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**MARKET INTEGRATION IN THE GOLDEN PERIPHERY
THE LISBON / LONDON EXCHANGE, 1854-1891**

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WP 15-05   November 2005

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Market Integration in the Golden Periphery

The Lisbon/ London Exchange, 1854-1891

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Abstract

The existence of a self-regulating arbitrage mechanism under the gold standard has been tradi-tionally considered as one of its main advantages, and attracted a corresponding research interest. This research is arguably relevant not only to test for the efficiency of the "gold points", but also to study the evolution of financial integration during the so-called first era of globalization. Our first aim with this paper is to contribute to the enlargement of the scope of the literature by considering the case of Portugal that adhered to the system, in 1854, at a much earlier phase than the ma-jority of countries, thus allowing for a broader perspective on the evolution of the efficiency of the foreign exchange market. As a typical "peripheral" country, Portugal can be used as the starting point for a study of the degree of integration of the periphery within the system. Furthermore, the Portuguese exchange also illustrates the role in practice of large players in sustaining currency stability, over and beyond the atomistic forces of arbitrage and speculation assumed in conven-tional theoretical frameworks. We also address the question of the credibility of the authorities' commitment to the standard, through the perspective of the target zone literature.

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The wise course, therefore, is to keep him shut in the shiny cage of gold reserves. For nothing could be more secure than such a golden cage. It has a though flexibility. If the beast grows larger, the space between the bars grows larger. If it grows smaller, it narrows. If we keep our specie reserves adequate, we prevent a falling off of our exchange rate, and we gain the confidence of other nations.[1]

1   Introduction

Among the burgeoning literature on the gold standard, a strand has been dedicated to the estimation of the efficiency of the system, somehow defined in terms of a measure of exchange rate stability within the bands delimited by the "gold points". These studies are relevant not only to test for the traditional arguments about the stability derived from international arbitrage and speculation, under a credible gold standard, but also to study the evolution of financial integration during the so-called first era of globalization. Despite the obvious interest in extending such inquiry, the literature is characterized by a greater variation in methodologies than geographical or time breadth. To our knowledge, only two bilateral exchange markets have been studied so far: the dollar/ sterling (Officer 1996, Spiller and Wood 1988, Canjels *et al.* 2004), and the franc/ sterling (Flandreau 1995, Boyer-Xambeau *et al.* 1994). Moreover, the latter case does not entirely fit with the standard gold points model, because of the bimetallic nature of the French monetary system until 1873.

The lopsided nature of the literature seems to be the result, on the one hand, of the extensive data requirements, and of the persistence of controversies about the best methodology for measuring market integration, on the other. Our aim with this paper is to contribute to the enlargement of the scope of the literature by considering the case of a country, Portugal, that adhered to the system, in 1854, at a much earlier phase than the US or France, thus allowing for a broader perspective on the evolution of the efficiency of the foreign exchange market.

This is not the only reason, however, for the interest in the Portuguese case. As a typical "peripheral" country, Portugal can be used as the starting point for a study of the degree of integration of the periphery within the system. A relatively happy and lengthy experience with the gold standard seems a worthwhile object of study, especially given the potentially problematic nature of Portuguese fundamentals.

Secondly, despite being a fairly liquid market, the Portuguese exchange against London also illustrates the role in practice of large players in sustaining currency stability, over and beyond the atomistic forces of arbitrage and speculation assumed in conventional theoretical frameworks. The legal requirement to guarantee convertibility imposed upon the Bank of Portugal, a private corporation, often led it to intervene in the market to sustain the exchange near to parity, in order to avoid costly arbitrage.

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[1]Mishima, Yukio (1973), *Runaway Horses*, New York: Alfred A. Knopf (1st. ed. 1969), p. 165.

Lastly, we address the question of the credibility of the authorities' commitment to the standard, but approach it through the perspective of the target zone literature (TZ).

The article is structured as follows. The first two sections provide an abstract of the major facts of the Portuguese experience with the gold standard, and a brief description of the workings of the foreign exchange market in Lisbon. In the wake of the methodological debate in the literature, we follow two empirical strategies. On the one hand, we offer a detailed reconstruction of the gold points based on weekly data of the foreign exchange market at Lisbon, and on extensive accounting records of gold transactions actually done by the Bank of Portugal during the period. On the other, we use the techniques of threshold autoregressions to estimate a theoretical model of arbitrage similar to Canjels *et al.* (2004). These two alternatives have a preliminary presentation in section 4. Section 5 then details the main data sources used to form our series of the exchange rate of the pound sterling in Lisbon, and of the costs of gold arbitrage between London and Lisbon. Section 6 is the core of the paper, and reviews in succession four topics – the direct reconstruction of the gold points, the indirect estimates of the same points, the workings of the Portuguese gold standard as a credible TZ, and the evidence on gold flows between Portugal and Britain. Some concluding remarks follow, and we also include two technical Appendices.

2   The Gold Standard in Portugal

After Britain, Portugal was the first country in Europe to join the gold standard, in 1854. As a result, although it also became inconvertible earlier than most, in 1891, it still remains among those with the longest histories of association with the "classic" era of this regime.

Several reasons dictated this adoption but, perhaps because its entry into this "club" was so precocious, they are not those that have been adduced by some recent authors regarding the movement to gold in the 1870s (Gallarotti 1995). Obviously, it was not a case of trying to reap network economies - also described in this literature as the "chain effect" - as happened later when an increasing number of economies adhered to this standard and thereby formed an informal international monetary union. Nor does it seem to have been an attempt to capitalize on a monetary standard that came to be recognized as a badge of financial integrity that would facilitate access to foreign capital markets. Indeed, what mattered most to London bankers regarding Portugal, at this time, was government stability and political will to meet commitments. As some of them told the Portuguese ambassador in London, "in order that our funds be employed in Portugal it is necessary first that you assure us that contracts will be religiously observed and that public tranquillity will not be disturbed" (Reis 1996: 176). There is no evidence either that the decision had anything to do with socio-economic cleavages generated by the monetary issue. Portugal, one of the poorest nations of Europe, was predominantly agricultural and its "urban-industrial class" was diminutive, none of them features alleged by this literature as favorable to the adoption of gold. Finally it should be noted that, in 1854, silver or bimetallism were regarded by many as a more robust solution than gold given the risks caused by gold mining development in

Asia and North America, and already made obvious, since 1851, by the steady fall of the gold-silver ratio.

In fact, Portugal joined the gold standard for pragmatic, rather than ideological or "scientific" reasons, and in response to the particular historical circumstances of the moment (Flandreau 1996). The most important of these was the need felt by governments for an effective and enduring reform of the monetary system. Since the mid 1840s, the latter had been bedevilled by a scarcity of sound means of payment, a confusing multiplicity of legalized foreign coin - at a peak they reached thirty six - and a plethora of often contradictory legislation that allowed three different metallic proofs (French, English and Spanish) and two types of paper money to circulate at the same time.

Although public discussion was riven with doubts as to the best choice, the logic of adopting an arrangement closely modelled on the British one was a strong one. One reason was that Britain had long been Portugal's main trading partner (Fisher 1971). By the 1840s and 1850s, this corresponded to 50% of Portugal's trade, not to mention the additional 20% with Brazil, a country very much in the British sphere of economic influence. Moreover, London was where most of the Portuguese foreign debt service was paid. A second reason was the tradition of a gold circulation which went back to the early 18th century, first fuelled by the rich mines of Brazil, and later reinforced by the military expenditures in sovereigns by Portugal's Oldest Ally, during the Napoleonic period and subsequent civil disturbances. In the third place, for a penurious government, the gold standard was clearly more attractive because it would cost much less to implement than other solutions. By the early 1850s, owing to earlier monetary policies which had overvalued gold, most of the coin in circulation was made of this metal anyway and, in fact, sovereigns seem to have prevailed. A silver standard, on the other hand, would have required importing a large quantity of this metal for minting - perhaps the equivalent of 10% of GDP - and selling off the nation's gold, probably at a declining price in a market which was overflowing with this commodity. Last of all, it was evident that the proposed system had worked well in Britain for over thirty years and had not prevented this country from becoming one of the world's most powerful in economic terms.

During the ensuing decades, Portugal remained locked into to the gold standard and though the conditions that led to its enactment changed, new advantages continued to justify the country's strict adherence to this policy. In particular, the spread of a globalization process focused on core economies that were also "gold club" members made it increasingly compelling, in terms of trade and capital movements, to belong too.

The Portuguese monetary law of 1854 set up a system that conformed in every way to the text book version of the gold standard. Full legal tender was kept for only new Portuguese gold coins (all the old vintages were withdrawn) and sovereigns and half sovereigns, the facial value for all of them being defined by their respective metallic content at the fixed exchange rate of 4500 Portuguese *réis* to the pound. Silver became a token means of payment. Its legal tender was restricted to 5000 *réis* per transaction and its total issue was calculated to be what would be strictly sufficient for the economy's need for small transactions. Gold and silver could be freely used in any form (coin or bar) and amount, and there were no limits to either their import or export, although the latter, in the case of gold, was

subject to a small tax until 1886. Non-monetary gold could be freely transformed into coin at the Mint by any member of the public, who could have the reverse operation performed there as well. Although no law ever expressly stated it, there were also no impediments to the free movement of capital in and out of Portugal, a fundamental requirement of such a regime, along with free convertibility and a fixed exchange rate.

In practice, it was a "full" gold standard, as opposed to a "limping" one, in that a large fraction of total monetary circulation was made up of gold coin, representing around 70% of M1 on average. Most of this was in the hands of the public. If the demand for cash increased, it was more easily satisfied by importing sovereigns from England than gold bars, which would have to be melted and converted into legal Portuguese coin at the Mint. Gold bars were therefore rarely found in the market and were sought after mostly for industrial purposes. Since notes and deposits had a low demand there was no need for the financial institutions that issued them to keep more than a small share of total gold as reserves.

There was hardly any intervention by governments in monetary matters during this period. They never attempted to issue their own fiduciary money, nor did they force the issuing banks to make loans to the state beyond their means in return for being allowed to put more notes into circulation. In particular, governments took little initiative to produce coin through the Mint, with the result that by 1890 Portuguese specie accounted for less than a tenth of all gold coin in the country. The bulk of the variations in the supply of gold coin (and indeed of all money) was thus left to market forces acting freely through the import and export of sovereigns by private operators. Nevertheless, the system functioned with considerable success and assured the economy of a money supply that kept more than adequate pace with the needs of a slowly expanding economy. While M1 grew at 3.3% *per annum* over the entire gold standard period, GDP increased by around 1%, allowing therefore for the needs of the increasing monetization of this society and for its fairly high propensity for hoarding gold. Prices showed slight change, and short run fluctuations were far from strong. Fixed parity and the other basic gold standard rules were consistently and faithfully observed throughout, and at no time was public consideration given to the possibility of abandoning them in any way. The only suspension of bank note convertibility to be allowed by the authorities occurred in 1876 and lasted a few days only. Portugal was thus remarkably free from the "convertibility crises, devaluations and internal dislocations" that beset the countries of the periphery who adopted this regime in the 19th century (Eichengreen 1985: 18).

In comparative terms, Portugal's experience with this monetary regime was unusual. While on the surface it was a "well-behaved" member of the club, in fact it failed two crucial criteria. It suffered from persistent deficits both on its budget and on its balance of trade. Thanks to vigorous borrowing in the market, it avoided monetizing the first, though relative to GDP the long-term debt almost doubled between the early 1860s and the late 1880s (Reis 2002). The solution for the second problem was to rely on the private and public capital inflows, as well as a growing stream of remittances by emigrants residing in Brazil. The combined effect of all this was that monetary growth did not generate inflationary pressure and the exchange rate was stable. Thus, outwardly the country satisfied the prerequisites

for wearing the international 'seal of approval' conferred by gold standard adherence, whilst in fact it deviated significantly from the basic norms followed by the majority of countries that earned this distinction (Bordo and Rockoff 1996). Portugal was not, however, a case of a 'deficit without tears', as Peter Lindert (1969) has put it. The market looked behind appearances, at the fundamentals, and, as a result, the yield on Portuguese bonds was always considerably higher than that of consols.

The gold standard ended on the day that the government found itself with no other recourse than to borrow heavily from the Bank of Portugal, after foreign and domestic capital markets had closed their doors to it. In order to satisfy this pressing financial need, the Bank was forced to over-issue and the inevitable run ensued, draining most of its reserves and making a legally-sanctioned suspension of payments inevitable. The country remained inconvertible thereafter, and in 1892 the final nail was driven into the coffin of Portugal international financial reputation, when the government also defaulted partially on the service of the Public Debt.

There are several interpretations for this course of events. For Valério and Mata (1994), the long term survival of the gold standard was impossible given the persistent worsening of the two deficits mentioned above and in 1891, a chance conjunction of highly adverse exogenous circumstances precipitated the demise of gold. The Baring crisis in 1890 made financial markets nervous about lending to South-American type countries. Following the abolition of slavery and the fall of the monarchy, the Brazilian exchange rate dropped 60% during 1890-1 and set off a steep decline in emigrant remittances to Portugal. In southern Africa, Britain clashed with Portugal over disputed territories, which led to doubts in London over Portugal's political stability and its financial capacity to sustain such an unequal military conflict. Fundamentally, however, this view argues that a fall could not have been avoided by the end of a decade during which the service of the foreign debt rose from 21 to 47% of exports and the foreign debt increased from 34 to 43% of GDP. As Salazar was to comment in 1916, "the falsity of the situation was too great for it to be maintained indefinitely" (1997: 54).

A second view, which is also based on the notion of the long term non-sustainability of the gold standard, focuses instead on the rigidity of internal prices as the fundamental cause of its demise (Llona Rodriguez 1997). In this "dependent economy" model, it is claimed that one of its structural features was that the price of non-tradables was excessively rigid relative to that of tradables. Thus, during the 1880s, the fall of the latter was not accompanied by that of non-tradables, and this generated a pressure on the balance of trade, which already was in the customary deficit. Under these circumstances, a return to equilibrium would require either a nominal devaluation (which was impossible under the gold standard) or an increased inflow of capital and/or remittances (which actually happened in some years). These flows, however, helped to further sustain the rigidity of the price of non-tradables and therefore delayed the adjustment. On the other hand, sooner or later external financial resources were likely to run out. If non-tradable prices continued to resist the downward pressure, as they did owing to presumed market imperfections, the economy would start to lose external reserves, and this is what happened. In the event, it was very sudden and brutal, in the manner already described, but such an outcome was inescapable, unless the structure of the Portuguese market for goods was to become more flexible.

