where gold exports from London to Paris were possible. This meant that when sterling was expensive in New York it was more profitable for arbitrageurs to export gold from New York to Paris and purchase cheap sterling paper in Paris to send to London than it was to

export gold from New York directly to London. In turn, this meant the maximum price of sterling paper in New York never reached the level where it was profitable to export gold to London.

The paper has a twin focus. One purpose of the paper is to demonstrate that bilateral econometric models cannot be used to estimate bilateral transport costs unless it is known that trade with third parties is unimportant. This point is made in a simple theoretical model in section 2. The second purpose is to refine our understanding of the trans-Atlantic gold arbitrage process, by documenting the frequency and direction of trans-Atlantic gold arbitrage transactions. In section 3, the dollar-sterling exchange rate market is outlined, and the data used in the paper are described. The data are used to estimate transactions costs between New York and London. In section 4, the dates on which gold was shipped to Paris and Berlin as part of a triangular arbitrage operation are documented and used to estimate the cost of sending gold from New York to Paris as part of a triangular arbitrage transaction. In this section it is shown that the increasing prevalence of triangular arbitrage was associated with the change in the Bank of France gold premium policy. Finally, a general discussion including a comparison with earlier literature is offered in section 5.

2 The identification problem in arbitrage models

Consider the Samuelson (1952) model of price arbitrage in which trade is instantaneous but costly, and where arbitrageurs ship goods to ensure that the price difference between any two cities never exceeds the cost of transport. The no-arbitrage condition can be expressed as the set of pair-wise conditions:

$$P_t^j - P_t^i - K_t^{ij} \leq 0; \qquad (P_t^j - P_t^i - K_t^{ij}).T_t^{ij} = 0 \qquad (1)$$

where

P_t^i = the price in location i at time t,

K_t^{ij} = transport costs from i to j at time t, and

T_t^{ij} = the non-negative quantity of exports from i to j at time t.

For simplicity, assume that it costs the same to export as to import, so that $K_t^{ij} = K_t^{ji}$.

If there are only two cities, i and j, the no arbitrage condition means $-K_t^{ij} \le P_t^j - P_t^i \le K_t^{ij}$. This is the case typically assumed by papers attempting to estimate transactions costs from price data. Suppose, however, that there are three centres, i, j, and h, and that it is cheaper to ship goods directly from one place to another rather than through a third centre; that is, for any combination of transport costs $K_t^{ij} + K_t^{jh} > K_t^{ih}$. In this case there are thirteen different combinations of trade between the three cities that are consistent with the no-arbitrage condition. Table 1 lists these combinations, organized to show how trade with city h affects prices in cities i and j. There are three combinations when city i exports to city h, three combinations when it imports from city h, and seven combinations when it does neither. When city i exports to city h, the price difference between i and j obeys the rule $K_t^{ih} - K_t^{jh} \le P_t^j - P_t^i \le K_t^{ij}$ with $P_t^j - P_t^i = K_t^{ij}$ if city i also exports to city j and $P_t^j - P_t^i = K_t^{ih} - K_t^{jh}$ if city j exports to city h (cases 1a-1c in table 1). When city i imports from city h, the price difference between i and j obeys the rule $-K_t^{ij} \le P_t^j - P_t^i \le K_t^{ih} - K_t^{jh}$, with $P_t^j - P_t^i = -K_t^{ij}$ if city j also exports to city i and $P_t^j - P_t^i = K_t^{jh} - K_t^{ih}$ if city h also exports to city j (cases 3a-3c in table 1). It follows, therefore, that the spatial price difference $P_t^j - P_t^i$ has a range of values that depends not only on the transport cost *Kij* but on the transport cost between each city and third cities as well.

Four of these thirteen cases are of particular interest. First, if third centres are unimportant, the no arbitrage condition means $-K_t^{ij} \le P_t^j - P_t^i \le K_t^{ij}$, and prices can be used to estimate transport costs (table 1, case 2d.) This is the same condition governing prices when there are only two cities. Secondly, if h is a major consumer of the good, and always imports from both i and j, the price difference $P_t^j - P_t^i$ will equal $K_t^{ih} - K_t^{jh}$, and there will be no trade between i and j (case 1a in table 1). Thirdly, if h is the major producer of a good and always exports to both i and j, the price difference $P_t^j - P_t^i$ will equal $K_t^{jh} - K_t^{ih}$, and again there will be no trade between i and j (case 3c in

table 1). In both of these circumstances the price difference $P_t^j - P_t^i$ is unrelated to the transport cost K_t^{ij}, and thus cannot be used to estimate transport costs between the two cities. The fourth case is when h normally trades with only one of these cities. Suppose, for instance, h always imports from j (table 1, case 2e). Then P_t^i can exceed P_t^j by the transport cost K_t^{ij}, but P_t^j will not exceed P_t^i by more than $K_t^{ih} - K_t^{jh}$, because at that point i will start exporting to h. In this case, city i will import from j, but never to export to it.

Most papers that have attempted to estimate transactions costs from bilateral price data have assumed that third centres are unimportant. However this assumption need not be true, particularly if production is regionally specialized. Indeed, third cities were only intermittently important to the New York-London gold trade between 1885 and 1900, and gold was regularly traded in both directions between London and New York. For this period, therefore, the difference between the London and New York prices can be used to estimate the cost of both exporting gold to and importing gold from London. In 1900, however, Paris started to import gold from London and New York on a regular basis and thereafter New York ceased exporting gold to London. In these circumstances, therefore, the difference between the London and New York prices cannot be used to estimate the cost of exporting from New York to London.

3 New York–London gold flows

3.1 The New York foreign exchange market[2]

Between 1880 and 1914 both the United States and Great Britain were on the gold standard. In the United States, notes could be redeemed for gold coin by the US Treasury at the rate of $20.67 per ounce, while pure gold could be coined or exchanged for notes for a 0.01 percent refining charge. In the United Kingdom, notes could be redeemed for gold sovereigns by the

[2] The foreign exchange market has been described in detail by Officer (1996), while additional information is available from contemporary texts including Margraff (1904), Escher (1913), and York (1923).

Bank of England at the rate of £3 17 s 10½ d or 77 shillings 10½ pence per 22 carat fine ounce, while gold could be sold to the Bank at the rate of £3 17 s 9d. As such, the local currency price of gold was essentially fixed in each country.[3] Consequently, trans-Atlantic gold shipments usually took place because of fluctuations in the dollar-sterling foreign exchange rate. The main foreign exchange security in New York was the demand or sight sterling bill, a cheque-like instrument that promised payment in sterling in London by a London bank upon delivery. If the price of sterling bills in New York were too high, an agent wanting to purchase sterling would find it cheaper to use dollars to buy gold and export that to London, where it would be converted into sterling. Conversely, if the sterling bills in New York were too cheap, agents could export gold from London to New York, sell it for dollars, and buy cheap sterling. The values of the exchange rate at which it was profitable to ship gold between London and New York were known as the gold points.

3.1.1 The gold export point

A gold export operation occurred when a bank sold a sterling bill in New York, purchased gold, and sent the gold to London. The gold was sold in London at the same time that the sterling bill was presented, so the bank would have funds in London to cover the bill without needing to borrow.[4] Arbitrage was profitable if the spot exchange rate S_t exceeded the gold point S_t^X,

$$S_t^X = \frac{P_t^{NY}(1+k_t^X)}{E[P_{t+1}^L]} \qquad (2)$$

---

[3] The bid-ask spreads at the US Treasury and the Bank of England meant that there was a little bit of variation in the price of gold in each country. Indeed, because of the technical rules governing the rates at which the Bank of England could buy and sell foreign gold coin, it was possible for the price of gold in Great Britain to vary from 77s 9d to 78s 1d, or by 0.43 per cent. See Sayers (1936) or Officer (1996) for a discussion. In an earlier version of the paper I compiled a new series on the gold price in London, and showed that fluctuation in the London gold price within this band explains some of the variation in the gold points. In keeping with earlier papers, this variation is ignored in this paper as it is of secondary importance.

[4] York (1923) chapter 3 discusses the transaction in detail.

where P_t^{NY} is the New York gold price, $E[P_{t+1}^L]$ is the expected sterling price of gold in London at t+1, and k_t^X is the cost of shipping gold from New York to London as a percentage of the New York price. Although the transaction was potentially risky, as the London gold price could change within the bid–ask spread by the time a gold shipment arrived, in practice there was little risk as the Bank of England purchased most of the gold exported to London at a price that was announced in advance. In this paper k_t^X is calculated from the spot exchange rate under the assumption that the Bank of England buying price was 77s 9d.