While recognizing these adverse trends, a different reading of the facts, would stress the resilience of the Portuguese gold standard over 37 years helped by the international reputation that this conferred on the country.[2] In this perspective, strong, austere domestic policies to fight the crisis, as happened after the suspension of convertibility in 1846, could have built on such an obvious commitment to gold (Bordo and Kydland 1995) and restored the standard in a few years, as indeed happened in some Latin American countries, once the storm was over. This was a short term problem caused by a momentary shock but what was lacking in Portugal at this time was the political resolve to curb public expenditure, withdraw the subsidies that were propping up certain large, quasi-bankrupt companies, increase fiscal revenue, and create conditions that would attract fleeing capital back to the country.

3   The Market for Foreign Exchange

Despite the paucity of research and evidence on the history of the Portuguese market for foreign exchange, it is possible nevertheless to outline its most important characteristics from the point of view of the analysis that is to follow. To begin with, it is clear that from the 18th century at least, there was a significant activity of arbitrage, both of bills of exchange and precious metals. The numerous books used at the time for the professional education of merchants and their clerks afford a wealth of detail about how these transactions were carried out between Portugal's two main port cities - Lisbon and Porto - and the rest of the world. They show, for example, what calculations must be made in order to estimate their profitability, or how to decide which currencies and which foreign places to use in multi-stage operations, and suggest, by means of detailed exercises, the importance of possessing a solid practical knowledge for anyone practicing in this field (Mendonça 1823).

By the end of the 18th century, the market had been formally organized, with a number of approved brokers who had the duty to provide regular and reliable price information, as well as, naturally, that of bringing together the "ultimate transactors", who needed to buy or sell bills for themselves (Officer 1996: 209). A sign of its dynamism is the occurrence of a considerable amount of parallel, informal dealing, often by foreign, unauthorized brokers, but there are also hints of strong price oscillation and complaints of "oppression" by certain participants, which suggest that it was far from perfect. Although it was an undifferentiated market, where commodities, freights, insurance and stocks were also traded, the main business was in bills and these were predominantly sterling denominated (Justino 1994). It is not clear whether dealers, as opposed to brokers, had much of a presence in it yet.

By the 1850s, the scene had changed to quite an extent. Governments continued to pursue interventionist goals and succeeded in establishing a body of official brokers, a schedule of fees and strict rules on publicity for prices. Most of this by now greatly expanded activity seems to have happened outside this regulated area, in brokers' exchange shops, at the counters of corporate and private banks, and in informal gatherings known as *bolsins*. Specialization in bills of exchange had separated completely from other traded items, and there was intense competition over fees, as the records of the Bank of Portugal reveal. The Portuguese trade in bills had become strongly concentrated in Lisbon, to which

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[2]Some of these ideas are suggested in Reis (2000).

the lesser port city markets, such as Porto, Madeira, Algarve and the Azores were linked by reasonable communications and through the branches, agents and commissioners of the Lisbon banks. This is hardly surprising, considering not only the predominant role of the capital city in the country's foreign trade, but also the fact that it had the largest banks, besides the representative offices of the Porto banks, the largest share of government bond holdings, and the largest and probably most monetized urban population. Moreover, as the seat of government, it harbored the substantial financial activity of the Public Debt Office, which was responsible for external payments on account of the service of the foreign debt. This probably came to some 25% of all public expenditure, not to mention the external transactions of other government departments.

A fairly standard description of a foreign exchange market emerges from a report, published in 1883 by the Bank of Portugal.[3] Bills were supplied by recipients of remittances and dividends from Brazil, by commodity exporters (e.g. wine dealers) and by exporters of sovereigns. The demand came from the government, for its payments abroad, commodity importers and the Bank of Portugal, as a major importer of sovereigns. Since these various flows were concentrated at different moments in the year, an opportunity arose for dealers, who had access to credit, to profit from uncovered transactions that ironed out the oscillations in the exchange rate produced by this frequent but normal mismatch between supply and demand. In Lisbon, it was banks and bankers that performed this function of "temporal integration", thanks to the credits they could draw on in places like London when there was a shortage of bills in Portugal. When the exchange became favorable, they would buy bills cheaply at home and use them to cover their foreign debits. A facilitating function was provided by brokers, who searched the market for suitable paper for buyers, or then for clients for paper they had on offer, while continuously providing their contacts with information on the evolution of the exchange rate. The Bank of Portugal had a dedicated broker already in 1864 and paid him a commission, but considered itself free to resort to any other broker it chose, a sign of the mobility within this market.[4]

Within this context, the Bank of Portugal was a case on its own. It started acting as an arbitrageur in the early 1860s, having discovered that this was a profitable line of business and that, having a capacity to finance itself in London on a large scale, it could reap the economies of scale that foreign exchange transactions offer. Soon, however, it also found that whenever the exchange rate approached the gold export point, it was having to use its portfolio of bills and drafts on London correspondents in order, either to import sovereigns, so as to strengthen reserves depleted by a gold drain; or then to intervene in the market for bills so as to drive their price away from the gold export point. Both types of operation entailed a loss. The unwritten but firm rule, however, was that as a privileged bank of issue, it had the obligation to prevent any commercial disturbances that might arise owing to sharp contractions in the money supply (Aragão 1964, Banco de Portugal 1883). Banking wisdom held that when the balance of payments was unfavorable, an alternative action, was to raise the discount rate and thus make the adjustment easier. But by law the Bank was not allowed to do this except under the most stringent conditions, and as time went by it found itself therefore increasingly obliged to get

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[3]Banco de Portugal (1883).

[4]Minutes of the Board of Directors, 26 February 1864, Bank of Portugal Archive.

involved in both types of "gold device". Only in this way could it maintain not only the level of its notes and of the reserves that backed them, but also that of the national supply of monetized gold, despite repeated adverse pressures on the Portuguese balance of payments (Reis 2002).

During the period we are considering, the Bank thus found itself in contradictory roles in the exchange market. At times, it was a profit-seeking arbitrageur. At others, it had the loss-making duty of stabilizing the exchange rate and protecting the money supply from shocks. This had two consequences. One was that the Bank paradoxically suffered frequent annual losses on an account that should have been a money spinner (Reis 2002). The other was that it rose to major player in this market, not just because of its exceptional resources, but also because this was the only way of intervening as often and effectively as the situation required. The available evidence shows that this predominance enabled it to influence the exchange rate, in the short run, but not to sustain any position indefinitely.[5] After a certain time, either an inversion of the market caused by exogenous forces must occur, or the discount rate had to be used at last in order to restore the balance of trade or encourage an inward movement of capital. An illustration of the Bank's ambiguous relationship with the market comes from late 1864, at a moment when the exchange rate had been close to the gold export point for some time. Two important Lisbon arbitrageurs, who needed to cover their positions in London, demanded that the Bank sell them sterling bills or drafts at the price that it would cost them to export sovereigns, otherwise they would resort to such a measure. The Bank of Portugal had no alternative but to comply, although in the previous September its board had proclaimed that it was able to determine the sterling rate by offering to sell paper on London at a suitable price. In other words, its market dominance gave the Bank the influence but did not make it the uncontested leader. Rather it was a market follower, because it could not act preemptively in this respect, either because it lacked the information or because it hoped to put off the costly necessity of doing so. Above all, as in all foreign exchange interventions, it lacked the infinite resources needed for correcting a chronically unbalanced situation.

4   Methodology

Among the several possible techniques for estimating market integration, or arbitrage efficiency catalogued by Officer (1996: 177-21), we decided to try and apply the two that seem to have attracted the most interest in the literature. The first one is Officer's own method of direct reconstruction of the several components of transaction costs conceivably associated with gold arbitrage. This is a very data-intensive exercise in retrospective accounting, but we were fortunate to gain access to an extremely detailed record of actual gold shipments during the period when Portugal was on gold. The second method follows a small literature that attempts to recover the "gold points" (the limits of the fluctuation band of the exchange under the gold standard) from the preferences revealed in the exchange rate series itself. The latter method replaces a fully specified model of arbitrage for the detailed data gathering of the former method. In this sense its results depend crucially on the assumptions regarding the preferences of the arbitrageurs and the technology of arbitrage, and also on

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[5]This is based on a reading of the board's minutes and correspondence with foreign and local banks.

the estimation technique chosen to operationalize the theoretical model.[6]

4.1   Retrospective accounting

A preliminary step to reconstruct the transaction costs of gold arbitrage is to identify the dominant agents in the foreign exchange market, the prevailing instruments for arbitrage, and also the preferred type of gold specie used in international shipments. The two last questions are relatively simple to address, compared to the first one. In fact, an answer to the first question requires a judgement on two related points: the major center of arbitrage, and the type of agents involved in it. Not having found, so far, decisive documental evidence to support either claim, we will base our estimations on the assumption of a Lisbon-based arbitrage essentially run by large financial institutions (banks or banking houses). That the Portuguese currency was at best of marginal interest to the London-based financial houses and banks seems obvious from the small share of Portugal in British economic interests abroad. The interest in establishing a London market for drafts in Portuguese currency seems therefore very remote.[7] Quite the reverse was the case in Portugal, which, in the period we are covering, had between a third and half of its total foreign trade done with Great Britain, and who placed 60% of its government external funded debt in London.[8] We choose to concentrate on the largest members of the financial community in Lisbon, because only they would probably have had the access to funds and information to make it worthwhile to engage in foreign exchange arbitrage, besides enjoying the advantage of being charged lower commissions by their correspondents abroad.

The relevance of this assumption lies in the fact that it conditions the data collection. Accordingly, we reconstructed a series of the exchange rate for sterling in Lisbon (instead of the real in London), and tried to estimate the transaction costs that a Lisbon-based arbitrageur would face. The choice of the largest banks and banking houses as the typical arbitrageurs also has an impact, albeit smaller, on the definition of the elements of the transaction costs (more on this in sub-section 5.2).

On the determination of the typical foreign exchange instruments, all documentary sources agree on the regular use of the sterling bill or, later, of the checks drawn on London, by contrast with the marginal importance of cable operations, long after the first international cable connections had been established.[9] Indeed, only for the very last year of our sample did cable rates on London start to be published regularly. As late as 1913, a contemporary author indirectly described the nature of the foreign exchange instruments as follows:

> The favorable exchange means the low price of the short term exchange paper, be it repre-
> sented by a trade bill drawn against the payment of exported merchandize, by a check sent
> from abroad or bought by the broker, by a government debt coupon, or by an entitlement

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[6]To gauge the degree of variation in model specification and estimation compare the earlier attempt by Spiller & Wood (1988) to the more recent endeavors of Canjels *et al.* (2004).

[7]An anecdote about this marginality is the fact that the *Economist* stopped publishing the Portuguese exchange on London in 1870, a necessary piece of information for two-point arbitrage.

[8]Data from Lains (1999) and Esteves (2002), respectively.

[9]The first submarine cable, connecting Lisbon to England and Gibraltar, entered service in 1870.

to dividends or commercial interest, etc.[10].

We leave the details of the identification of which bills and types of specie were used, in several periods, to the next section. We finish with a description of the sequence of operations required to complete the two types of gold arbitrage, which is necessary in order to understand the enumeration of the transaction costs, dealt with also in the next section.

In the case of the import of gold, the arbitrageur would start by buying sterling bills of a certain maturity at their market price in Lisbon. Then, he would send the said bills to London, where he would have them discounted at the going market rate. The proceeds from this would then be used to buy gold from the Bank of England, at the price charged by this institution. Finally, the gold would be shipped back to Lisbon, and sold there at the official Mint parity. This operation would only be profitable if the current exchange rate was sufficiently *low* relative to par (appreciation), so that the difference between the par and the current exchange rate would be greater than the transaction costs involved. Otherwise, it would not take place.

Conversely, an export of gold to London would start with the sale of sterling bills in Lisbon, at the current market price, the proceeds of which would be used to buy gold. The bills, and a fraction of the gold would then be shipped to London, where the gold would be used to buy the amount in pounds (again at the price offered by the Bank of England) necessary to repay the bills. The proceeds of the operation would be the difference between the original exchange rate in Lisbon and the par value, after deducting the corresponding transaction costs.

Both cases are essentially riskless, because the foreign exchange transaction is completed at the beginning (with the sale or purchase of the sterling bills), and the remaining prices were typically held constant under the gold standard. It is in this sense that we refer to these transactions as "arbitrage", as they do not involve any significant measure of expectations on the future values of the relevant variables (speculation).[11]

4.2 Revealed preferences

We now pass to the description of a partial equilibrium model for the foreign exchange in Lisbon, along the lines of Canjels *et al.* (2004). This model can be solved, and estimated, from only 3 simple relations that describe preferences and technology. The first is the market demand for sterling bills in Lisbon:

$$E_t = \alpha - \beta B_t + u_t \tag{1}$$

in which E_t is the market exchange rate for bills of a certain maturity, B_t is the stock of sterling bills available in Lisbon, and u_t is an error term, probably nonstationary and serially correlated.[12]

The second relation is the market supply for these bills:

$$\Delta B_t = -p_G^{£} \Delta G_t \tag{2}$$

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[10]Rocha (1913: 182)

[11]In fact, there was also no liquid futures market in Lisbon during this period.

[12]B_t is expressed in pounds sterling. E_t is the price of a pound in réis.

where $p_G^£$ is the Mint price of gold in pounds, and ΔG_t is the net gold inflow into Lisbon from London.[13] This specification implies that the sole source of bills in Lisbon comes from arbitrage operations, which although convenient for keeping the model under manageable proportions may underestimate the supply of bills. First, it is not clear that "trade bills", accumulated as a counterpart to exports to the UK, would not be bought for arbitrage purposes. Secondly, emigrant remittances from Brazil were also typically transferred to Portugal via sterling bills bought in Rio de Janeiro, and sent to Lisbon. Finally, the Portuguese banks themselves issued drafts in sterling, which they would cover in London, either by selling sterling assets there or by using the credit lines they had with London banks.[14] However, at this stage, we are not sure how to adjust the model for these additional levels of complexity, so that we will work with the same framework of Canjels *et al.* (2004) bearing in mind its limitations.

Finally, the third element of the model is the arbitrage cost function, which is specified as simply quadratic:

$$
C_t = \begin{cases} a + b_0 \Delta G_t + \frac{1}{2} c_0 \Delta G_t^2 & \text{if } \Delta G_t > 0 \\ a + b_1 \Delta G_t + \frac{1}{2} c_1 \Delta G_t^2 & \text{if } \Delta G_t < 0 \end{cases} \tag{3}
$$

That is, we allow for varying (arguably decreasing) marginal costs with the amount shipped, and also for asymmetric costs between gold export and import.[15]

From these three simple equations, it is possible to derive a closed-form solution for the dynamics of the exchange rate, by using simple economic intuition. Take the case of gold import. Marginal cost and marginal revenue for this transaction are given by:[16]

$$
MC_t = b_0 + c_0 \Delta G_t \tag{4}
$$

$$
MR_t = (E_{par} - E_{t-1}) \, p_G^£ \tag{5}
$$

Arbitrageurs will import gold up to the point when

$$
MC_t = MR_t \Leftrightarrow \Delta G_t = \frac{1}{c_0} \left[(E_{par} - E_{t-1}) \, p_G^£ - b_0 \right] \tag{6}
$$

which gives the optimal level of gold import, in case the exchange rate falls sufficiently below the par. Repeating the argument for gold export we get to:

$$
\Delta G_t = \begin{cases} \frac{1}{c_0} \left[(E_{par} - E_{t-1}) \, p_G^£ - b_0 \right] & \text{if } E_{t-1} - E_{par} < -\frac{b_0}{p_G^£} \\ 0 & \text{if } -\frac{b_0}{p_G^£} \leq E_{t-1} - E_{par} \leq -\frac{b_1}{p_G^£} \\ \frac{1}{c_1} \left[(E_{t-1} - E_{par}) \, p_G^£ - b_1 \right] & \text{if } E_{t-1} - E_{par} > -\frac{b_1}{p_G^£} \end{cases} \tag{7}
$$

Now replace (2) in (1) to get:

$$
\Delta E_t = \beta p_G^£ \Delta G_t + v_t \tag{8}
$$

---

[13] As described in the previous subsection, a gold export(import) operation involves an increase (decrease) of the stock of sterling bills in Lisbon. Hence, the negative sign in equation (2).

[14] More on this in section 6.

[15] All coefficients are positive, except c_1, because in the second branch of the cost function $\Delta G < 0$.

[16] Notice that the marginal revenue is defined by comparing the par with the lagged exchange rate, or the exchange rate observed at the moment of decision to engage in arbitrage.

where $v_t = \Delta u_t$ is assumed to be stationary. Finally, replace (7) into (8):

$$\Delta x_t \;=\; \begin{cases} -\lambda_0 \left(x_{t-1} - \gamma_0\right) + v_t & \text{if } x_{t-1} < \gamma_0 \\ v_t & \text{if } \gamma_0 \leq x_{t-1} \leq \gamma_1 \\ -\lambda_1 \left(x_{t-1} - \gamma_1\right) + v_t & \text{if } x_{t-1} > \gamma_1 \end{cases} \qquad (9)$$

in which $x_t \equiv E_t - E_{par}$ is the exchange rate deviation from par. Equation (9) has a direct interpretation in terms of the dynamics of the exchange rate in a gold standard regime. In this context, γ_0 and γ_1 are respectively the gold import and export points. Inside the band defined by them, the exchange follows a pure random walk, whereas outside the bands it follows an AR(1) process that converges back to the bands with speeds λ_0 and λ_1.[17] The comparative statics of these four parameters with respect to the parameters of the original equations (1)-(3) is also intuitive. The absolute values of the gold points increase with the intercept of the marginal cost (the bs). As for the speeds of convergence, they decrease with the slope of the marginal cost (the cs), and increase with β, the slope parameter of the demand function for sterling bills in Lisbon. Why the speed of convergence decreases with the slope of the marginal costs of arbitrage is simple to understand, and, in the limit, with a constant marginal cost ($c_0 = c_1 = 0$) the adjustment would be instantaneous. Likewise, because β measures the sensitivity of the market exchange rate to the amount of bills (and, through (2), to gold movements), the higher this sensitivity the higher the speed of convergence of E_t back to the band.

The interest of this derivation comes not only from the simplicity of the closed form of (9), but also from its direct correspondence with a class of discrete-time econometric models. As stated, equation (9) can be estimated as a threshold autoregressive model (TAR) with 3 regimes, order 1, and with a delay parameter also of 1. In short, a TAR(3,1,1) model. These models are fairly straightforward to estimate by Conditioned Least Squares (CLS), and their asymptotic properties have already been established by Chan & Tsay (1998) for the continuous case, which is precisely the formulation of (9).[18] In particular, these authors have shown that all the parameters of the model ($\gamma_0, \gamma_1, \lambda_0,$ and λ_1) are $\sqrt{N}$-consistent and asymptotically normally distributed, what allows for inference. More details on the estimation method, and on several alternative specifications follow in section 6.

5 Data Sources

5.1 Exchange Rates

In this subsection we define the primary data set in terms of the nature and maturity of the exchange rate, and the extent and frequency of the sample period. The exchange rate series is defined as the sterling/real exchange as quoted in Lisbon for bills drawn on London with a certain maturity. The sample period runs between June 2nd, 1854, and May 23, 1891, coinciding with the Portuguese adherence to the gold standard.

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[17]To be more precise, the closed forms of the parameters are: $\gamma_0 = -\frac{b_0}{p_G^\mathcal{L}} < 0$, $\gamma_1 = \frac{b_1}{p_G^\mathcal{L}} > 0$, $\lambda_0 = \frac{\beta \left(p_G^\mathcal{L}\right)^2}{c_0} > 0$, and $\lambda_1 = -\frac{\beta \left(p_G^\mathcal{L}\right)^2}{c_1} > 0$.

[18]By continuous we mean that the Δx_t function is continuous everywhere, namely at the threshold values γ_0 and γ_1.

Contrary to Officer (1996), and Canjels *et al.* (2004), we decided to use a weekly periodicity. This choice is due both to data limitations, and to our appreciation of the market's volatility. Officer (1996: 64) argues for using monthly averages in the reconstruction of gold points, in order to average out *atypical observations.* This may make sense for the New York/ London arbitrage, where until 1866 information crossed the Atlantic with the 9 to 11 days delay of a one-way oceanic trip. It is hard to justify such a large lag in the information set of the potential arbitrageurs between two financial centers, like Lisbon and London, that were separated by 5 days of steaming in the North Atlantic.

Canjels *et al.* (2004), and also Boyer-Xambeu *et al.* (1994), on the other hand, prefer to collect data at the highest possible frequency for the period (daily). Although we are convinced that the market did not display such short oscillations in the exchange, we also tried to collect daily data, but it was only available for 287 weeks (or 15% of our sample). Nevertheless, in this sub-sample we only observed within-week exchange rate changes in 111 weeks.[19] Indeed, in the final sample itself, defined with weekly periodicity, there is also no change of price between two successive weeks in 40% of cases.

The primary source for the exchange rate data were the bulletins of the Lisbon stockbrokers chamber. These were published fairly regularly in the official government newspaper, the *Diario do Governo.* In order to fill in the gaps in this source, we also made use of the information published in the Portuguese financial press of the time.[20] Overall, these two sources covered 92.4% of the sample period. The remaining 7.6% (146 weeks) were interpolated, by assuming that the exchange didn't change relative to the last week for which we had information.[21]

As mentioned in section 3, foreign exchange operations during this period were mediated by sterling bills traded in the Lisbon market. Officer (1996) emphasizes the need to identify the dominant instruments of gold arbitrage for an accurate reconstruction of its costs. Because we could not find as detailed information as Officer did on the maturity of the bills traded, we followed the rule-of-thumb of choosing the type of bills, which in each period had the highest data frequency in the sources.[22] The division of periods by type of bills is in Table 1.[23]

[Table 1 about here.]

One further problem with the available data is that, up to the last part of our period, the sources only quote one price for the pound, instead of the usual "bid" and "ask" rates. According to Officer (1996: 72) single rates typically quoted the price at which pounds could be bought from brokers and dealers, that is, the "ask" rate. Officer reconstructs the "bid" rates by using data on the broker's commission in the foreign exchange market. His preferred measure of the exchange rate is the midpoint

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[19]Moreover, in 68 out of the 111 weeks there was only one price change.

[20]The publications we used were, by decreasing participation in the sample, the *Commercio de Portugal*, the *Gazeta da Bolsa*, the *Jornal do Commercio*, and the *Commercio do Porto*.

[21]We choose to do so, instead of simply interpolating, for two reasons. First, because almost all the missing values corresponded to single weeks (123 in 146). Second, because there is a reasonable expectation that the sources we used would skip a week whenever there was no a change in the market.

[22]This is taken as an indirect measure of the liquidity of each category of bills.

[23]Again because of data gaps we deviated from this rule in 61 weeks (3.2% of the sample), for which we used quotes of bills of different maturities from those in Table 1. Also notice that the 'checks' drawn on London can be interpreted here as demand bills.

between the "ask" and the reconstructed "bid" rates. We could not find independent information on the commissions charged by Portuguese financial agents, so that our series may overestimate the "true" measure of the exchange rate in the earlier part of the sample.[24]

The final operation to reach our exchange rate series is to make it homogeneous. To do this, we follow the usual practice in the literature of converting it to a demand bill-equivalent series through the simple formula:

$$E = E_m \left(1 - b\frac{m}{365}\right) \tag{10}$$

where E is the demand bill-equivalent, and E_m is the quoted exchange for a bill with a maturity of m days, discounted at rate b.[25] This transformation of the base exchange rates requires two additional pieces of information: the maturity m of bills used in foreign exchange transactions, and the appropriate discount rate b. Regarding the first, we have not yet been able to find a representative compilation of these maturities, so we used the maturity stated in the rates. As the actual maturity of sterling bills traded in Lisbon would have been no larger than the stated, this implies an underestimation of the "true" demand bill-equivalent rate, as can be gathered from equation (10). This underestimation bias, which may exaggerate the incidence of gold import violations (minimize gold export violations), probably compensates the overestimation from using "ask" rates.

With respect to the discount rate b, we had to decide which money market, Lisbon or London, to use as reference. Following Perkins (1978) we compared the available data on discount rates in the two markets with the implicit rates obtained from inverting equation (10):

$$b = \frac{365}{m} \left(1 - \frac{E}{E_m}\right) \tag{11}$$

We have a full series of exchange rates for bills of 30 days of sight, 90 days of sight, and of checks only for the period 1886-1891, which we compare with the weekly data published in the *Economist* on the Lisbon "open market" short-term interest rate, and the London discount rate on 90 days bills.[26] As can be seen from Table 2, there's an appreciable coherence between short-term London discount rates, and the implicit rates in the 30 and 90 days bills, contrary to the Lisbon rates.

[Table 2 about here.]

Naturally, the correlation is higher between the London rate for 90 days bills, and the implicit rate for the same maturity. However, the largest complete series that can be recovered from the *Economist* for

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[24]That is, we took the midpoint for periods in which we had both rates. We also attempted to infer the commissions from the observations in which we had both rates, 1886-1891. Around 2/3 of the inferred commissions lie between 0.05% and 0.12%. However, because there is considerable volatility in the data (coefficient of variation = 0.95), and we only have data for the last 6 years of the sample, we choose not to extrapolate this information.

[25]That contemporaries used *simple* instead of compound discount is attested both by Officer (1996: 68) for the US case, and by contemporary evidence for the Portuguese case. On the latter see Aragão (1964: 227).

[26]The data on market discount rates comes from Neal and Weidenmier (2003), and from our own soundings in the *Economist*. To be more precise, we used the rates for "3 months trade bills" until 1880, and for "90 days bank bills" thereafter. In principle, the exchange operations carried out by the Bank of Portugal should involve bills of the highest quality, i.e. bank bills. However, that was not necessarily the case for other possible arbitrageurs. Anyway, the *Economist* only started separating the rates for bank and trade bills in 1881.

the whole period is the 90 days bills. Therefore, as Officer (1996), we chose to use this rate throughout, irrespective of the maturity of the exchange rates. This was possible for the period 1860-81. For earlier years, when the *Economist* did not publish this information, we used the Bank of England's bank rate.[27]

A first summary description of the data is given in Figure 1, and in Table 3. For ease of interpretation all values are expressed as percentage deviations from par.[28]

[Figure 1 about here.]

[Table 3 about here.]

Overall, the pound exchange rate in Lisbon kept itself within a band of ±3% from par. Within this band, the exchange tended to gravitate more frequently towards depreciation (above par), which was natural to expect from a peripheral economy with a systematically negative trade balance, and highly dependent from foreign capital flows (especially through the public debt), and the remittances of its emigrants.[29] Nevertheless, there were also periods of persistent rates below par: 1854-56, 1862-63, and 1871-75. Although our current knowledge of the Portuguese balance of payments is very imperfect, the available data seem to suggest that these three periods coincided with improvements in the external accounts, mainly driven by emigrant remittances from Brazil.[30] We also divided the sample in Table 3 into 3 sub-periods to stress the main tendencies observed in the evolution of the exchange series. Beyond the trend towards depreciation against the pound, we can also observe a systematic decrease in volatility, when measured either by the standard deviation or the maximum amplitude of the exchange rate.

As an alternative representation of the data, we also estimated the Kernel density of the exchange rate.[31] The results are summarized in the last two rows of Table 3, and in Figure 2.

[Figure 2 about here.]

The latter Figure clearly illustrates two developments. On the one hand, the drift of the distribution to the right, which corresponds to the tendency for depreciation of the Portuguese currency, already mentioned; on the other, the convergence, through time, to a well-behaved target-zone model à la Krugman (1991). Indeed, in the later two periods there is an obvious bi-modal distribution of the exchange. The values of these modes are given in Table 3. Interestingly however, the values of the modes for the later period do not conform with our results for the estimation of the gold points, as

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[27]The latter from Hawtrey (1938), Appendix I.