The above transaction describes what Officer (1996, chapter 8) called gold point arbitrage, as the bank both sold a sterling bill in New York and shipped gold to London. If the bank were simply choosing the cheapest way to create a sterling balance in London, the gold point would be slightly lower as the bank would have chosen either to buy a sterling bill or to send gold. Officer used the term "gold-effected transfer of funds" to describe gold shipments made when the bank chose to send gold rather than purchase a sterling bill. The gold export points associated with gold point arbitrage and gold-effected transfer of funds differ only by the bid-ask spread for sterling bills. According to Officer (1996, p 75), this was 0.25 cents per pound (or 0.05 percent) prior to 1910, and 0.05 cents per pound (or 0.01 percent) from 1910-1914.

3.1.2 The gold import point

A gold import operation occurred when a bank bought a sterling bill in New York and sent it to London, and simultaneously purchased gold in London and sent it to New York. The bank would borrow sterling in London to buy the gold, and borrow dollars in New York to buy the bill, so it would need to cover two interest payments while the gold and bills were in transit. It usually took ten days to send sterling bills or gold across the Atlantic. A transaction was profitable if the spot rate for bills S_t was less than the gold import point S_t^M,

$$S_t^M = \frac{P_{NY,t}}{P_{L,t}(1+k_t^M)} \frac{1}{(1+r_{L,t})^n} \frac{1}{(1+r_{NY,t})^n} \tag{3}$$

where k_t^M is the transaction cost to ship gold from London to New York as a percentage of the London price, rL,t is the London sterling interest rate, rNY,t is the New York dollar interest rate, and n is the time it took to ship gold, typically ten days (York 1923, p 107-114). If the two transactions were conducted simultaneously, the trade was riskless. Again, a distinction can be made between the gold import points associated with gold point arbitrage and gold effected transfer of funds, with the difference equal to the bid-ask spread associated with buying and selling a sterling bill in New York.

Equations (2) and (3) determine the exchange rates at which exports and imports of gold between London and New York were profitable, as a function of the transaction costs k_t^X and k_t^M , interest rates, and the price of gold in London and New York. These rates are also the maximum and minimum exchange rates that could occur without gold exports or imports to London being triggered. If third markets were unimportant, these rates would be the maximum and minimum values of the exchange rate, and it would be possible to estimate to the transactions costs k_t^X and k_t^M from the extreme values of the exchange rate. Several papers including Spiller and Wood (1988b), Prakash and Taylor (1997), and Canjels, Prakash-Canjels, and Taylor (2004) have used econometric procedures to estimate the gold points from high frequency dollar-sterling exchange rate data using this principle. Note, however, their procedures will not have identified the transactions costs k_t^X and k_t^M if trade with third markets were important.

3.2 Estimating the NY-London gold points using trade data

In this paper, the New York−London gold points S_t^X and S_t^M are estimated from the values of the exchange rate on the dates that trade occurred. To estimate the gold points, I assume that $S_t^M = S_t$ on the dates when imports occurred, and $S_t^X = S_t$ on the dates when exports occurred. In keeping with the earlier econometric literature, I ignore the way in which variation in interest rates and gold prices affected the gold points, but treat variation in these variables as part of the variation in the transactions costs. The information needed for these estimates are the dates on which gold was

shipped between New York and London, and the exchange rates on these dates.

3.2.1 Exchange rates

The exchange rates used in this paper are the "actual" rates for prime sterling sight bills, or the rates at which wholesale business was conducted. Daily data from 1896 onwards are obtained from Andrew (1910a), while earlier data were obtained from daily issues of the New York Times.[5] The exchange rates used to calculate the gold points are the maximum daily exchange rate during the week that gold was exported from New York, or the minimum daily exchange rate during the week that gold was exported from London. Figure 1 shows the average weekly exchange rate during the period. It fluctuates around the mint parity rate, the ratio of the dollar price of gold in New York and the sterling price of gold in London, equal to $4.8665 per pound.

3.2.2 The dates when gold arbitrage occurred

This is the first paper to estimate the gold points from the value of the exchange rate when gold was shipped. This method has not been used before because of doubts about the quality of the official gold shipment data. These doubts were first expressed by Virtue (1892), who showed that while the United Kingdom recorded $28 million in gold exports to the United States between 1887 and 1891, the United States only recorded $19 million in imports. He concluded the official figures were error riddled. Morgenstern (1955) came to a similar conclusion. He analysed official data from the United States, the United Kingdom, France, Germany and Canada for the years 1900, 1907, 1928 and 1935 and showed there was very little agreement between the amounts one country claimed to be exporting and the amounts the other country claimed to be importing. He also concluded that the official figures were sufficiently unreliable to be useless.

---

[5] Andrew (1910a) only records the posted or retail rates prior to 1896. The posted rates are only quoted to the nearest half cent, whereas the actual rates were quoted to quarter cents or sometimes finer, and they do not accurately reflect the high frequency variation in the actual rates. The pre-1896 data are different than those used by other authors and available on request.

In contrast, Goodhart (1969, p 171) examined United States and United Kingdom statistics for the years 1900 to 1913 and concluded that "the original figures recorded by the United States customs officials were usually reliable and that the resulting statistics of gold flows are not wildly inaccurate". He found that while monthly US data from the "Monthly Summary of Commerce and Finance of the United States"[6] were in close agreement with monthly UK data from the "Economist Monthly Trade Supplement of London", they were not always consistent with weekly customs data reported in the "Commercial and Financial Chronicle." Goodhart argued that the total shipments recorded by customs officials and reported each week in the Chronicle were accurate, but the separate country figures were sometimes wrong.

This paper uses a new source to identify the dates when gold was shipped. Each week the Commercial and Financial Chronicle printed an extensive summary of the foreign exchange market, noting whether or not gold had been engaged as a foreign exchange operation. The details the Chronicle published differed over time, but at best included the name of the bank making the shipment, the amount shipped, the date the engagement was made, the source or destination country, and the ship upon which it was shipped. The commentary was not always so detailed, and often shipments were recorded without a destination being named, or with the destination named as "Europe" or "the Continent". Nonetheless, for much of the period these data can be used to identify when gold was shipped between New York and Britain, and between New York and France or Germany. The commentary was published each Saturday and reflects information gathered from a variety of sources including the New York Assay Office, the Bank of England, and traders in London, Europe, and New York. The commentary is thus distinct from the weekly tables published in the Chronicle that are complied from customs figures.[7]

---

[6] Department of Commerce and Labor, Bureau of Foreign and Domestic Commerce (Washington).

[7] The difference is best seen in the reporting of gold exports from London. The commentary reported the departure from London, but the customs table only reported their arrival in New York two weeks later.

To create a series indicating whether or not a gold shipment occurred, the market commentary was first cross-checked with the customs officials' figures reported in the Chronicle. The two were normally in agreement, but if the commentary were unclear and the customs officials reported a shipment to or from Britain that was confirmed by British data, it was presumed that a shipment took place. In addition, for data from 1896 onwards, the market reports were compared with a weekly shipping table published in the New York Times. This table included myriad details about specie shipments including the name of the ship, the date of arrival or departure, the port of origin or destination, and the quantity and type of gold imported or exported (bullion, US gold coin, or foreign gold coin.) The original source of these data is the same as the Chronicle Table, but the additional information could sometimes be useful in determining the origin or destination of gold on a ship that stopped at multiple European ports.

The weekly export and import data provided by these three US sources were compared with monthly British data to ensure there was a British record of shipments that matched those in the United States sources. The data came from the Economist's Monthly Trade Supplement. A Chronicle record of an import engagement was considered verified if in the same month there were a British record of a large export. A Chronicle record of an export was considered verified if in the same month, or the next month if the export occurred during the last ten days of the month, there were a British record of a large import. Only dates when shipments of at least £100 000 were noted in the British records were used. The shipment dates are listed in appendix B.

The accuracy of the paper's empirical estimates naturally depend on the accuracy of the constructed series indicating whether or not a gold shipment occurred on a particular date. While it is possible to query some of the dates, the commentary in the Chronicle is normally consistent with the other sources, and, in the absence of strong a priori reasons to disbelieve the Chronicle's reporting, it seems reasonable to accept their reporting at face value unless contradicted by other sources. In the next two paragraphs I discuss some of the occasions when the three sources are not consistent. The vast majority of these cases occurred between June 1892 and December 1896, and for this reason I place much less emphasis on this sub-period than the rest of the period.