[28]The style of the time was for the pound *to give the par*, that is, the rates were quoted as pence per thousand Portuguese réis. The par was accordingly defined as $53\frac{1}{3}$ pence per thousand réis, which was equivalent to 4500 réis per pound.

[29]On the foreign position of the Portuguese economy in the second half of the nineteenth century see Reis (2000) and Mata (2002).

[30]A similar association seems valid for the improvement in the exchange after 1886, which coincided with a positive shock to the remittances and foreign capital inflows (public debt) in the years 1887-1890.

[31]We used a Gaussian Kernel with optimal bandwith (in the sense of minimizing the mean integrated square error) $h_n = \frac{0.9 * \sigma_x}{n^{1/5}}$, in which σ_x is the standard deviation of the sample, and n the sample size.

we will see. In particular, as the lower mode is positive, this would imply that rational market agents expected the exchange to always float above par, which probably may have meant that the system, in their eyes, lacked credibility.

5.2 Direct Expenditures

There were two classes of arbitrage costs: direct expenditures of gold shipments, and indirect costs. The former class is common to both types of arbitrage: gold export and import. Officer (1996) catalogues five main direct costs: freight (and other expenditures in transit), insurance, commissions, abrasion, and deviations from the Mint parity. Our main source for these expenditures is the accounting records of the Bank of Portugal for 285 shipments of gold from London, between 1857 and 1891.[32] Although we only have the records for one direction of the gold flows, it is reasonable to assume that the majority of the direct expenditures were symmetric for the two directions of gold shipments. Figure 3 illustrates the time path of the three main classes of direct expenditures.[33]

[Figure 3 about here.]

The overall downward trend in these figures accords with the increasing market efficiency, and can be traced to specific improvements in the technology. In particular, the stepwise profile of the freight charges is in direct correspondence with the size and type of the ships used in the Lisbon-Southampton route. As the accounting records of the Bank of Portugal also kept the name of the ship used in each operation, we could cross that information with the technical specifications of the ships as described in the Lloyds' Register.[34] During the first "plateau" (1850s), freight costs were of the order of 0.5% for sailing ships with an average displacement of 200 tons (gross). The second level, around 0.2%, and lasting until the 1870s was characterized by an evolution towards larger ships (average 800 tons), built of iron, but still with mixed propulsion, sail and steam. Finally, the later period, with costs around 0.15%, benefited from another increase in scale (average 3200 tons), and from the generalization of iron steamships.

The forth major component of the direct expenditures consisted of commissions paid at several stages of the arbitrage transaction. Contemporary sources mentioned three types of payments: to buy the bill ("brokerage"), to sell it ("commission" proper), and to buy the gold in London (in case of gold import). We chose to ignore the latter one under the impression that the largest Portuguese financial houses would have their own correspondents in London. As for the remaining two, our sources pointed out to fairly stable rates throughout the whole period. "Brokerage" was quoted at 1/8% in Lisbon, and 1 ‰ in London, while a "commission" of 1/2% was charged to small customers in both markets, reduced to 1/4% for larger values. Because the larger customers would dominate the market for sterling bills, we decided to include the smaller value of 1/4%.[35] Hence, we included total costs with commissions

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[32] We used both the *Diário*, and the *Mestre auxiliar* ledgers, as well as the internal records of foreign correspondence.

[33] "Other expenditures in transit" includes costs with boxes and with transhipment from London to Southampton.

[34] Actually, it was not always possible to match this information, because some ships had fairly common names, such as Nile, London, or Sultan. We used the *Lloyd's Register of British and Foreign Shipping* for 1857, 1868, and 1887.

[35] We based these estimates on evidence from the accounting records of the Bank of Portugal, and on some treatises on foreign exchange. For an earlier example of the latter see Guerra (1837), and Monteiro (1889) for the later end of our

of 0.375% (1/8%+1/4%) for gold import, and 0.35% (1‰+1/4%) for gold export.

Like Officer (1996), we filled in the blanks between these 285 observations with simple interpolations.[36] As regards Officer's last two classes of direct transaction costs, i.e., abrasion, and deviations from the Mint parity there are several reasons to ignore them. Under normal circumstances, abrasion should be added to the costs of exporting gold, on the assumption that the British monetary authorities (namely the Bank of England) would receive abraded gold coins by weight, instead of tale. Conversely, abrasion would reduce the transaction costs of importing gold, inasmuch as it could circulate in Portugal at par. This line of reasoning assumes that the dominant form of gold shipped was domestic gold coins. Indeed, as shown in Table 4, gold coins clearly prevailed in the gold imported, and also in the gold exported to London.

[Table 4 about here.]

However, the Portuguese monetary law of 1854 gave legal tender to British sovereigns, and British gold coins had a disproportionate share in the total stock of monetary gold held in Portugal.[37] Based on this evidence, it is possible to identity the British sovereign as the dominant specie used in both export and import arbitrage. The question therefore hinges on the quality of the sovereigns shipped from Lisbon to London and vice-versa. In a letter of October 5, 1888 to the Portuguese Treasury, the Financial Agency of the Portuguese government in London described the care of the Bank of England in assaying all gold coins entering or leaving its safes:

> The sovereigns that enter the Bank are all weighed with several very ingenious machines, driven by steam, which reject to one side the non abraded coins, and to the other those, which by their long circulation no longer have the weight with which they had originally came out of the Mint. This system thus guarantees the export only of gold with legal weight.

This implies two things. First, gold sovereigns imported from London had a high quality, which eliminated the possibility of profiting from the introduction of debased coins at par in Portugal.[38] Second, any abraded sovereigns sent to London would be easily detected there, and bought by weight. Anyway, in the case of private arbitrageurs, they could readily get their gold in Lisbon without cost from the Bank of Portugal, and this coin would have to of high quality for reputational reasons, since

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period.

[36] Nevertheless, it should be noticed that our data base is much more detailed than the one that Officer uses. For instance, for our period, he bases his interpolations on 5 data points for freight and 4 for insurance.

[37] According to Reis (1990) between 85% and 90% of total gold coins in circulation between 1854 and 1891. For the repeated complaints in Portugal about the scarcity of domestic gold coin see the same source. Actually, the foreign trade statistics only distinguish between Portuguese and British coins before 1880. That all gold imports from Great-Britain were made in British coin is attested both by the foreign trade statistics in this sub-period, and also by the records of the Bank of Portugal, that only bought sovereigns and half-sovereigns. On the side of exports, although the statistics are less reliable, British coins outnumbered Portuguese currency 55 to 1, in the same sub-period.

[38] This does not exclude that such arbitrage was indeed practiced. Some contemporary sources, like Aragão (1964: 230) mention protests against abraded sovereigns entering Portugal from Spain. But as this was happening in border regions, they may never have reached Lisbon.

it might be known in London where the sovereigns came from.Abrasion losses are therefore not taken into consideration.

Likewise, there was no added cost from the use of "gold devices", such as charging or offering a price of gold different from the official Mint parity. The Bank of England always sold sovereigns at par (Officer 1996: 147), and these were accepted, also at par, under the Portuguese monetary law.

There was a final component of the direct transaction costs, which was specific to the Portuguese case. The Portuguese state taxed gold exports until 1886, at 4537 *réis* per Kilogram of pure gold until 1860, and 5000 until March 24, 1886.[39]

5.3   Indirect costs

The second class of transaction costs, the indirect ones, has to do with the opportunity losses, or profits foregone, during the time that funds used in arbitrage were retained somewhere in the Atlantic Ocean. These costs, which were usually ignored in the contemporary descriptions of gold arbitrage, varied with the direction of the shipment. In the case of gold exports, because the exchange operation was completed at the start, and only the amount of gold necessary to pay for the bill at maturity was sent to London, there was no interest cost. Gold imports, on the other hand, required that the arbitrageur wait the time corresponding to a round trip before he could cash his profit. In order to estimate this latter cost, we need an appropriate interest rate for the best short-run alternative opportunity, and we need to know the likely duration of a trip between the two money markets. Data limitations made us use the discount rate of the Bank of Portugal as the proxy for the best alternative interest income. For the duration of the round trip we took 12 days. This estimate is based on two elements. The first is the duration of the maritime voyage between Lisbon and Southampton, which the notices of maritime traffic of the port of Lisbon placed between 4 and 6 days, throughout our period.[40] We took the midpoint, i.e., 5 days. The second is an addition of 2 days for travel between the harbor and London, and for the necessary time to buy the gold to ship back to Portugal. Interest cost is then given by: $2d \times \frac{i}{365}$, where d=6 days, and i is the (annualized) discount rate of the Bank of Portugal.[41]

Officer (1996) also adds a component of risk præmium and normal profit to his estimates. Despite the essentially riskless nature of arbitrage, there were some residual components of risk, namely the possibility that interest costs could vary with the duration of the maritime travel.[42] However, most of the instances of risk mentioned by Officer (1996: 172-73) do not apply to the Portuguese case, once more because of the peculiarity of having as the dominant arbitrage instrument the sovereigns, which simultaneously had legal tender in both countries. Because of this residual nature of the risk

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[39]As we are taking the sovereign as the dominant instrument for arbitrage, we calculated the value of one Kg of pure gold based on the official definition of the sovereign in the Portuguese monetary law of 1854. This implies a cost of 0.708% until 1860, and 0.813% thereafter.

[40]These notices were regularly published in the *Diario do Governo*.

[41]We are also using simple interest in this formula, as Officer (1996: 161).

[42]That is, either because of an unexpectedly long passage, or because the best alternative rate i changed significantly between the moment of deciding to export gold, and the moment of realizing the revenue from the operation.

component, and also because it is not clear to us how to disentangle the interest loss from the "normal profit" components, we chose not to try and add an estimate for this type of indirect costs. Nevertheless, we will duly have in account this possible omission when commenting later on the size distribution of the gold points' "violations".

6 Results

In this section we will use our data to approach the workings of the Portuguese gold standard from a number of perspectives. In the first two sub-sections, we test the efficiency of the system in producing one of its most cited properties, viz., exchange rate stability within the band defined by the gold points (what Officer 1996 calls "market efficiency"). For this purpose, we marshalled the results from the two methodologies described in section 4. Next, we turn to a different perspective, which started with Krugman's (1991) seminal paper on target zones (TZ). We not only test some of the implications of the TZ model, but also use it to give a quantified answer to the important question of the credibility of the Portuguese adherence to the gold standard.[43] Finally, we make use of another piece of evidence, the direction and timing of gold shipments between Portugal and the UK, which, theoretically at least, provides another testable corollary of the efficiency of the monetary regime.

6.1 First pass: gold points and their "violations"

We will start the description of our empirical results with the direct reconstruction of gold points, following the methodology described in sub-section 4.1. Table 5 and Figure 4 summarize the estimates of the gold export (GX) and import (GM) points for the pound/real exchange in Lisbon.

[Figure 4 about here.]

[Table 5 about here.]

The first impression from these results is the overall decrease in the estimated gold points, which on average are halved between the first and the last sub-periods. If we decompose this trend by the components of the two gold points, we come to the conclusion that the decrease was largely driven by the declining costs of freight and insurance, with the exception of the last sub-period for the GX point, where the abolition of the duty on gold exports is dominant in explaining the narrowing of the gold point spreads after 1886.[44] Indeed, it is interesting to notice the clear reaction of the exchange to this reduction in costs, which may be taken as confirmation of the influence of gold arbitrage in determining the fluctuation spreads of the pound in Lisbon (more on this in sub-section 6.4).

The simplest test of the "market efficiency" of the system is to count the number, size, and persistence

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[43]This relates to Officer's "regime efficiency".

[44]Except for the last period of the GX, the share of freight reductions varies between 70% and 86%, while the fall in insurance costs explains between 23% and 28% of the decrease in the gold points. The contribution of the other components is much smaller and, in some cases, negative, e.g., the opportunity cost in the GM increases between the first and the second sub-periods, due to a rise in the average discount rate of the Bank of Portugal.

of the gold points' "violations" (to use Morgenstern's 1959 expression). This information is summarized in Table 5. On a first approximation, our results lie closer to the negative results of Morgenstern (1959), and Clark (1984) than to Officer's remark about the "remarkable efficiency" of the dollar/sterling gold standard, or to Flandreau's (1995) results for the bimetallic exchange between Paris and London. For the whole period, we counted 12.9% weeks of GX violations, and another 4.6% of GM violations, with an average duration of 3.7 weeks for both types of violations. Moreover, the profit opportunities were, on average, quite high throughout. These values seem too high to characterize the workings of an efficient arbitrage mechanism. Nevertheless, there are reasons why this conclusion may not be fully warranted. To begin with, the period we study does not entirely overlap with the periods of reference for the estimates of the two other bilateral exchanges. In particular, the dollar/sterling data estimates tend to be concentrated in the last two decades before World War I, whilst Flandreau's (1995) stop in the 1870s. In this sense, the comparison with the dollar/sterling case may be too stringent, because it is possible that technological improvements, only available in the later period, could have substantially improved the market efficiency of the system. On a related point, Canjels *et al.* (2004) consider that Officer's (1996) gold points estimates are "almost certainly too high", thereby underestimating the incidence of "violations". Unfortunately, the authors do not report the frequency of violations under their estimates, so that we cannot compare our own results to theirs. Still on this point, the data in Table 5 show some improvement in the efficiency of the system, when measured by the frequency and duration of gold points' violations. This is true for the GM point, which converged from 16.8% of violations in the first sub-period, to less than 1% in the last one, and with a persistence of about 1/4th of the former period. This is contradicted by the evidence for the GX, whose frequency of violations actually increased throughout the whole period, with no substantial decrease in average persistence.

Second, and more important, looms a question of measurement error, probably on the side of the underestimation of some components of arbitrage costs. As discussed in sub-section 5.2, our estimates are mainly conservative, in that they exclude components, which we do not find relevant for the case at hand (abrasion, deviations from Mint parity), or for which we could not find data (normal profit and risk præmium). To try and gauge the possible relevance of such omissions, we identified the exchange rate observations that lay *outside* the correspondent gold points by up to 0.3125% of parity (see the last lines of each of the sub-panels in Table 5). This value comes from adding Officer's (1996) estimates for abrasion, normal profit, and risk præmium for the later end of our sample (1871-90).[45] We then take these observations as a measure of a possible overestimation of gold points' violations. The results imply a distribution of gold points' violations highly skewed to the right, because the frequencies of exchange rate points outside this enlarged band falls to 2.0% in the case of the GM, and 4.3% for the GX point. Average persistence also falls to 2.6 weeks for GM, and 3.4 for GX violations.