In the Chronicle commentary, there were 87 announcements of imports from England, and 34 announcements of imports from Europe. On 108 of these occasions, the shipping tables reported an import of gold from England within two weeks. Six of these could not be clearly confirmed by British sources, including three occasions in the immediate run up to the 1893 New York banking panic, when the Chronicle reported the importation of very small amounts of gold. In another ten cases, there were special circumstances mentioned about the gold imports which meant I did not use the records for they were not normal gold arbitrage operations. (For instance, at the beginning of 1895 there were five weeks when gold was imported by the Morgan Belmont syndicate as part of a U.S. Treasury gold bond issue; the terms of the bond specifically stipulated that the loan be made in foreign denominated gold, so these imports were not conducted as arbitrage operations.) I also added eight extra imports to the list, twice when there was an announcement supported by British sources but not recorded in the shipping table, and six times when imports were announced without mentioning a source, but all other indications suggest they came from England. In total, therefore, the three sources are consistent for 88 per cent of the import dates considered for inclusion in the paper, with the remainder subject to interpretation.

The Chronicle also had 28 announcements of exports to England and a further 156 exports to Europe. 103 of these announcements occurred in a week when the custom table reported an export to England. Of these, 13 export announcements were not consistent with the United Kingdom gold import records, of which nine occurred between June 1892 and December 1896. I also added three weeks when an export was announced in the Chronicle without specifying a destination, but when the customs table and United Kingdom import records indicated the export was to England, and two occasions when Chronicle announced an export to "the Continent" but the customs table and United Kingdom import records indicated the export went to Britain. In four of these five additions, there were exports to England in a string of preceding and succeeding weeks. Three of these additional weeks were in 1894 or 1895. In total, the three sources are consistent for 83 per cent of the export dates considered for inclusion in the paper, with the remainder subject to interpretation.

3.3 Direct estimates of the dollar-sterling gold points

Gold was shipped frequently, with imports or exports occurring on one fifth of the weeks. The values of S_t^X and S_t^M when gold was shipped are shown in figures 2 and 3, and the means and standard deviations of these values for different periods are shown in table 2. Separate estimates were made for four periods: January 1886–December 1889; January 1890–June 1892; July 1892–December 1896; and January 1897–December 1905.

3.3.1 1886 – 1889

There were 209 weeks in the period. Gold was exported to Britain during 27 weeks, and imported during 20 weeks, or 13 and 10 percent of the time. The mean exchange rate when gold was imported was \$4.8370, or -0.61 percent from mint parity and the mean exchange rate when gold was exported was \$4.8925, or 0.53 percent above mint parity.

3.3.2 1890 – June 1892

There were 130 weeks in the period. The end-date of the period is somewhat arbitrary, and was chosen because of the poor quality of the data during the last six months of 1892. Gold was exported to Britain during 18 weeks, and imported during 13 weeks, or 14 percent and 10 percent of the time respectively. The mean exchange rate when gold was imported was \$4.8338, or -0.67 percent from mint parity, and the mean exchange rate when gold was exported was \$4.8872, or 0.42 percent above mint parity. The decline in the gold export and import points occurred primarily because after 1890 the Bank of England regularly manipulated its bid–ask spreads to attract gold from New York, or to prevent an outflow from London.

3.3.3 July 1892 – 1896

The estimates for the third period are the most problematic, and the least useful guide to normal transactions costs. First, the data for 1892 to 1895 were the least informative, for the Chronicle frequently omitted the name of the destination or source country when a shipment occurred. Secondly, gold was shipped at highly irregular values of the exchange rate on several

occasions in response to doubts about the ability and willingness of the US government to redeem its notes in gold. The doubts surfaced after the passage of the 1890 Sherman Silver Act, which obliged the Government to purchase fifty million dollars silver annually, and continued until McKinley was elected in 1896 on a "hard currency" platform. During this period there were four major instances of foreign capital flight and three occasions when US currency traded at a discount to gold.

Three examples illustrate why gold point values estimated for the period 1892–1895 are unrepresentative of the normal gold points. First, when the reserves of the New York banks collectively fell below the statutory minimum during the July 1893 financial panic, the exchange rate fell to $4.8200, the lowest value for the whole period 1886-1905.[8] Without reserves, the arbitrage banks could not buy sterling bills even though they were heavily discounted. Second, on the three occasions when gold was trading at a premium to currency, gold was imported when the exchange rate was $4.8500 or more.[9] Third, when the US government issued bonds payable in gold through the Morgan-Belmont syndicate of foreign exchange banks gold in 1895, gold was only exported at extraordinarily high rates. The syndicate banks agreed not to export gold even if the exchange rate were above the gold export point, in return for the right to manage the sale of the bond, and the exports were made by gold bullion dealers and coffee houses.

There were 236 weeks in the period. Gold was exported to Britain during 39 weeks, and imported during 21 weeks, or 16.5 percent and 9 percent of the time respectively. The mean exchange rate when gold was imported was $4.8408, or -0.53 percent from mint parity, and the mean exchange rate when gold was exported was $4.8960, or 0.61 percent above mint parity. These values reflect the exceptional circumstances of the period and are not

---

[8] The exchange rate fell to $4.8200 on July 27 and remained extraordinarily low until August 7 when the SS Umbria arrived in New York from London with gold.

[9] The first occasion a gold premium was paid occurred in August 1893 when New York banks became illiquid and were forced to use clearinghouse certificates. The second occasion was in January 1896, when the government floated a bond payable in gold. The third occurred in October 1896, when many people converted currency into gold as a precaution against an election victory by presidential candidate Bryant.

a useful estimate of arbitrage costs.

3.3.4 1897 – 1905

There were 471 weeks in the period. Gold was exported to Britain during 11 weeks, and imported during 46 weeks, or 2 percent and 10 percent of the time respectively. Ten of the exports to London occurred between June 1899 and August 1900 when the Bank of England paid interest on gold shipments and manipulated the gold bid-ask spread to attract US gold because of the disruption caused by the war in South Africa. The mean exchange rate when gold was imported was $4.8408, or -0.53 percent from mint parity, and the mean exchange rate when gold was exported was $4.8805, or 0.29 percent above mint parity. While New York imported gold from Britain throughout the period, the last gold shipment to Great Britain as a part of an ordinary arbitrage transaction was a shipment of $1000 000 on April 27 1901.[10]

3.3.5 Summary

Gold was shipped between New York and London throughout the twenty year period. According to this data set, there were one hundred weeks when gold imports occurred, and ninety five weeks when gold exports occurred. With one exception, the frequency of the trade means it is possible to estimate the costs of shipping gold between the two cities, if trade data are used to indicate when the shipments occurred. The estimated average cost of exporting gold from New York to London declines from 0.53 percent between 1886 and 1889 to 0.42 percent between 1890 and 1892 to 0.29

---

[10] This is the last shipment in the period ending 1905. There were three additional shipments between 1907 and 1910, but none of these was a traditional arbitrage transaction. In June 1907, nearly $3 million gold was exported to London after the Bank of England advanced credit to the arbitrageurs to induce them to ship gold for the end of year settlement. In March 1909, nearly $14 million of gold was shipped to London so that the London joint-stock banks could create their own vault reserves of American gold coin. In April and May 1910, $32 million American gold coin was sent to London. It was imported partly by joint stock banks building their own vault reserves, and partly by the Bank of England, which paid an unusually high price for it. The Bank was wishing to rebuild their reserves after they had fallen extraordinarily low, and deliberately paid a premium for US gold rather than obtain gold from France.

percent between 1897 and 1901. The decline occurred partly because of Bank of England incentives to make exporting more attractive. The estimated cost of importing gold range from 0.61 percent between 1886 and 1889 to 0.67 percent between 1890 and 1892 to 0.53 percent between 1897 and 1905. These costs are higher than the cost of exporting because of the double interest charge, which over the period averaged 0.22 percent.[11] The exception concerns gold exports from New York after 1901. Since there were no exports after April 1901, it is not possible to estimate the export transactions costs after this date.

4 Triangular arbitrage through France and Germany

There is a simple explanation as to why gold exports from New York to London ceased in 1901. After 1900, Paris started to import gold from New York and London on a regular basis, and these imports meant that the difference between the New York and London gold prices was never as large as the New York−London transactions cost. Consequently, to properly understand the trans-Atlantic gold market, it is necessary to understand the process of triangular arbitrage through Paris or Berlin.

In a full triangular arbitrage operation, a New York bank would sell sterling exchange in New York and use the proceeds to purchase gold in New York, which would be sent to Paris. Simultaneously they would borrow francs to purchase sterling exchange in Paris, which would be sent to London to offset the drafts sold in New York. When the gold arrived in Paris, it would be used to pay back the franc loan. Because the shipping costs to Paris were slightly higher than those to London, triangular arbitrage would be profitable only if sterling in Paris were trading at a discount to the mint parity value.

Triangular exchange operations have been ignored in the recent literature, but were described in contemporary documents such as Escher's 1913 text

[11] The figure of 0.22 percent is calculated on the basis of a ten day voyage, and assumes interest rates were at the average rates for the period, namely 3 percent in the UK and 5 percent in the US

on foreign exchange (Escher 1913, pp 120 - 121). The weekly commentary on the New York foreign exchange market in the Chronicle also refers to these shipments. The first reference to triangular arbitrage that I could find occurred in 1888, when sterling in Berlin fell to 20.365 marks, 0.32 percent below par. By 1894 the first triangular arbitrage operations through Paris were noted and on six occasions that year the Chronicle reported that gold had been sent to Paris because sterling in Paris was selling at a discount. More detailed notes were published in later years when the practice was commonplace. For instance the Chronicle reported on June 27 1904: ([Vol 76 No 1983] p 1377)

> "The feature of the week was the export of $4,096,504 58 gold to Paris and Berlin, which shipment was made possible because of favourable conditions of exchange at these centres on London. On Monday the Berlin rate was quoted at 20 marks 39 ¾ pfennigs, and as the rate for sterling in New York on London was 48770 @ 48780 , there was a profit in shipping gold to Berlin as an arbitration operation, the reimbursing draft being covered with exchange at that centre on London. At the same time, exchange at Paris on London was 25f. 14 c., and calculations showed a profit in the shipment of gold to Paris, also as an arbitration operation, the reimbursing draft being covered in a similar manner."

Formally, triangular arbitrage was profitable if:

$$\frac{P_t^P}{S_t^P}\frac{\left(1+r_{UK,t}\right)^{n-1}}{\left(1+r_{FR,t}\right)^{n}} \geq \frac{P_t^{NY}(1+k_t^P)}{S_t} \quad or \quad S_t \geq \frac{S_t^P}{P_t^P}\frac{\left(1+r_{FR,t}\right)^{n}}{\left(1+r_{UK,t}\right)^{n-1}} P_t^{NY}(1+k_t^P) \tag{4}$$

where S_t^P is the franc price of 1 pound sterling in Paris, P_t^P is the franc price of gold in Paris, r_{FR} is the French call interest rate, and k_t^P is the transaction cost of shipping gold from New York to Paris as part of a dollar-sterling arbitrage transaction. The interest rate terms are included because an arbitrageur would borrow francs to purchase sterling in Paris on the day the arbitrage was undertaken, but the sterling bill would be immediately sent to London (a trip taking one day) where sterling interest would be earned until the sterling bill sent from New York arrived. In the calculations below I

ignore the interest terms as they approximately offset each other.

The dates on which triangular arbitrage operations took place were determined by analyzing the weekly commentary in the Commercial and Financial Chronicle. Sometimes the references to a triangular arbitrage operation were explicit, such as that quoted above; more often they would involve an explanation that sterling had been sold in New York against gold sent to Paris or Berlin because of the cheap price of sterling in the latter centres. Some reference to a sterling operation was necessary before a gold export to Paris or Berlin was considered a triangular arbitrage operation, because gold was often sent to these cities as a direct arbitrage operation in francs or marks. No attempt has been made to cross-check these dates. The list of dates is unlikely to be comprehensive, for some gold exports to France may have been part of a triangular operation but were not reported as such.

Triangular arbitrage transactions through France were profitable so long as the New York sterling premium exceeded the Paris sterling premium by the costs of shipping gold from New York to Paris and making the arbitrage transactions. Table 3 lists the sterling premiums in Paris and New York on the occasions that triangular arbitrage occurred, while the mean sterling premiums are calculated in table 4. The difference between the sterling premiums in New York and Paris, along with the dates on which triangular arbitrage through Paris was said to have occurred, are shown in Figure 4. Triangular arbitrage was reported to have taken place on eleven weeks between 1894 and 1899, and twenty-eight weeks between 1900 and 1905 (see table 3).

According to table 4, between 1894 and 1899 the mean sterling premium in Paris when triangular arbitrage occurred was –0.27 percent while the mean premium in New York was 0.38 percent. The difference is 0.65 percent. Between 1900 and 1905, the mean sterling premium in Paris when triangular arbitrage occurred was –0.36 percent while the mean premium in New York was 0.18 percent, a difference of 0.54 percent. These data suggest that it cost 0.54-0.65 percent to conduct a triangular arbitrage operation. These cost estimates are strikingly evident in figure 4, which indicates that triangular arbitrage occurred after 1900 whenever the difference in premiums reached or slightly exceeded 0.55 percent.

The increase in the frequency of triangular arbitrage through Paris after 1900 can be traced to a change in the operating procedures of the Bank of France. The Bank of France operated a bimetallic standard, so it could choose to redeem notes in silver coin rather than gold coin if it wished. Prior to 1900 the Bank often refused to pay out French gold coin, but would sell foreign gold coin or gold bullion at a premium. Agents wanting gold could purchase it at this premium, or, if the price were more favourable, purchase sterling bills and import gold from London. In 1900, the Bank of France discontinued the practice of charging a gold premium, making gold cheaper to obtain in Paris, and the demand for sterling bills declined. (White 1933, chapter 13). White collated monthly data on the premium charged by the Bank of France for the years 1880 –1913 (see Figure 5). The mean premium was 0.27 percent from 1886 to 1893, 0.13 percent from 1894 to 1899, but only 0.01 percent from 1900 to 1905. The mean sterling premium in Paris also declined, from 0.11 percent, 1886–1893, to -0.04 percent , 1894–1899, to -0.22 percent 1900–1905 (see Figure 6). The decline in the average sterling premium is associated with a much higher number of occasions when the sterling premium on any particular date was low enough to make triangular arbitrage profitable.

The increased frequency of triangular arbitrage explains why gold exports from New York to London ceased in 1901. The maximum price of sterling in New York was limited by the possibility of shipping gold to London as part of a direct arbitrage operation, or shipping gold to Paris or Berlin as part of a triangular arbitrage operation. After the Bank of France stopped charging a premium for foreign gold, sterling prices in Paris were so frequently below the parity rate that triangular arbitrage was normally more profitable than direct arbitrage. This meant the New York price of sterling never reached the level where it was profitable to export to London.

Three issues deserve further discussion. First, at first sight, it is curious that the sterling premium declined so much after 1900, for when the Bank of France ceased charging a foreign gold premium only the Paris–London gold export point declined, not the gold import point. Since sterling fell so much, sterling prices in Paris must have been artificially high before 1900, sustained by agents who chose to obtain gold from London rather than the Bank of France. When this demand ceased, the sterling price often fell to the point where gold could be profitably imported from London, approximately

25.12 francs or 0.40 percent below mint parity. Indeed, the sterling discount in Paris was usually very close to this rate when gold was exported from New York to Paris, and gold shipment data confirm that unusually large exports from England to France frequently took place on these dates.12 As such, it appears that the main effect of the Bank of France's gold premium policy prior to 1900 was to deter triangular arbitrage, creating a premium for the sellers of sterling in Paris and New York.

Second, it is strange that there was so little triangular arbitrage activity. Between 1894 and 1900 there were thirty-five weeks when the difference in sterling premiums exceeded the estimated transaction cost (0.65 percent), but triangular arbitrage was reported on only five of these weeks. After 1900, there were twenty-nine weeks when the difference in sterling premiums exceeded the estimate of the transactions cost (0.54 percent), and arbitrage was reported on only twelve of these weeks. In fact it is likely that triangular arbitrage occurred on many of these occasions, but the Chronicle did not record the information necessary to identify the shipments as an arbitrage transaction. Indeed, the Chronicle reported gold was exported to Paris, Europe, or the Continent on twenty-five of the thirty-five occasions that the difference in premiums exceeded 0.65 percent prior to 1900, but only five of these shipments were identified as triangular arbitrage shipments.