Nonetheless, we also cannot exclude the presence of measurement error (of unclear direction) in those cost components, for which we have high-frequency information, like freight or insurance. We therefore turn to the results of the indirect estimation of the gold points' spread from the arbitrage model of sub-section 4.2.

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[45]If anything, they will underestimate the value of such items of expenditure, which fell over time.

6.2 Indirect estimation

As Canjels *et al.* (2004), we run different versions of the model of equation (9). Contrary to these authors, we did not adjust a model of symmetric thresholds, given the evidence on the different nature of some of the transaction costs between the two types of gold arbitrage.[46] We start with a model of asymmetric, but time-invariant thresholds, estimated both under the other assumptions of the model, and relaxing them. We then move on to flexibilize the time dimension, namely to allow the thresholds to change over time. We do this in two ways. First, we repeatedly estimate model (9) with a moving window of 2 years. Next, we re-specify (9), so that the thresholds γ_0 and γ_1 can follow a smooth time trend.

Table 6 lists the results of the estimation of the TAR(3,1,1) model of equation (9).

[Table 6 about here.]

In order to identify the parameters of the three regimes ("lower" or GM violation, "middle" or within band, and "upper" or GX violation), we imposed the restriction that, at least, 2.5% of observations should fall in each of the outer regimes, while the middle regime should include no less than 5% of observations.[47] To be able to test for the random walk behavior of the exchange in the middle regime (as implicit in (9)), we added a constant μ_0 to the middle branch of equation (9), and a slope coefficient μ_1 to the lagged value of the deviation of the exchange rate from par, i.e., we estimated $x_t = \mu_0 + \mu_1 x_{t-1} + v_t$, if $\gamma_0 \leq x_{t-1} \leq \gamma_1$. For more details on the estimation procedure see Appendix 1.1.

Despite allowing for asymmetric thresholds, the estimation converged to the same gold points in absolute value, of about 0.87% of parity. The threshold parameters were estimated very precisely, less so the speeds of convergence. Contrary to assumed in the model, the hypothesis of random walk within the gold points' spread (i.e. that $\mu_0=0$ and $\mu_1=1$) is not sustained by the data.[48] Relative to the results of the direct reconstruction, the estimate of the GX is substantially lower, which implies a higher estimated frequency of violations of 38.2%. On the contrary, the new value of the GM is close to the one we obtained through direct reconstruction, with a more similar frequency of violations (6.8%). The estimates of the convergence speeds imply a half-life of the deviations from the gold points of 0.82 weeks for the GM, and 2.48 weeks for the GX point. Such speeds are nearer to the original estimates of the persistence of gold points' violations from Table 5 than to the revised estimates with an enlarged measure of the costs of arbitrage.[49]

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[46]For instance, the absence of an interest cost in gold export transactions, or the presence until 1886 of a duty on gold exports, but not on imports.

[47]For the full sample 2.5% means 49 observations. We choose this value to match roughly with the minimum frequency of violations of a gold point from the previous sub-section, which was 2.6% for the GM point.

[48]Although the coefficient of μ_0 is not significantly different from zero, that on μ_1 is lower than one, which indicates a mean-reverting process. The Wald statistic for the joint hypothesis is $\chi^2 = 18.66$.

[49]Although under the partial adjustment mechanism of equation (9) full convergence back to the respective gold point takes infinite time, we can measure, e.g., the time it takes to complete 99% of the convergence. For the GM violations we get 5.45 weeks, and 16.5 for the GX. To compare, Canjels *et al.* (2004) results imply about 5.8 weeks for 99% convergence in their model of symmetric and constant thresholds.

Finally, we also test the model specification. In running a TAR model with 3 regimes, we are assuming there are no additional non-linearities in the exchange rate behavior, after controlling for the two thresholds. Luukonen *et al.* (1988) propose a test for this hypothesis. The test statistics (LST) are in the second column of Table 6 (see details in Appendix 1.2). The p-values underneath each LST statistic imply that there is no evidence of additional non-linearities.

From the results of Table 6 it appears obvious that this model is too restrictive to account for the dynamics of gold arbitrage in our period. We accordingly relaxed some of the assumptions underlying the TAR(3,1,1) model, namely:

- the order and the delay of the selection variable, and

- the time-invariance of the thresholds.

To address the first question, we ran TAR(3,k,d) models with $1 \leq k \leq 3$ and $1 \leq d \leq k$, and chose the model that minimized the Bayesian Information Criterion (BIC). The chosen model was a TAR(3,2,2). We defer the full results to Appendix 1.3, and only report in Table 7 the main statistics.

[Table 7 about here.]

First of all, the estimates of the gold points are larger in absolute value, and the LST statistics allow again to reject the hypothesis of additional non-linearities. Then, by comparing the new estimates of the gold points to the steady-state implied by the AR(2) processes in the outer regimes we can also check, informally, whether the exchange did indeed converge back to the gold points. This seems to have been more the case for GX than GM violations. Similarly, the steady-state in the middle regime appears close enough to zero (as in a white noise process), even though we cannot assign a test statistic to this statement. Nevertheless, we are still not comfortable with such results in that they imply an excessive frequency of inefficiencies in the system.

Our final variation to the model flexibilizes the time dimension. We do this in two alternative ways. First, we estimate the model with a moving window of 261 weeks (5 years), shifted each time by 104 weeks (2 years). We believe these values strike a reasonable balance between the number of degrees of freedom, and the over-smoothing problem of the two previous constant thresholds models. In the second alternative, we allow the thresholds to follow smooth exponential time trends:[50]

$$
\begin{aligned}
\gamma_0 &= \gamma_{00} e^{-\gamma_{01} t} \\
\gamma_1 &= \gamma_{10} e^{-\gamma_{11} t}
\end{aligned}
\tag{12}
$$

To spare on degrees of freedom we reverted to estimating TAR(3,1,1) models. The results of both methods are summarized in Figures 5 and 6, and in Table 8.[51]

[Figure 5 about here.]

[Figure 6 about here.]

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[50]Again, look for details in Appendix 1.4.

[51]The full results of the model with smooth time trends are available in Appendix 1.4.

As can be readily seen, the two methods have complementary problems: whereas the moving window tends to mimic too closely the behavior of the exchange series (implying a somewhat erratic evolution of the arbitrage costs), the trend over-smooths that evolution. To partly control for the latter problem, we reestimated the GX trend (γ_1) adding a dummy for the known discontinuity in the arbitrage costs, which occurred in 1886 with the abolition of the duty on gold exports. That is, we amended the second equation of (12) to $\gamma_1 = (\gamma_{10} - \gamma_d \, \text{dum}_{1886}) e^{-\gamma_{11} t}$, where $\text{dum}_{1886} = 1$ for all dates after March 24, 1886.

Globally speaking, the estimates of the smooth trend model (especially with the dummy) are closer to the results of the direct reconstruction in Table 5, then the averages of the 5-year moving windows. Nevertheless, the 95% confidence intervals for the smooth trend estimates (the shaded areas in Figure 6) are somewhat wide, particularly in the earlier period. The over-smoothing problem of the smooth trend model also seems confirmed in Figure 6. Indeed, by forcing a single smooth trend throughout, the first version of this model overestimates the GX in the earlier period. Although the introduction of the dummy dum_{1886} seems to have been warranted, it doesn't make sense to further refine the model with other categorical variables for observed discontinuities in arbitrage costs. This would, in fact, mimic the direct reconstruction of the gold points with interpolation of sub-section 6.1.

After this conspectus of alternative estimates, it seems fitting to pass a preliminary judgement on their relative merits. First of all, despite the variation in time trends, all estimates agree in what is arguably their most important property, namely, the declining costs of gold arbitrage throughout the period. Although a necessary condition for an increasingly efficient arbitrage, this decrease doesn't seem to have been sufficient to bring about a "remarkably efficient" exchange rate mechanism. True, the reported efficiency depends on the estimates of the gold points, which, in the case of direct reconstruction, are subject to measurement error. The main advantage of the model of revealed preferences lies in the possibility of accounting for unobservable, or not easily estimable cost components. But the validity of the latter estimates depends crucially on the appropriateness of the pure arbitrage-driven exchange rate mechanism summarized in equations (1)-(3). For reasons we mentioned in page 12, and for others to follow, we find this model insufficient to describe the workings of the sterling exchange in Lisbon. Accordingly, we will give precedence, over the next pages, to the estimates from direct reconstruction of arbitrage costs.

6.3   Target zones and credibility

Since the inception of the TZ literature, there have been some attempts at testing its implications, and using its insights for the gold standard period (Flood *et al.* 1990, Giovannini 1993, Hallwood *et al.* 1996). We are interested in both, i.e., testing the correspondence between the assumptions and implications of the model and the Portuguese data, and using the TZ framework to discuss the question of the credibility over time of the Portuguese gold standard. We start with a brief abstract

of the relevant theory.

Krugman's (1991) model starts from a minimalist log-linear monetary model of the exchange rate (all variables in natural logs):

$$e_t = f_t + \alpha E_t \left(de_t \right) / dt \tag{13}$$

where e_t, f_t, and E() stand for the spot exchange rate, a composite measure of fundamentals, and the expectation operator, respectively.[52] Krugman also assumes purchasing power parity, and uncovered interest parity (UIP). The latter can be notated as $i_t = i_t^* + E_t \left(de_t \right) / dt$, where i_t (i_t^*) are the domestic (foreign) short-run interest rates.[53] From these two relations, Krugman derives the basic result of the TZ literature, the *honeymoon effect* that implies a S-shaped relationship between the spot exchange e and the measure of fundamentals f, *within* the fluctuation band. For illustration take the case of a positive shock to the fundamentals. If the exchange rate was allowed to float freely, it would change one-to-one with the fundamentals. Not so in a TZ, where the instantaneous expectation of depreciation, $E_t \left(de_t \right) / dt$, will dampen the effective change in e. Because f increases, the domestic interest rate must fall to clear the domestic money market. But from UIP this implies an expected *appreciation* of the domestic currency, $E_t \left(de_t \right) / dt < 0$, which, by (13), attenuates the effective depreciation (increase in e). In the limit, if e threatens the upper band limit (the GX in the gold standard), the expected intervention of the monetary authorities would correct the level of f downwards, returning e to the band. In the case of the gold standard, no such interventions were typically observed, but the adherence to the convertibility rule, and the opportunities for gold arbitrage were equivalent means to the same end result. That is, in this example, a gold outflow would produce the required reduction in fundamentals.

Going back to the UIP condition, this logic allows for the domestic interest rate to fall *below* the international rate, despite the fact that the exchange depreciates. That is, a TZ allows the monetary authorities a measure of autonomy in conducting domestic monetary policy. Naturally, this comes at a cost, which is the credible commitment of the authorities to defend the band. It is this credibility that justifies the expected appreciation in the example.

To sum up, the theory implies three corollaries that we can test, viz., a mean-reverting exchange, a distribution of the exchange more concentrated in the band limits, and a negative relation between the interest rate differential $i_t - i_t^*$ and the exchange.[54]

The first corollary is indeed supported by the data. All the test statistics in Table 9 allow to infer that the exchange series is strongly mean-reverting. These results are also robust to different sub-periods.

[Table 9 about here.]

[Figure 7 about here.]

On the contrary, the *contemporaneous* negative relation between the interest rate differential and the exchange, predicted by the theory, is not borne out by the data. We use weekly data for the exchange

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[52]f includes the money supply, and any other variables affecting the demand or the supply of money.

[53]Furthermore, the country is assumed to be small, which implies that i_t^* is exogenous, a reasonable approximation for Portugal.

[54]The pattern of the exchange density is a consequence of the "smooth pasting" property of the solution for the exchange rate in a TZ model.

rate, and the short-run British and Portuguese interest rates. Because we only have data on Lisbon "open market" interest rates from 1885 on, we use bank rates for the interval 1854-84.[55] The two scatterplots of Figure 7 support, if anything, a moderate-to-strong positive relation, which bodes problems for the credibility of the TZ.[56] However, if we split the sample into 3-year periods, we do get a negative and significant relationship in three periods: 1854-56, 1866-68, and 1872-74.

Yet another problem lies in the distribution of exchange rates. As mentioned previously, this distribution, although presenting the bimodal pattern predicted by "smooth pasting", shifted to the right throughout the period, so that in the last decade of our sample both modes stood above par (see Figure 2 and Table 3). Even though it is not clear what the shape of the exchange distribution on a non-credible TZ would be, this displacement seems to fit with the idea of increasing expectations of devaluation of the Portuguese currency. This questions the assumption of Krugman (1991) that the TZ is credible.

Bertola & Svensson (1993) extended Krugman's model to a situation where agents can expect a realignment of the central parity. A high expectation of realignment naturally implies a non-credible TZ to start with. The authors redefine the exchange rate into two components: $e_t = c_t + x_t$, where c_t is the central parity and x_t is the exchange deviation from it, as we have been using. This implies a similar decomposition of the expectation of devaluation:

$$E_t\left(de_t\right)/dt = E_t\left(dx_t\right)/dt + E_t\left(dc_t\right)/dt \tag{14}$$

so that the last term is the expected realignment. Replacing (14) in (13) and rearranging, we get to another solution for the deviation of the exchange *within* the band:

$$x_t = h_t + \alpha E_t\left(dx_t\right)/dt \tag{15}$$

The fundamentals term is now a composite of the previous term and of the expectations of realignment: $h_t = f_t - c_t + \alpha E_t\left(dc_t\right)/dt$. Incidentally, compared to equation (13), this new equation no longer implies a necessarily negative relation between the exchange and the interest rate differential. As in Krugman's model, a negative relation is still to be expected between x and $E_t\left(dx_t\right)/dt$ (expected rate of depreciation within the band), but UIP holds for the "total" exchange rate e, and it is not clear what would be the sign of the association between the current exchange and the expected realignment. In this sense, the evidence of Figure 7 may not be enough to reject the credibility of the Portuguese pegging to gold. Two other tests of credibility have been proposed in the literature.