Lastly, some comment is warranted as to why the triangular arbitrage activity switched from Berlin to Paris. While all of the triangular arbitrage operations reported by the Chronicle prior to 1892 were through Berlin, only five triangular arbitrage operations through Berlin were reported after 1892, all on dates when arbitrage through Paris occurred. The switch from Berlin to Paris reflects a change in the relative cost of the activity. The mean sterling premiums in Berlin were -0.22 percent from 1886 to 1893, -0.04 percent from 1894 to 1899, and -0.02 percent from 1900 to 1905. In Paris, the mean premiums were 0.11 percent, -0.04 percent, and -0.22 percent respectively. Before 1894, therefore, Paris had an average 0.33 percent disadvantage to Berlin; after 1900 it had a 0.20 percent advantage and thus

---

[12] England-France gold flows are available from the Economist's Monthly Trade Supplement.

became the main location where triangular arbitrage activity took place.

5 Discussion and conclusions

This study of gold arbitrage demonstrates that threshold models cannot be used to estimate the cost of making an arbitrage transaction unless it is known that third markets are unimportant. If third market effects are important, prices in two different cities will differ by an amount that depends on the difference between the transport costs between each of the two cities and the third city, as well as on the transport costs between the two cities. In these circumstances, the theoretical underpinnings of many econometric techniques including threshold autoregressions and switching regressions are suspect. While this point is easily made theoretically, the paper shows it can be important empirically. In particular, this paper shows that the cost of shipping gold from New York to London cannot be estimated from price data after 1901 as no exports from New York to London took place. Prior to 1901, the Paris and Berlin markets also affected the flow of gold between London and New York, but because there was a regular two way trade between New York and London transactions costs can be estimated from price data so long as trade data are used to indicate when a trade transaction occurred.

It may be argued that this case is special, as the triangular arbitrage that linked New York, Paris, and London was conducted with financial instruments on the Paris-London leg. While this example is special, the basic theoretical point is clear: price differences between any two cities may reflect trade costs to a common import source or export destination. In any case, if sterling bills had not been sold in Paris, gold would have been shipped from London to Paris to complete the arbitrage transaction and the maximum price difference between London and New York would have been the New York– Paris transport cost minus the London–Paris transport cost.

The other results of the paper are specific to the New York foreign exchange market during the Gold Standard era. The main contribution of this paper has been to identify the dates on which arbitrage shipments of gold between London and New York took place. Despite earlier skepticism about the reliability of the gold flow data, the weekly financial commentary of the Commercial and Financial Chronicle proved to be of sufficiently high

quality that, in conjunction with other sources, the dates of direct shipments could be determined. The dates have proved useful for refining estimates of the gold points. The mean gold points in the periods 1886–1889 were (4.8370, 4.8925), while from 1897 –1905 they were (4.8408, 4.8805). These estimates correspond to export transactions costs of 0.53 percent and 0.29 percent respectively, while import transactions costs were 0.61 percent and 0.53 percent. The decline in export costs partly reflect inducements made by the Bank of England to attract gold.

The estimates can be compared with previous estimates. Officer (1996, p 174) constructed detailed cost estimates to estimate the transaction cost for shipping gold between New York and London. He estimated the normal cost of exporting gold from New York to be 0.66 percent in 1881–1890 and 1891–1900, and 0.50 percent for 1901–1910. His estimates for the normal transactions costs associated with importing gold were –0.71 percent, -0.63 percent, and –0.60 percent for the three decades. These estimates are comparable with those in this paper, although typically a little bit higher. The difference between his estimates and those in this paper reflect the different methodological concerns. Officer estimated the normal average cost to make an arbitrage transaction, whereas in this paper I estimate the actual cost on the occasions that transactions occurred. Some of these occasions would have been ordinary arbitrage; others would have been gold effected transfers; still others occurred when the Bank of England was altering the price of gold or making special inducements to shippers; in sum, they are unlikely to be exactly the same as the normal cost.

The comparison with the econometric estimates of Spiller and Wood (1988b) and Prakash and Taylor (1997) provide an interesting test of their methodologies, because neither paper takes into account the possibility of triangular arbitrage. Spiller and Wood estimated a two-limit stochastic Tobit model with separate costs for import and export transactions over the period 1899–1908. They estimated mean export costs to be 0.23 percent to 0.25 percent, while mean import costs were 0.28 percent to 0.38 percent percent, with the estimates varying slightly according to different modeling methodologies.

Prakash and Taylor estimated a symmetric threshold autoregression, over different sub-periods; for both 1899–1901 and 1901–1904, transactions

costs were estimated to be 0.31 percent. In contrast, the estimates in this paper suggest that imports took place when the exchange rate averaged 0.53 percent below mint parity, that direct exports took place when the exchange rate averaged 0.29 percent above mint parity, and that triangular exports took place when the exchange rate averaged 0.18 percent above mint parity.

The Spiller and Wood estimate of the mean export transactions cost is therefore midway between the cost of triangular and direct exports, while their estimate of import costs is substantially lower than the mean value of the exchange rate at which imports took place. (Note, however, that the periods are not identical.) The Prakash and Taylor estimates are very close to average of the import and the two export transactions costs. It is thus plausible that these estimation techniques underestimated the true cost of shipping gold between New York and London, because they ignored the effect of triangular arbitrage on the New York sterling exchange rate. Unfortunately, such bias is likely whenever bilateral transactions costs are estimated from bilateral price data and third markets are important.

References

Andrew, A P (1910a), *National Monetary Commission: Statistics for the United States, 1867-1909,* Senate Document Number 570, (61st Congress, 2nd session), Government Printing Office, Washington, DC.

Andrew, A P (1910b), *National Monetary Commission: Statistics for Great Britain, Germany, and France, 1867-1909,* Senate Document Number 578, (61st Congress, 2nd session), Government Printing Office, Washington, D.C.

Canjels, E, G Prakash-Canjels, and A M Taylor (2004), "Measuring Market Integration: Foreign Exchange Arbitrage and the Gold Standard 1879-1913," *Review of Economic Statistics,* 86(4), 868-882.

The Commercial and Financial Chronicle, W. B. Dana Corp, New York, 1884 – 1906.

Department of Commerce and Labor, Bureau of Foreign and Domestic Commerce, *Monthly Summary of Commerce and Finance of the United States,* January 1899-December 1914, Washington, DC.

*The Economist, (*1885-1906), London, UK.

Engel, C, and J H Rogers (1996), "How Wide is the Border?" *American Economic Review,* 86(5), 1112-1225.

Escher, F (1913), *Elements of Foreign Exchange*, 3rd Edition, The Bankers Publishing Company, New York.

Goodhart, C A E (1969), *The New York Money Market and the Finance of Trade, 1900-1913,* Harvard University Press, Cambridge MA.

Margraff, A W (1904), *International Exchange,* 2nd Edition, G.E. Marshall & Co, Chicago.

Morgenstern, O (1955), *The Validity of International Gold Movement Statistics,* Special Papers in International Economics No. 2, Princeton University, Princeton NJ.

New York Times. (1884 – 1906), New York.

Obstfeld, M, and A M Taylor (1997), "Nonlinear Aspects of Goods-Market Arbitrage and Adjustment: Heckscher's Commodity Points Revisited," *Journal of Japanese and International Economics,* 11, 441-479.

Officer, L H (1996), *Between the Dollar-Sterling Gold Points: Exchange Rates, Parity, and Market Behavior,* Cambridge University Press, Cambridge.

Prakash, G, and Taylor, A M (1997), "Measuring Market Integration: A Model of Arbitrage with an Econometric Application to the Gold Standard, 1879 – 1913," *NBER Working Paper,* 6073.

Samuelson, P A (1952), "Spatial Price Equilibrium and Linear Programming," *American Economic Review,* 42(3), 283-303.

Sayers, R S (1936), *Bank of England Operations 1890 – 1914,* P.S. King and Son Ltd, London.

Spiller, P T and R O Wood (1988a), "The Estimation of Transactions Costs in Arbitrage Models," *Journal of Econometrics*, 39, 309-326.

Spiller, P T and R O Wood (1988b), "Arbitrage during the Dollar Sterling Gold Standard 1899 - 1908: An Econometric Approach," *Journal of Political Economy*, 96(4), 882 – 292.

Virtue, G O (1892), "Official Returns of Gold Shipments," *Quarterly Journal of Economics,* 6(4), 465-471.

White, H D (1933), *The French International Accounts 1880 – 1913,* Harvard University Press, Cambridge.

York, T (1923), *International Exchange: Normal and Abnormal,* The Ronald Press Company, New York.