The first, originally proposed by Svensson (1991), uses the gold points' estimates to gauge the maximum limits of deviation of the exchange *within* the band (the x_t). That is, if we note x_t^m and x_t^x as the gold import, and gold export points, respectively, then:

$$\left(x_t^m - x_t\right)/dt \leq E_t\left(dx_t\right)/dt \leq \left(x_t^x - x_t\right)/dt \tag{16}$$

Now, using (14) and UIP we get to:

$$\left(i_t - i_t^*\right) - \left(x_t^x - x_t\right)/dt \leq E_t\left(dc_t\right)/dt \leq \left(i_t - i_t^*\right) - \left(x_t^m - x_t\right)/dt \tag{17}$$

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[55]We used the Lisbon "open market", and the London "3 months" rates from Neal & Weidenmier (2003).

[56]Still, transaction costs might also blur the evidence in this case. See Flandreau & Komlos (2003).

This expression gives the equivalent to a "100 percent" confidence interval for the expected realignment rate in each period. We represented the results for the Portuguese case in the two panels of Figure 8, where we replaced x_t^m and x_t^x with their values estimated by direct reconstruction in sub-section 6.1. Once again, we are limited by the availability of data on short-term market interest rates in Lisbon, which we proxy with the discount rates of the Banks of Portugal and England before 1885. In the second panel of Figure 8 we superimpose the two "confidence intervals", calculated from discount (shaded) and market (non-shaded) rates.

[Figure 8 about here.]

The global impression we obtain from this Figure is that of a non-credible parity for the greater part of Portugal's commitment to gold. Only in the 1850s, the early 1860s, and the early 1870s do these results imply no expectations of devaluation (when the confidence interval intercepts the 0 line), or expectations of revaluation (both limits of the interval below the 0 line). These intervals partly coincide with periods of persistent exchange nearer or *below* the par, although the correlation is not perfect. Concentrating in the sub-period 1885-91, for which we have information on market short-term interest rates, it is interesting to note that, despite the relative improvement with the abolition, in 1886, of the duty on gold exports, the confidence interval remained steadily above the 0 line (apart from some brief periods). The rate of expected devaluation after 1885 averaged 2.8% *per annum*. This is in agreement with the other evidence of lack of credibility, namely from the Kernel estimates of the distribution of the exchange rate in this period.

Another interesting observation regarding the second panel of Figure 8 regards the relation between the two intervals. Because the Bank of Portugal's discount rates were often below market rates, the expected rate of depreciation is underestimated when calculated with the Banks' discount rates. Moreover, because expression (17) requires an estimate of the gold points, our results are conditional on these estimates. Instead of repeating the exercise with our different gold points' estimates, we now pass to the second test of credibility, proposed by Bertola & Svensson (1993), and which is independent from the gold points. Rather than taking a maximalist estimate of the expected variation of the exchange *within* the band (the width of the gold point's half-intervals), we now solve equation (14) for $E_t \left(dc_t \right) / dt$ by replacing a direct estimate of $E_t \left(dx_t \right) / dt$. Although this is potentially a complicated estimation problem, the literature on TZ finds that a simple linear approximation produces fairly sensible estimates:[57]

$$x_{t+m} - x_t = \alpha_0 + \alpha_1 x_t + \phi_t \tag{18}$$

According to equation (18) the m-period ahead change in the deviation of the exchange can be predicted from a linear projection of the contemporary deviation. For the sake of comparison with Figure 8, we ran this regression with $m = 1$ week. Estimates are in Table 10, the Dickey-Fuller test supporting once more the hypothesis of mean reversion.

[Table 10 about here.]

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[57] For the references see Hallwood *et al.* (1996).

With this estimate, we can now form a 95% confidence interval for the expected realignment by subtracting the 95% confidence interval for the coefficient of x_t in (18) from the interest differential, similarly to (17). The outcome is represented in Figure 9.

[Figure 9 about here.]

Relative to Figure 8, the outlook is very similar, in terms of the distribution of the periods of credible and non-credible parity. There are some differences, though. On the one hand, the average expected rate of depreciation (measured by the midpoint of the confidence intervals) is between 9% and 15% smaller, depending on the sub-period and the interest rate series used.[58] On the other, and not surprisingly, the substitution of the estimate of $E_t(dx_t)/dt$ for the maximum variation within the band yielded narrower intervals.[59]

At this point it is interesting to compare the results from the previous two tests of credibility with the "efficiency ratios", with which Officer measures what he calls "regime efficiency", that is, "*the probability of maintenance of the gold standard with the existing mint parity*" (Officer 1996: 255). We refer the reader to this author's book for the specific assumptions behind such ratios, and just reproduce the results for our case in Table 11.

[Table 11 about here.]

Under the assumptions stated by the author, the interpretation of the results is straightforward: a ratio above (below) 100 means a non-credible (credible) parity. This measure yields results, which are in broad agreement with the two previous confidence intervals, except that it identifies the period after the abolition of the export duty (1886-1891) as being credible. However, it is considerably less informative, because it is based on period averages, and does not provide an estimate of the devaluation expectations. Furthermore, it is very sensitive to the gold points' estimates. Depending on whether we use our original estimates from sub-section 6.1, or add to them 0.3125%, as in Table 5, the period 1882-91 is assessed, respectively, as non-credible, or credible.[60]

To finalize the section on credibility, we try to identify the underlying determinants of credibility. We will follow Hallwood *et al.* (1996) in estimating a simple two-country reduced-form model of the expectation of realignment on a number of variables usually included in theories of exchange rate determination. Despite the data limitations, we were able to include 7 covariates in the regression:[61]

- the log difference in lagged banknote circulation $m_{t-1} - m_{t-1}^*$

- the log difference in lagged income $y_{t-1} - y_{t-1}^*$

- the difference in inflation rates $\pi_{t-1} - \pi_{t-1}^*$

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[58]This may compensate the problem of underestimation alluded in connection with the "100% confidence intervals".

[59]We also estimated the confidence intervals for longer horizons m, namely 1, 3, and 12 months. The results were similar, except for an increasing width of the intervals.

[60]We are also not prepared to accept some of Officer's assumptions, particularly an uniform distribution of the exchange within the gold points. Even if the exchange rate follows a mean-reverting process within the gold points, an uniform distribution is only a particular case of a stationary process.

[61]Starred variables correspond to the UK.

- the log difference in the balance of trade $bt_{t-1} - bt^*_{t-1}$

- the log difference in a measure of government's debt burden $f_{t-1} - f^*_{t-1}$, to allow for a "fiscal channel" of monetary policy

- the difference in the reserve ratios of the banks of Portugal and England $r_{t-1} - r^*_{t-1}$ and

- the lagged value of $E_t(dc_t)/dt$ itself, to control for the persistence in expectations.[62]

For details on the data sources, we refer the reader to Appendix 2. Table 12 lists the results from three alternative specifications.[63]

[Table 12 about here.]

The three alternative models differ in two respects: the measure of the money supply, and the reserve ratios. In regressions (1) and (3), we proxied for the log difference in money supply with the bank note issues in Portugal and Britain. This is naturally a very imperfect substitute for the money supply in a typical monetary model of the exchange rate.[64] However, because the only aggregate available for Britain in this period is M3, which was not relevant to characterize the Portuguese money supply, we were forced to adopt this solution.[65] In alternative, regression (2) uses the money base, although at the cost of a smaller sample, because the British data is only available since 1870.[66] Regression (3) differs from the other two in that it uses a broader definition of the reserve ratio for the Bank of Portugal. Ideally, we want to capture with this variable the ratios, which were effectively tracked by the monetary authorities, and influenced their conduct of policy. As argued in Reis (2002), the directors of the Bank of Portugal based their decisions on the ratio of gold and net external reserves to short-run liabilities. These net "external reserves", which the Bank had an obvious interest in holding, because they were profitable and could be easily converted into gold, included such disparate components as foreign stocks, and bonds of the Portuguese external debt, first class bills on foreign markets, and accounts in foreign bankers.[67]

With these limitations in mind, the striking conclusion to be taken from Table 12 is the autoregressive behavior of the expectations of realignment. All three models predict a relatively high level of persistence (from 0.6 to 0.73), which incidentally is the only coefficient significant throughout. Despite the small sample size, this seems to be in agreement with the long-term drift towards depreciation,

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[62]Actually, this was precisely assumed in equation (18).

[63]The LM statistics refer to the Breusch-Godfrey test, and they allow to reject the hypothesis of serial correlation of residuals in all three regressions.

[64]Especially for Portugal, where the narrower definitions of the money supply (M0 and M1) were dominated by gold currency until 1891.

[65]The best references to our knowledge on the money supply in the two countries are Reis (1990) for Portugal, and Capie & Webber (1985), for Britain.

[66]Otherwise, the sample in regression (1) is limited by the start of a continuous series of Portuguese foreign trade in 1865.

[67]Unfortunately, we only have the information compiled on these net "external reserves" between 1865 and 1888, which reduces the number of observations in regression (3) to 23.

already mentioned. In contrast, almost all the remaining covariates are not significant.[68] Similar results where found for the dollar/sterling case by Hallwood *et al.* (1996), which the authors interpret as a sign that the monetary authorities did not violate the "rules of the game" sufficiently to trigger a readjustment in expectations. Nevertheless, we did find one variable to be significant, namely, the difference in reserve ratios, when we measure the ratio of the Bank of Portugal in the broader sense defined previously. That this variable is significant in the "broad", but not in the "narrow" sense seems to confirm Reis's (2002) interpretation of the decision-making process at the Bank of Portugal. Furthermore, it suggests the idea that the Bank played an important role in keeping the Portuguese gold standard within the limits of a working TZ.

6.4 Gold flows

It should come as no surprise that this part of our study is the most fraught with data problems. The statistics of international gold movements are renowned for their inaccuracy, at least since Morgenstern's (1955) classical rendition of the question. For Portugal we have three independent data sources for gold movements with Great Britain. They are, by increasing frequency of data, the Portuguese official trade statistics (annual), the returns of the British Board of Trade (monthly), and the gold imports of the Bank of Portugal (daily).

All three have problems of their own, which may blur their usefulness in testing whether gold flows actually occurred in the expected direction during the estimated gold points' violations. In other words, they are very imperfect measures of gold arbitrage. Starting with the last, the Bank of Portugal import statistics have three obvious caveats: they only refer to one side of gold arbitrage, they do not cover all gold shipments from London to Lisbon, but only those of the Bank, and, thirdly, the Bank of Portugal mostly used these shipments for reasons unrelated to making a profit out of arbitrage (we will develop this point more fully next). On the upside, these data have the highest frequency, and don't share in the measurement errors or omissions usual in official trade statistics. Indeed, the source is the same records used to establish the direct expenditures in sub-section 5.2. Moreover, as regards the representativeness of these data, the Bank of Portugal gold shipments made up 53% or 73% of total Portuguese imports from Great Britain, according to the British or the Portuguese trade statistics, respectively.

The official trade statistics of the two countries have complementary problems. In principle, one would expect that gold exports would be underreported in the Portuguese data, before the end of the duty on exports, in 1886. In fact, the British export data are only slightly above the Portuguese statistics, what may seem surprising in face of the obvious incentives for gold smuggling, at least until 1886. Still, if the illegal export of gold was mainly done via a third country, as Spain, it would also not show up in the British statistics as an import of Portuguese gold. On the imports side, British statistics probably overestimate the true flow, because they include gold reexported from Portugal

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[68]Although the large standard errors do not warrant any definite conclusion, we would like to point out that the coefficients of two variables (money supply, and fiscal burden) are incorrectly signed in all regressions, and that the same applies to the difference in inflation rates in the middle regression.

to other countries, namely Brazil and Spain. [69] Indeed, British figures are systematically above the Portuguese statistics of gold imports throughout the period.

An approximate solution would then be to use the British data for export, and the Portuguese sources for the import flows. However, the two sources differ in frequency and coverage. We could reconstruct a complete monthly series running from March 1861 to the end of our period, from the tables of the Board of Trade published in the *Economist*. Annual Portuguese statistics of the gold trade are available for 1855-56 and 1861-91, but they don't break up the data by country of origin in 5 years.[70] Because of the gaps in the Portuguese series, and the possibility of using monthly data, we will use the British series in what follows.

Our first piece of evidence is a simple contingency table, based on the highest frequency data from the British statistics. In Table 13 we check whether gold flowed in the directions predicted by all of our estimates of gold points in each month. In building Table 13, we coded the gold points' violations simply as a categorical variable that takes the value 1 if there was a week in the month when the exchange deviated from the parity by more than one of the gold points. This means we are consolidating the weekly information and ignoring the severity of the measured violations. Even so, we can learn something useful from this Table.

[Table 13 about here.]

For each gold point, we list the number of months conforming to the arbitrage model ("Flows with violations"), as well as the cases where it fails - "Flows without violations", and "Violations without flows". The first impression from these figures is that our indicators of gold points' violations do a very good job in predicting gold flows (the "Violations without flows" being fairly rare), but that they grossly underestimate such flows (the " Flows without violations"). This is especially the case of the GM point, but even in the best case for the GX, our original direct estimates only predict 36% of months with gold exports. Before rejecting our gold points' estimates as too wide, we should remember a number of caveats in drawing conclusions from the gold flows data.

First, there is the possibility that British statistics undervalued exports and overvalued imports of gold, as mentioned before. Because the simple contingency table only counts instances of gold flows, but not their amount, there is no direct correspondence from these biases to the cells in the Table. Still, one possibility is that the over (under) reporting of flows would translate into an excessively high (low) number of months reported with gold imports (exports). If so, this would help to explain the severe misfit between gold imports and GM violations, although the actual impact cannot be quantified. But it would also aggravate the problem on the GX side. Second, gold was obviously being shipped between Britain and Portugal for other reasons than arbitrage. One of these would be the simple settling of trade accounts in specie, instead of foreign exchange.[71] Because a debt had to be settled in any case, the shipment of gold did not incur any opportunity cost, so that the relevant gold points for this type of operations would be narrower than for gold arbitrage. Still, if we recalculate the GM points by this

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[69]On this see Reis (1990).

[70]1862-64, 1874, and 1879.

[71]What Officer (1996) calls "gold-effected transfer of funds" to distinguish from "gold points arbitrage" proper.

definition we only increase the number of conforming cases from 10 to 17.

Third, and more promising, is the identity of the sender. Taking the original direct estimates as benchmark, it is possible to count the number of months with gold import flows, in which the Bank of Portugal also bought gold from London. Out of the total 260 months with gold imports, the Bank had gold shipped from London in 124. What is interesting is that in 117 of these we did not record a violation of the GM. Given that the Bank was not importing gold to reexport it, there had to be another reason for these shipments, unrelated to arbitrage. Indeed there was.

As mentioned in section 3, the Bank of Portugal, as other central banks under gold, resorted to a number of "gold devices". Two of them are relevant to our case. First, the Bank sometimes used gold shipments from abroad as a window-dressing device, which could be useful to face internal gold drains, because of a loss of confidence. It also did so in order to face a shift in the public's preference in favor of specie. Second, the Bank also tried to influence the exchange before it actually reached the GX point. It offered to sell bills on London at a slightly better rate than the GX point. These bills would either come from the Bank's own portfolio, or were drafts drawn on the Bank's London correspondents to be covered later.

Unfortunately for the Bank, this device usually had to be carried at a loss, because of the increasing tendency of the exchange to gravitate above the parity (see Table 3 and Figure 2), which meant that the bills were probably sold at a lower price than they had been bought for, while the drafts would later have to be covered with paper bought in worse terms.[72] This was especially costly before the abolition of the duty on gold exports that allowed the exchange to depreciate by an extra 0.8%, which added to the losses of the Bank. The report of the Bank for 1886 registered an accumulated loss of £ 64,508 (or 0.23%) from such operations, in 1885-86.

Despite these losses, the Bank of Portugal used this device persistently in order to limit the gold drain from its reserves. According to the Bank reports of 1884 and 1886, the Bank sold £ 43.7 million worth of bills on London just in the four last years of the duty (1883-86). The alternative, i.e. import gold to replenish the coffers, would have been much more expensive. The Bank estimated that the gold shipments from London, between 1876 and 1882, had cost 1.5% in direct charges.[73] This can be corroborated for the period 1880-83, for which we have the actual exchange at which the Bank sold bills on London. Figure 10 compares these rates to the actual exchange in Lisbon and our estimate of the GX point (original direct reconstruction).

[Figure 10 about here.]

It confirms the fact that the rates at which the Bank intervened were below the GX point, and also that its ability to keep the exchange in that range waned with time. In the last 2 years of this period, the interventions were being carried below the actual exchange, what meant a loss in managing the Bank's portfolio of sterling bills, or in covering the drafts open in London. In the first half of 1882, the severity of gold exports (represented by the bars in the Figure) even led the Bank to intervene up to

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[72]The Bank also routinely took upon itself the commissions involved in buying and selling the bills used in this operation.

[73]Banco de Portugal (1883: 32).

the GX rate itself.

Notwithstanding these remarks, the magnitude of the misfit of the arbitrage model still seems puzzling, especially in the GX case. To try to make some headway, we will now use the information on the size (and not only the timing) of the gold flows. Tables 14 and 15 contain the results of regressing the exports and imports of gold on a number of covariates.[74]

[Table 14 about here.]

[Table 15 about here.]

Starting with Table 14, we were limited in our ability to using monthly data, because some of the variables are only available on an yearly basis. Nonetheless, the first two specifications use monthly information on the levels and one month-lags of the average size of GX violations, a dummy variable for Portuguese financial crises, and the discount rate of the Bank of Portugal (BP).[75] The regressions are globally significant (see the F statistics), but the obvious candidate to explain gold exports, i.e., the amplitude of GX violations, is not significant.[76] The discount policy of the Bank of Portugal doesn't seem to have been able to contain the exit of gold from the country, or only marginally so. This is not exactly surprising, given the severe legal constraints that the Bank faced in managing its bank rate (on this see Reis 2002). The crisis variable has a greater purchase. We coded it to take a value of 1 in the months of May-August 1876, and September 1890 - May 1891 to coincide with the two major Portuguese financial disturbances of the period.[77] According to the estimates, the gold imports would rise on average by 122 thousand pounds during a crisis month. This conclusion transposes to the regressions with annual data.

For comparison with the monthly regressions, we provide the results of the (Annual 1) and (Annual 2) regressions, which use the same covariates.[78] We excluded the lags, however, because it seems excessive to admit a one year delay for a variable to influence gold exports. Contrary to the monthly regressions, the measure of the violations of the GX point has some explanatory power. The variable Balance of Trade, which is coded in the same way as in sub-section 6.3, is introduced as a proxy for the "gold-effected transfers" we mentioned above. That is, if a substantial share of gold flows was driven by the settling of international debits, instead of arbitrage, this would be captured by a significant and negative estimate for the coefficient of this variable. This is indeed the case in regression (Annual 3).[79]

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[74]All reported figures were estimated by GLS (Prais-Winsten) to correct for autocorrelation. We also ran the OLS regressions with Newey-West standard errors, and the results didn't differ materially, either in the sign, size, or significance of the estimated coefficients.

[75]We only include the lagged discount rate, because of an obvious endogeneity problem. That is, higher gold export volumes would typically trigger a rise in the discount rate.

[76]We used our original direct estimates of the gold points from Table 5 to form the violations series, because those had the best fit from the contingency table 13.

[77]For the coding of the 1876 episode we followed Reis (2002), whereas we chose the failure, of the *Banco Lusitano*, one of the largest deposit banks, in September 1890, to start the period of financial and monetary instability that would lead to the abandon of gold in June 1891. In the regressions with annual data we coded 1876, 1890, and 1891 as crisis years.

[78]With the exception of the discount rate in regression (Annual 2) because of the endogeneity problem already mentioned.

[79]The number of observations in this regression is down to 27, because we only have data on foreign trade from 1865 on.

The structure of Table 15 is similar. Like in the exports case, the average GM violations are not good predictors of gold imports in the regressions with monthly data.[80] Compared to Table 14, the dummy for crisis is now only marginally significant, while the average expectation of realignment, which we took from the previous sub-section on TZ, is significant and has the right sign.[81] Still, the sign pattern is strange. A rise in the lagged expectations of realignment leads to an increase in the imports of gold, as expected. Not so a *contemporaneous* realignment expectation, even though this result is not significant.

Again for comparison, the third and fourth regressions replicate the first two with annual data. The most significant difference is the now strong and significant effect of the measure of violations of the GM point. The crisis indicator has also a positive and significant coefficient, while the average expectations of realignment have an insignificant effect upon the volume of gold imports. Finally, for the third annual regression we introduced two other covariates - the trade balance variable, already used in Table 14, and the a measure of currency hoarding. The widespread phenomenon of hoarding of gold coins is generally attested by the contemporary literature, and it sometimes led to internal drains of gold that affected the Bank of Portugal and made it take measures to defend its reserve.[82] One of the corollaries of such phenomenon was the abnormally high percentage of gold currency in the Portuguese money supply. As Reis (2000), we proxied the hoarding intensity by the ratio of gold currency in circulation over M0. We use this variable to test the "window dressing" motive of the gold imports of the Bank of Portugal, which seems to have been strong and significant. Interestingly, the impact of the trade balance disappears, when combined with the hoarding variable. This may attest to a number of points, namely, the high proportion of gold imports through the Bank of Portugal to defend its reserve, and the infrequency of surpluses in the Portuguese balance of payments (that would establish a *positive* link between trade and gold imports).

To sum up, the observed misfit between the gold flows data and the predictions on the timing (Table 13) and size (Tables 14 and 15) of those flows, from the conventional arbitrage model leaves us with three options. First, to blame the bad quality of the flows statistics. Second, to recant on the remarks we made at the end of sub-section 6.1, on the possible underestimation of the gold points. In fact, we don't think this to be a valid candidate for explanation, for even if we decreased our estimates of the gold points to match them with the timing of the flows, there would be a considerable number of abnormal cases to account for. For instance, if we use the monthly data series, 0.1% of gold exports and 59% of gold imports occurred respectively below, or above par.

The third alternative is to acknowledge, from the evidence at hand, that the conventional arbitrage model is too simplistic to describe the real workings of the Portuguese exchange rate mechanism. The fact that other macro variables (balance of trade, crisis, expectations, hoarding) have an explanatory

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[80]We also introduced seasonal terms in the monthly regressions, but these came out as insignificant, and the estimates of the other coefficients were not substantially affected.

[81]We used the second measure of realignment expectations to limit the collinearity between this variable and the measure of GM violations. As can be seen from equation (17), the upper limit of the interval for $E_t \left(dc_t \right) / dt$ is a linear function of the GM violation.

[82]For some references see Reis (1990, 2002).

power *over and above* the measure of gold points violations seems to warrant such interpretation. In particular, one should stress the margin available to the monetary authorities to influence the exchange, even in a peripheral country, with no central bank in the modern sense, and with severe legal constraints as to the use of the bank rate as a monetary policy instrument.

7 Concluding remarks

The reader can take two sorts of messages from the previous pages. The first sort raises the question of whether the Portuguese case is a useful addition to the debate on the market "efficiency" or "integration", under the classical gold standard; or, instead, is as an illustration of the deficiencies of such debate, and of the correlative need to understand the "fundamentals", or institutional factors that in each case determined the course of the exchange, together with, or despite the revered "gold points". In this last section, we recapitulate the main evidence supporting either of these two interpretations, and suggest a direction for future research.

Despite some disagreement among the three main sets of estimates of the gold points (direct reconstruction, moving window, and smooth trend), the evidence points to a narrowing band of fluctuation over time. Depending on the estimation methods, its breadth would have fallen from 16% to 48% between the limiting periods of 1854-61 and 1882-91. That the exchange reacted to the evolution of the fluctuation bounds is also confirmed by the "natural experiment" provided by the elimination of the duty on gold exports in early 1886. From a conventional viewpoint, this evolution should be interpreted as a consequence of the rising efficiency of the monetary regime in providing exchange rate stability. Indeed, it seems notable, if not remarkable, that a such peripheral country as Portugal could have enjoyed some 37 years of relatively unproblematic adherence to gold. During this period, the Portuguese exchange fluctuated very moderately against the central currency of the system, in 90% of cases within a band of $\pm$ 1.8% of parity. Admittedly, by some measures of the gold points, the record on market inefficiencies (in terms of the number, size, and persistence, of exchange rate "violations" of those points) does not compare favorably with the results obtained for two of the core currencies of the system – the franc, and the dollar. Still, this should not be surprising, given the apparently uncontroversial fact that the Portuguese currency had a much less liquid market worldwide (especially forward) and that Portuguese arbitrageurs could not compete in technology or access to information with their counterparts in New York, London, or Paris. Alternatively, the high proportion of "violations" might only be a consequence of our excessively conservative estimates, compared to other similar studies. Finally, the increase in measured "inefficiency" in the last years of the Portuguese gold standard could also be ascribed to the mounting pressures of an unsustainable foreign position, which would unfold into a simultaneous banking, debt, and currency crisis in the years 1890-91. The data on gold flows, flawed as they may be, raise some doubts as to the wisdom of this line of interpretation, especially in the case of gold imports.

Our second set of messages emphasizes a point, which should have been obvious to contemporaries, and which has been raised elsewhere in the literature (Reis 2000, 2002), i.e., the incompleteness of

characterizing an exchange rate regime without fully taking into account its institutional underpinnings, especially the banking structure. The Bank of Portugal, although a private corporation, was bound by the rule of convertibility. Moreover, the Bank was, by far, the largest banking house, the principal banknote issuer, and the holder of the largest gold reserve in the banking system. It also tended to enjoy a close relation with the government, a fact often resented by other banks. All these circumstances combined to make the Bank the leading player in the foreign exchange market, with a vested, albeit unwilling, interest in the maintenance of stability. The Bank directors knew that an exchange excessively depreciated would translate into a run on its reserve, an event which they actively tried to discourage with a number of "gold devices". As mentioned in the sub-section on gold flows, a substantial share of total gold imports can actually be traced to the shipments of sovereigns from London, which the Bank used as a window-dressing strategy, or to replenish its reserves in periods of larger internal demand for gold.

The Bank also intervened by selling short bills on London at a cheaper rate, in an attempt to prevent the exchange from reaching the GX point, and forcing it to buy sovereigns. For the end part of our period, we could confirm the influence of such devices on the course of the exchange, despite the increasing costs to the Bank (see Figure 10).

In one important respect, though, the position of the Bank of Portugal differed from that of other central banks of the time, namely, its control over its discount rate. Contrary to the Bank of England, the Bank faced serious legal limitations to its autonomy to conduct a bank rate policy, and consequently had to resort to alternative "devices" sooner than other banks. Although thwarted in its freedom of action, it is significant that the Bank of Portugal deviated as frequently and persistently from the so-called "rules of the game", as any other monetary authorities of the time. This leads to the topic of the credibility of the Portuguese exchange as a target zone (TZ).

Recovering a point made by Keynes (1930), the TZ literature demonstrates the considerable leeway for an independent monetary policy even in the context of a narrow fluctuation band, providing that the TZ is credible. But the classical gold standard is supposed to have been a credible regime *par excellence*. In fact, when we apply the credibility tests available in the literature, we come to the conclusion more often than not that the Portuguese parity lacked credibility (Figures 8 and 9). Taken literally, this implies that the Bank of Portugal could not benefit from the *honeymoon effect* to set a lower interest rate in the economy, and, in fact, the reverse was the case. The discount rate of the Bank of Portugal stood above the British bank rate in 79% of our period of study. On a more fundamental level, it would be interesting to inquire into the factors that determined this credibility, and understand how it was possible to sustain a non-credible parity for so long. Our incomplete data set only allows a preliminary answer to these questions, but the results in Table 12 point again to the relevance of the behavior of the Bank of Portugal in this respect.

Finally, a suggestion. Canjels *et al.* (2004) conclude their article by stressing the relevance of the estimation of the gold points as the "*key ingredient in a fundamental method of market integration analysis*", while offering their methodology as a promising approach to any study of market integration, namely among currencies. We are prepared to accept both of these as valid points, but if a

broader lesson can be drawn from our Portuguese tale it would be that "the forest should not be missed for the trees". To our mind, an equally important research agenda would be to integrate the detailed data gathering involved in reconstructing (Officer 1996) or estimating (Canjels *et al.* 2004) gold points into a broader picture of the classical gold standard. The latter would of necessity combine pure "market efficiency" with credibility, speculation, and the autonomy of monetary policy, not to mention the institutional arrangements particular to each country in the system.