Appendices

A Data sources

Sterling Bill Prices

New York
1886 – 1895: *New York Times*, daily newspapers, rates of actual business.

1896 – 1905: Andrew (1910a), pp195-204

Paris
1886 – 1898: *The Economist*, weekly issues, "Foreign Rates of Exchange on London"

1899 – 1905: Andrew (1910b), pp352 –354

Berlin
1886 – 1898: *The Economist*, weekly issues, "Foreign Rates of Exchange on London"

1899 – 1905: Andrew (1910b), pp257-263

London Gold Price

1886-1905: *The Economist* or *Commercial and Financial Chronicle*, weekly issues.

Bank of France Gold Premium

1886-1905: White (1933, pp 319-330) "Gold Premium at Paris".

UK Call Interest Rates

1886 – 1889: *Commercial and Financial Chronicle*, weekly issues.

1890 (1/1 – 5/9): *The Economist*, weekly issues

1890(5/16) – 1905: Andrew (1910b, pp 43-62)

US Call Interest Rates

1886 – 1889: *Commercial and Financial Chronicle*, weekly issues. ("Average" call rate quoted)

1890 – 1905: Andrew (1910a, pp 119 -129).

B Gold flows between New York and London

The dates on which gold arbitrage between New York and London occurred were determined by comparing the data and commentary in the following sources:

The Economist Monthly Trade Supplement: "Bullion and Specie Table";
The Commercial and Financial Chronicle,

(1) the commentary in the first section of the paper, "The Financial Situation";
(2) the table "Exports and Imports of Specie at New York"; and

The New York Times, the table "Specie Movements."

The British monthly gold exports and imports data published in *The Economist* during the period 1899–1905 was copied from Goodhart (1969, pp 173-176.)

This appendix lists the import and export dates by year.

1886
Arbitrage exports took place on January 16, 23; February 13, 20; March 6, 20, 27; May 8, 29; and June 5. Arbitrage imports occurred August 21, August 28; September 18; October 9, 16, 23, 30; November 27; and December 18, 25.

1887
There were no exports. Arbitrage imports occurred July 2, 23; August 6,13,20,27; September 3, 10, 17; and October 8.

1888
Arbitrage exports took place on January 16, 23; February 13, 20; March 6, 20, 27; May 8, 29; and June 5. Arbitrage imports occurred August 21, August 28; September 18; October 9, 16, 23, 30; November 27; and December 18, 25.

1889
Arbitrage exports took place on February 23; March 16, 23; April 27; May 4

– 25; June 1, 8,22; and October 5. There were no imports.

1890
Arbitrage exports took place each week July 12 – August 9. An arbitrage import occurred December 13.

1891
Arbitrage exports occurred each week May 2 - July 4. Arbitrage imports occurred each week from September 26 – October 31. Gold was also imported each week until December 14, but not as an arbitrage operation.

1892
There were large exports to France and Germany in 1892. Unfortunately, the Commentary is not particularly useful, for exports were normally recorded as being to Europe, rather than to a specific country. Arbitrage exports were March 5, 12, and April 30. Data after May are unreliable. There were no arbitrage operations resulting in imports.

1893
Arbitrage exports occurred February 18, April 22, May 13 – June 10. They may have occurred April 29 and May 6, although these dates are not confirmed and are not used. Arbitrage imports occurred each week between July 28 and September 9, and on October 28 and November 4.

1894
Arbitrage exports probably took place on April 14, April 28 – June 2, and June 16. Confirmation is not possible. There were no arbitrage imports.

1895
Arbitrage exports occurred January 19 - February 2; July 13 – September 21; November 16 – December 7; December 21, 28. Gold was engaged for import on February 16, 23, March 9, March 30, and April 27, plus probably 4 other occasions. On each occasion the gold was for the Treasury gold bond issue, so these imports were not part of an arbitrage operation.

1896
Arbitrage exports occurred January 4 – 25. Arbitrage imports occurred each week from August 22 – November 7. The gold was largely US gold coin.

1897
There were no exports. October 9 was the sole arbitrage import date, and US gold coin was imported.

1898
There were no exports. Gold was engaged for import on February 26 – May 14, July 30, August 6, September 3 – October 22, December 3. Half of the gold was bullion and one third US gold coin.

1899
Arbitrage export dates were June 3, 10, 24, July 1, December 16 – January 6. All exports were US gold coin. Gold was engaged for import on January 7, 21; February 4; and September 23, 30. Most gold was bullion.

1900
Arbitrage exports occurred August 11, 18. All exports were bullion. Arbitrage imports occurred October 13, 27. The majority of the gold was bullion.

1901
An arbitrage export occurred April 27. All exports were bullion. There were no imports.

1902
There were no exports. Gold bullion was engaged for import on September 20.

1903
There were no exports. Gold was engaged for import from November 7 – December 19. The gold was predominantly bullion.

1904
There were no exports. Gold was engaged for import on January 2, 9. The gold was predominantly bullion.

1905
There were no exports. Gold was engaged for import from September 16 – October 14. The gold was all bullion.

Table 1

Trade flows consistent with the no-arbitrage condition.

Centre i trade		Other trade	$P^j - P^i$	Equation
Centre I exports to k				
$T^{ih} > 0$		$T^{jh}>0$	$P^j - P^i = K^{ih}-K^{jh}$	1a
$T^{ih} > 0$			$K^{ih}-K^{jh} \leq P^j - P^i < K^{ij}$	1b
$T^{ih} > 0$	$T^{ij} > 0$		$P^j - P^i = K^{ij}$	1c
Centre i has no trade with k				
	$T^{ij} > 0$		$P^j - P^i = K^{ij}$	2a
	$T^{ij} > 0$	$T^{hj}>0$	$P^j - P^i = K^{ij}$	2b
		$T^{hj} >0$	$K^{jh} -K^{ih} \leq P^j - P^i \leq K^{ih}$	2c
No trade	No trade	No trade	$-K^{ij} \leq P^j - P^i \leq K^{ij}$	2d
		$T^{jh}>0$	$-K^{ij} \leq P^j - P^i \leq K^{ih}-K^{jh}$	2e
	$T^{ji} > 0$	$T^{jh} >0$	$P^j - P^i = -K^{ij}$	2f
	$T^{ji} > 0$		$P^j - P^i = -K^{ij}$	2g
Centre i imports from k				
$T^{hi} > 0$	$T^{ji} > 0$		$P^j - P^i = -K^{ij}$	3a
$T^{hi} > 0$			$-K^{ij} \leq P^j - P^i \leq K^{jh}-K^{ih}$	3b
$T^{hi} > 0$		$T^{hj} >0$	$P^j - P^i = K^{jh}-K^{ih}$	3c

The table indicates the thirteen combinations of trade flows between three cities i, j and h, that are consistent with the non-arbitrage condition holding, and indicates the range of the price difference P^j-P^i on each occasion.

Table 2

Average dollar - sterling gold points: the mean and standard deviation of the exchange rate when gold was shipped.

Imports					
		1886-1889	1890-1892(6)	1892(7)-1896	1897-1905
Number of imports		20	13	21	46
Exchange rate	**mean**	4.8370	4.8338	4.8408	4.8408
	std deviation	(0.46)	(0.43)	(1.15)	(0.71)
% from parity	**mean**	-0.61 %	-0.67 %	-0.53 %	-0.53 %
	std deviation	(0.09)	(0.09)	(0.24)	(0.15)
Exports					
		1886-1889	1890-1892(6)	1892(7)-1896	1897-1905
Number of exports		27	18	39	11
Exchange rate	**mean**	4.8925	4.8872	4.8960	4.8805
	std deviation	(0.27)	(0.44)	(0.57)	(0.33)
% from parity	**mean**	0.53 %	0.42 %	0.61 %	0.29 %
	std deviation	(0.06)	(0.09)	(0.12)	(0.07)

Table 3

Triangular arbitrage dates

Country	Date	New York price	European price	Premium
Germany	6/16/1888	489.00 (+0.48%)	20m 36.5 (-0.32%)	0.80%
Germany	6/21/1890	488.25 (+0.33%)	20m 35 (-0.39%)	0.72%
Germany	2/28/1891	488.25 (+0.33%)	20m 36 (-0.34%)	0.67%
Germany	4/25/1891	488.75 (+0.43%)	20m 40.5 (-0.12%)	0.55%
France	4/21/1894	489.00 (+0.48%)	25f 18 (-0.16%)	0.65%
France	5/12/1894	489.00 (+0.48%)	25f 19 (-0.12%)	0.61%
France	6/2/1894	489.00 (+0.48%)	25f 18.5 (-0.14%)	0.63%
France	6/9/1894	488.75 (+0.43%)	25f 18.5 (-0.14%)	0.58%
France	6/23/1894	488.75 (+0.43%)	25f 17 (-0.20%)	0.63%
France	7/14/1894	488.25 (+0.33%)	25f 16.5 (-0.22%)	0.55%
France	5/2/1896	489.00 (+0.48%)	25f 16 (-0.24%)	0.73%
France	5/9/1896	489.00 (+0.48%)	25f 17 (-0.20%)	0.69%
France	5/1/1897	488.00 (+0.28%)	25f 9.5 (-0.50%)	0.78%
France	5/8/1897	487.50 (+0.17%)	25f 10 (-0.48%)	0.66%
France	5/29/1897	487.25 (+0.12%)	25f 10 (-0.48%)	0.60%
France	6/23/1900	487.25 (+0.12%)	25f 12 (-0.40%)	0.52%
France	7/21/1900	487.75 (+0.23%)	25f 12 (-0.40%)	0.63%
France	1/19/1901	487.50 (+0.17%)	25f 12 (-0.40%)	0.58%
France	1/26/1901	487.75 (+0.23%)	25f 12.5 (-0.38%)	0.61%
France	5/25/1901	488.50 (+0.38%)	25f 18.5 (-0.15%)	0.52%
France	11/2/1901	487.25 (+0.12%)	25f 9.5 (-0.50%)	0.62%
France	11/9/1901	487.125 (+0.10%)	25f 11 (-0.44%)	0.54%

France	2/8/1902	487.375 (+0.15%)	25f 12.5 (-0.38%)	0.53%
France	3/1/1902	487.875 (+0.25%)	25f 15 (-0.28%)	0.53%
France	4/12/1902	487.875 (+0.25%)	25f 16.5 (-0.22%)	0.47%
France	8/2/1902	487.95 (+0.27%)	25f 16 (-0.24%)	0.51%
France	6/27/1903	487.80 (+0.24%)	25f 14 (-0.32%)	0.56%
France	7/11/1903	487.45 (+0.16%)	25f 12 (-0.40%)	0.57%
France	4/9/1904	487.40 (+0.15%)	25f 13.5 (-0.34%)	0.50%
France	4/16/1904	487.45 (+0.16%)	25f 13.5 (-0.34%)	0.51%
France	4/23/1904	487.55 (+0.18%)	25f 12.5 (-0.38%)	0.57%
France	4/30/1904	487.30 (+0.13%)	25f 10 (-0.48%)	0.62%
France	5/21/1904	487.00 (+0.07%)	25f 10.5 (-0.46%)	0.53%
France	5/28/1904	487.25 (+0.12%)	25f 12.5 (-0.38%)	0.51%
France	6/4/1904	487.55 (+0.18%)	25f 13 (-0.36%)	0.55%
France	10/29/1904	486.85 (+0.04%)	25f 11 (-0.44%)	0.48%
France	11/5/1904	486.75 (+0.02%)	25f 11.5 (-0.42%)	0.44%
France	11/19/1904	487.00 (+0.07%)	25f 13 (-0.36%)	0.43%
France	1/14/1905	487.65 (+0.21%)	25f 14 (-0.32%)	0.53%
France	1/21/1905	487.75 (+0.23%)	25f 13 (-0.36%)	0.59%
France	1/28/1905	488.00 (+0.28%)	25f 14 (-0.32%)	0.60%
France	2/4/1905	488.15 (+0.31%)	25f 15 (-0.28%)	0.59%
France	2/11/1905	488.10 (+0.30%)	25f 16.5 (-0.22%)	0.52%

Table 4

The sterling premium in New York and Paris when triangular arbitrage occurred.

		Sterling in New York		Sterling in Paris		Difference
1894 -- 1899:12	N= 11	**Level**	**% from mint parity**	**Level**	**% from mint parity**	
Mean		4.8850c	0.38%	25f 15.5c	-0.27%	0.65%
Std Dev		0.65c	0.13%	3.7c	0.15%	0.07%
1900:1 – 1905:12	N= 28	**Level**	**% from mint parity**	**Level**	**% from mint parity**	
Mean		4.8754c	0.18%	25f 13.1c	-0.36%	0.54%
Std Dev		0.42c	0.09%	2.1c	0.08%	0.05%

Figure 1
The $/£ exchange rate, 1886-1905 (weekly average)

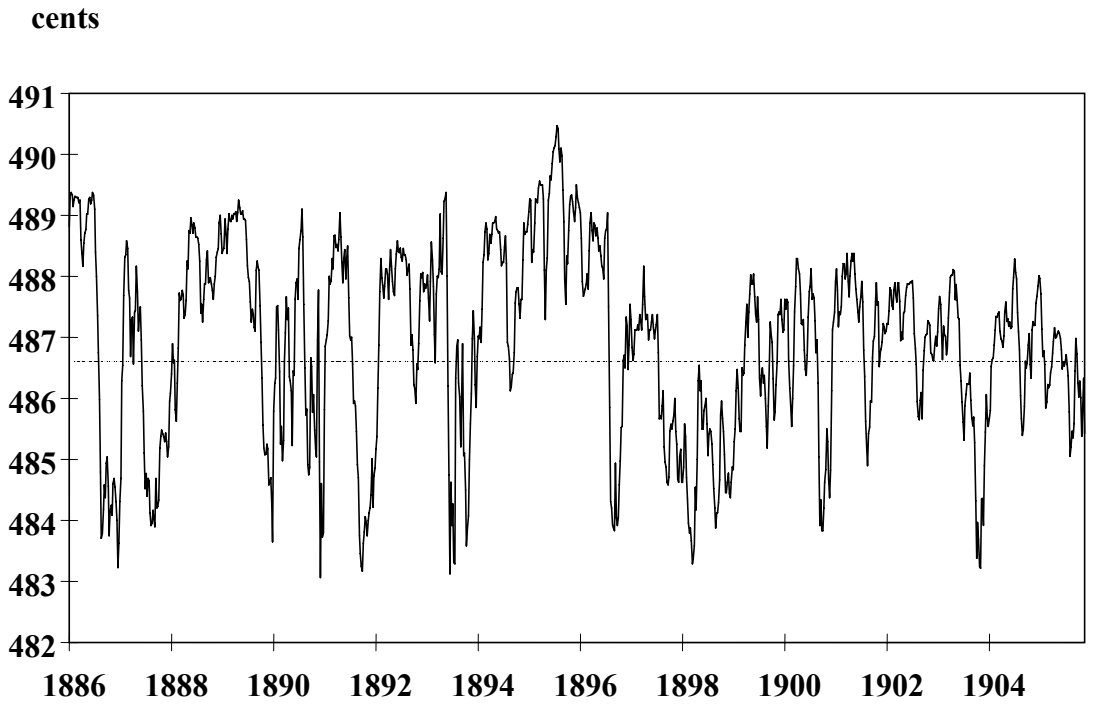


Figure 2

Weekly maximum and minimum exchange rates, 1886-1896

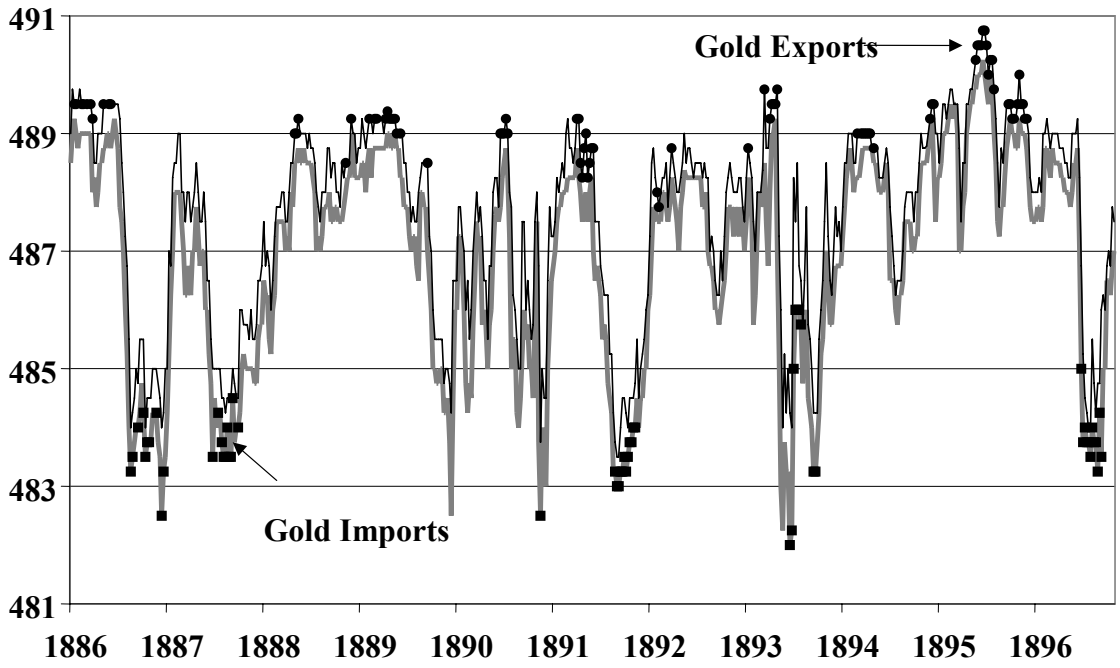


Figure 3
Weekly maximum and minimum exchange rates 1897-1905

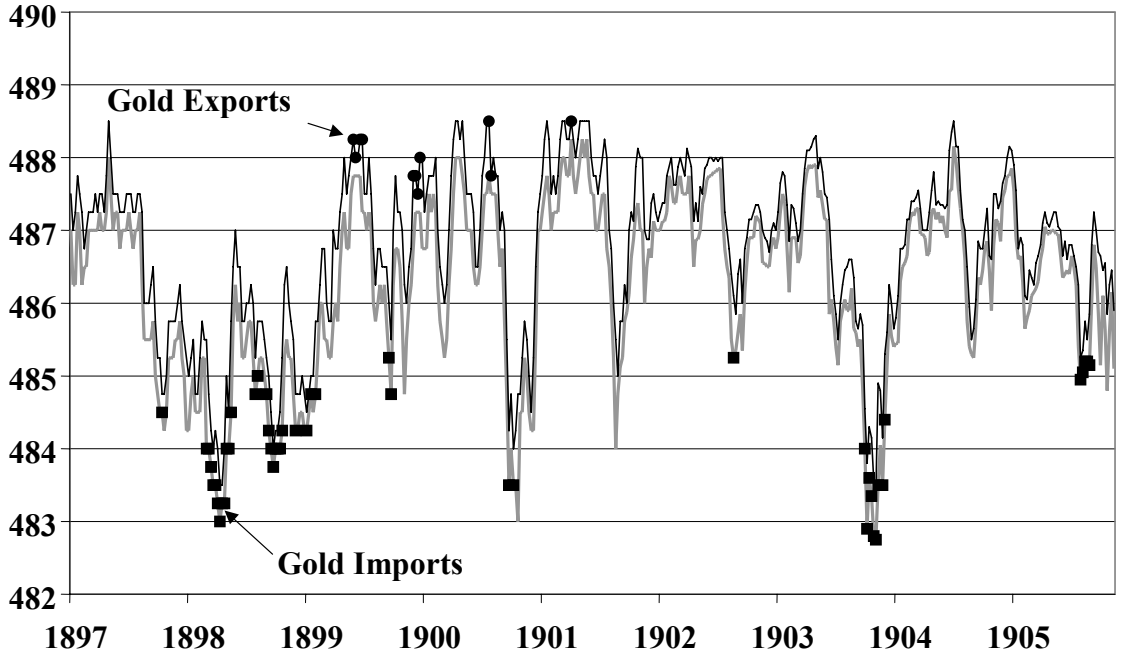


Figure 4

New York sterling premium – Paris sterling premium, 1886-1905

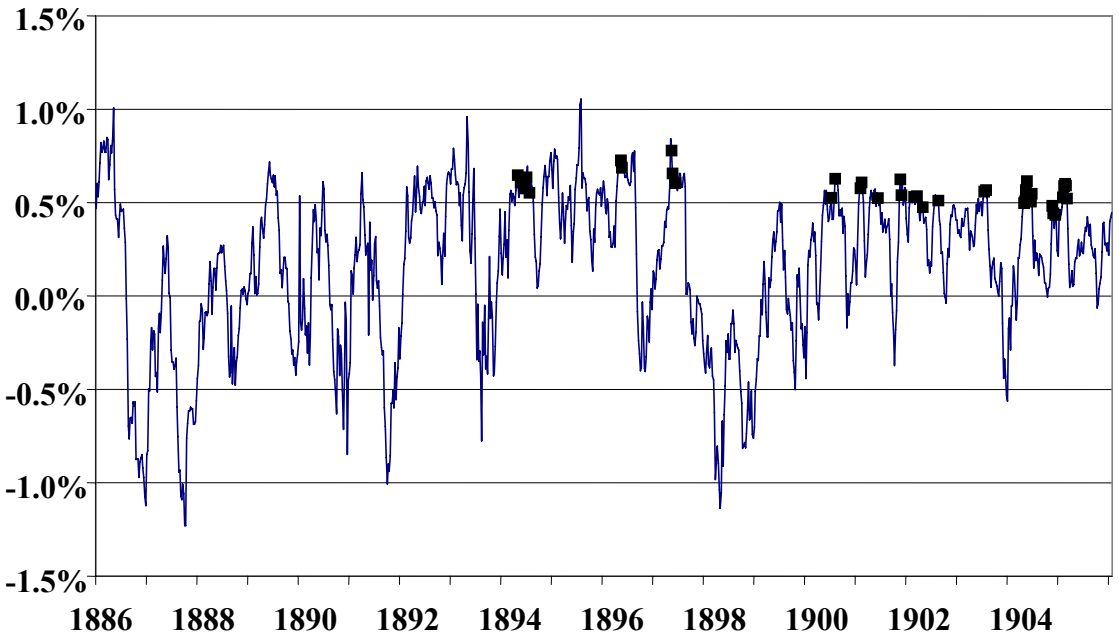
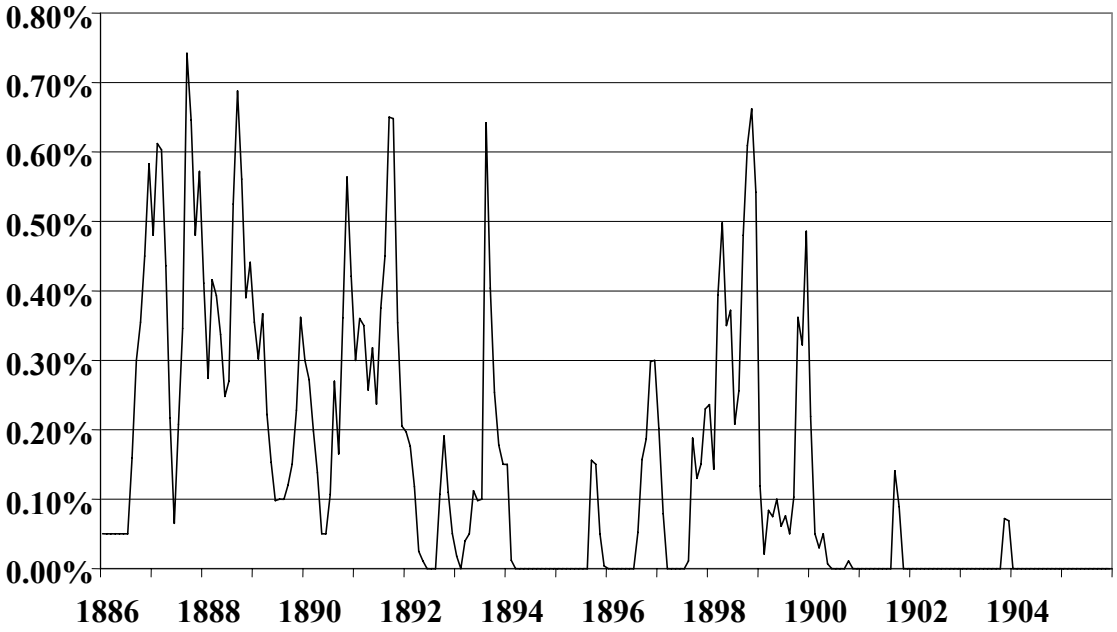


Figure 5

Bank of France premium on gold bullion, 1886-1908



Source: HD White (1933), monthly

Figure 6

Price of sterling bills in Paris, 1886−1905