Appendix 1

1.1 CLS algorithm and distributional properties

The CLS algorithm is applied in two simple steps:

- Given values for the thresholds (γ_0 and γ_1), we estimated the other parameters by OLS within each regime, and collect the residual sums of squares.

- To select among thresholds, we used a grid search and picked the threshold values that minimized the sum of the residual sums of squares of the three regimes.

The finer the grid the higher the precision of the threshold estimates. However, precision comes at a cost of computational burden. We decided to define a fairly coarse grid in intervals of 0.217% of parity, or 1/8 of pence. Ideally, we would like to refine the grid to intervals of 1/64 pence (the maximum detail with which the pound was quoted in Lisbon), but that implied too long a convergence delay for some variations of the model.

In order to test the random walk behavior of the exchange series within the band, we estimated the model in *levels*, instead of first differences. That is, instead of equation (9), we ran CLS on:

$$x_t = \begin{cases} (1-\lambda_0)x_{t-1} + \lambda_0\gamma_0 + v_t & \text{if } x_{t-1} < \gamma_0 \\ \mu_0 + \mu_1 x_{t-1} + v_t & \text{if } \gamma_0 \leq x_{t-1} \leq \gamma_1 \\ (1-\lambda_1)x_{t-1} + \lambda_1\gamma_1 + v_t & \text{if } x_{t-1} > \gamma_1 \end{cases} \tag{19}$$

The asymptotic distributional properties of the estimators of continuous TAR models have been established by Chan & Tsay (1998). Let θ be the vector of parameters, $e_t \equiv x_t - E(x_t|\theta)$, and $H_t = \frac{\partial e_t}{\partial \theta}$ its Jacobian. Under regularity conditions, the authors show that:

$$\sqrt{N}\left(\hat{\theta}_N - \theta\right) \xrightarrow{d} \mathcal{N}\left(0, U^{-1}VU^{-1}\right) \tag{20}$$

in which $U \equiv E\left(H_t'H_t\right)$, and $V \equiv E\left(e_t^2 H_t'H_t\right)$.[83]

1.2 Tests of non-linearities

Luukonen *et al.* (1988) offer three procedures to test linear versus Smooth Transition Autoregressive (STAR) models. As Canjels *et al.* (2004) we followed their "augmented first-order procedure", which had the best small-sample properties in the simulations of the former authors. Given a TAR(R,k,d) model, this procedure has three steps:

1. Regress x_t on $\{1, x_{t-i}; i = 1, \ldots, k\}$, and keep residuals $\hat{\epsilon}_t$ and $SSE_0 = \sum_t \hat{\epsilon}_t^2$

2. Regress $\hat{\epsilon}_t$ on $\{1, x_{t-i}, x_{t-i}x_{t-j}, x_{t-i}^3; i = 1, \ldots, k; j = i, \ldots, k\}$, and form residuals $\hat{\eta}_t$, and $SSE_3 = \sum_t \hat{\eta}_t^2$

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[83]The empirical counterparts of these matrices are: $\hat{U} = \frac{1}{N}\sum_t \hat{H}'_t \hat{H}_t$, and $\hat{V} = \frac{1}{N}\sum_t \hat{e}_t^2 \hat{H}'_t \hat{H}_t$

3. The test statistic is $S_3 = \frac{SSE_0 - SSE_3}{SSE_0} \xrightarrow{d} \chi^2 \left[\frac{1}{2}k(k+1) + k\right]$, which allows to reject the null hypothesis (of no additional non-linearities) for sufficiently high values.

1.3 Unrestricted TAR models

To test the order k and the delay d of the selection variable of a TAR(3,k,d) model, we estimated the 6 combinations of:

$$x_t = \begin{cases} \beta_0^1 + \beta_1^1 x_{t-1} + \cdots + \beta_k^1 x_{t-k} + v_t & \text{if } x_{t-d} < \gamma_0 \\ \beta_0^2 + \beta_1^2 x_{t-1} + \cdots + \beta_k^2 x_{t-k} + v_t & \text{if } \gamma_0 \leq x_{t-d} \leq \gamma_1; \quad 1 \leq k \leq 3, 1 \leq d \leq k \\ \beta_0^3 + \beta_1^3 x_{t-1} + \cdots + \beta_k^3 x_{t-k} + v_t & \text{if } x_{t-d} > \gamma_1 \end{cases} \tag{21}$$

The choice criterium is the BIC, which is defined as:

$$\text{BIC} = \sum_{r=1}^{R} \left[n_r \ln \hat{\sigma}_r^2 + (k+1)\ln n_r\right] \tag{22}$$

where R is the number of regimes (3 in our case), n_r the number of observations falling in regime r, and $\hat{\sigma}_r^2$ the standard deviation of the estimated errors of the equation for regime r: $\hat{\sigma}_r^2 = \frac{1}{n_r} \sum_t \hat{\epsilon}_{r,t}^2$. As mentioned in the text, the model that minimized the BIC was a TAR(3,2,2), whose results are in Table 16.

[Table 16 about here.]

Because this model is not continuous, the asymptotics are different from the restricted TAR model. On the one hand, as shown by Chan (1993), the intercepts and slope parameters in each regime have the same asymptotic distribution of standard OLS estimators.[84] On the other, the threshold parameters, although $\sqrt{N}$-consistent, converge in distribution to a random variable which follows a compound Poisson process. Given the complexity of the latter, we only report the OLS estimators for the standard deviations of the beta coefficients.

1.4 Smooth trends

We only want to make two remarks to this model. One refers to the estimation, and the other to the asymptotic properties of the estimators.

Relative to the CLS procedure to estimate equation (19), the only difference is that we now need two grid-searches to identify each gold point - one for the multiplicative constant, and another for the parameter of the exponential. To spare on computational burden we defined the grid search as 4 steps of increasing precision. We started with grids between 0.005 and 0.05, with steps of 0.005, for the constants, and between -0.001 and 0.001 (steps of 0.0002) for the exponential parameters. After this first iteration, we repeated the grid search within intervals of $\pm$ 5 times the previous value of the step, with a new step worth a tenth of the former one. And we repeated this procedure two extra times, so that the final estimates should be within ± 0.000005 of the "true" value of the constant, and

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[84]See, as well, Tong (1990: 385).

±0.0000002 of the "true" parameter of the exponential.

Despite the time-varying thresholds, the model is still continuous, hence, the asymptotic properties derived by Chan & Tsay (1998) still apply. We only need to re-specify the vector θ to include the extra parameters, i.e., $\theta \equiv (\mu_0, \mu_1, \gamma_{00}, \gamma_{01}, \gamma_{10}, \gamma_{11}, \lambda_0, \lambda_1)$. As for the confidence intervals in Figure 6, they were estimated from the asymptotic distribution of θ by using the so-called "Delta method".

Table 17 lists the estimates of the two variants of this model, i.e., with and without the dummy for the abolition of the duty on gold exports. The impact of the 1886 tax hike is confirmed by the positive and significant estimate of the coefficient of γ_d. Moreover, the over-smoothing in the first set of estimates can also be inferred from the fall in the estimated constant (γ_{10}) from 4.88% to 2.71%, and in the rate of decrease (γ_{11}) in the GX arbitrage costs from 0.096% to 0.040% per week. All coefficients were estimated very precisely, with the exception of γ_{10} and λ_1 in the second specification. In fact, the latter result is strange, because the estimate of the convergence speed back to the GX point has the wrong sign and is not significantly different from 0. Also contrary to intuition is the fact that the estimates of μ_0 are significantly different from zero, which violates the trendless random walk assumption for the exchange within the band. As in the time-invariant specification of Table 6, the joint hypothesis of random walk within the gold points is rejected for both variants of the smooth trend model, with Wald statistics of 21.18, and 8.40.

[Table 17 about here.]

Appendix 2

The data sources underlying the results of Table 12 are as follows.

Banknote circulation: for Portugal the data comes from Reis (1990), for Britain from Mitchell (1998).

Money base: the same source for Portugal, whereas for Britain we used the data in Capie & Webber (1985).

Income: we used Lains's (1991) "Total Production Index" for Portugal, and Mitchell (1998) again for the British GDP.

Inflation: the annual rates of increase in consumer price indices are from Valério (2001) for Portugal, and Mitchell (1998) for Britain.

Balance of trade: we define this variable as the ratio of exports to imports. Foreign trade statistics come from Valério (2001) and Mitchell (1998).

Debt burden: defined as the ratio of debt service charges to total government revenue. Data from Mitchell (1998) for Britain, and Mata (1993) for Portugal.

Reserve ratios: we used the definition of Reis (2002) for Portugal (for the data sources see the original article). This is the ratio between the total gold reserve of the bank and its immediate liabilities, i.e., banknotes held by the public, and deposits in the bank. To calculate a comparable ratio for the

Bank of England, we collapsed the reserves and liabilities of the "banking" and "issue" departments. The data was gathered from US National Monetary Commission (1910).

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Table 1: **Maturity of bills used in exchange series**

1854-76	1877-81	1882-91
30 d.s.	8 d.s.	Check

d.s.=days of sight

Table 2: **Correlations between market and implicit discount rates, 1886-1891**

	London 90 days bills	Lisbon "open market"	30 days implicit	90 days implicit
London 90 days	1			
Lisbon	0.6514	1		
Implicit 30d	0.4085	0.2706	1	
Implicit 90d	0.6213	0.3068	0.4083	1

Table 3: **Summary statistics of Exchange rate, 1854-1891**

	1854-61	1862-81	1882-91	1854-91
Average	-0.1063	0.5782	0.2496	0.3627
Max	2.5792	2.7083	2.4410	2.7083
Min	-2.5290	-2.5692	-1.1201	-2.5692
St. Dev.	1.1474	0.8963	0.6290	0.9297
Mode 1 (Kernel)	-0.8525	-0.3361	0.1445	0.0119
Mode 2 (Kernel)	0.3177	1.4025	1.2557	1.2795

All values in percentage deviation from par

Table 4: **Share of coined gold in gold flows with the World, and Great Britain, 1854-1891**

	Exports	Imports
World	99.8%	98.0%
Great-Britain	99.9%	99.9%

Sources: *Mapas Gerais do Commercio de Portugal com as suas possessões ultramarinas e as nações estrangeiras* (1855-56, 1861, 1865-67), *Estatistica Geral do Commercio de Portugal* (1868-73, 1875-78, 1879), and *Commercio do Continente do Reino e ilhas adjacentes com os Paizes estrangeiros e com as Provincias Portuguesas do Ultramar* (1880-91).

Table 5: **Summary statistics of gold points, 1854-1891**

	1854-61	1862-81	1882-91	1854-91
GM				
Average*	-1.21958	-0.93926	-0.75197	-0.94867
St. Dev.*	0.05007	0.05903	0.01737	0.16531
"Violations"	66	19	3	88
Average duration**	3.9	4.8	1	3.7
Average profit***	20.43	13.01	10.70	18.50
$-0.3125\% <$ Deviation < 0	32	15	2	49
GX				
Average*	1.76651	1.5443	0.90958	1.42799
St. Dev.*	0.03984	0.06078	0.40122	0.37731
"Violations"	31	162	56	249
Average duration**	1.9	6.8	2.1	3.7
Average profit***	9.68	17.27	13.27	15.43
$0 <$ Deviation $< 0.3125\%$	21	106	39	166

* Values in percentage deviation from par ** In weeks
*** Profit measured as annualized rate of return, after discounted expenditures.

Table 6: **Restricted TAR(3,1,1) with constant thresholds**

Coefficient	Estimate	Statistics	
γ_0	-0.00868	# upper	735†
	(0.00236)***	# middle	1060
γ_1	0.00868	# lower	130
	(0.00291)***	ΣRSS	0.02398
λ_0	0.57027	LST(upper)	0.00248
	(0.28124)**		(0.99876)‡
λ_1	0.24358	LST(middle)	0.00191
	(0.11730)**		(0.99905)
μ_0	0.00018	LST(lower)	0.02150
	(0.00009)		(0.98931)
μ_1	0.88969		
	(0.02938)***		

Asymptotic standard errors in parenthesis from Chan & Tsay (1998).
***(**) Values significant at less than 1%(5%) † Values in weeks ‡ p-value.

Table 7: **Unrestricted TAR(3,2,2) model**

γ_0	-0.01085		
γ_1	0.01302		
ΣRSS	0.02175		
BIC	-24924.416		
	Lower	**Middle**	**Upper**
Steady-state	-0.01347	0.00831	0.01360
LST	0.15556	0.01221	0.13727
	(0.99952)	(0.99999)	(0.99965)

Table 8: **Average time-varying estimates of gold points**

	1854-61	**1862-81**	**1882-91**	**1854-91**	**"Violations"**
GM					
Moving window	-0.86800	-0.49910	-0.21700	-0.49782	206†
Trend	-1.75109	-0.91376	-0.42546	-0.95998	48
Trend with dummy	-1.24057	-0.62018	-0.27310	-0.65817	159
GX					
Moving window	0.86800	1.23690	1.24775	1.17435	395†
Trend	4.06198	2.11963	0.98693	2.22684	263
Trend with dummy	2.51027	1.89261	0.74606	1.72654	197

Values in percentage of par. † Values counted relative to an interpolation of the gold points' estimates.

Table 9: **Tests of stationarity of exchange rate, 1854-91**

lags	Variance ratio	ADF
2	-12.97882†	-8.844
4	-11.41208	
6	-10.55743	Phillips-Perron
8	-9.65390	-7.143
10	-8.89590	
12	-8.34045	

†$z_1(k)$ statistic of Lo & MacKinlay (1988).

Table 10: **Estimates of equation (18)**

Constant	0.00036
	(0.00011)***
x_t	-0.07791
	(0.01183)***
	[-8.844]
R^2	0.0391

Robust standard errors within curved brackets
Dickey-Fuller statistic in square brackets.

Table 11: **Officer's efficiency ratios (linear loss function)**

Gold points	**1854-61**	**1862-81**	**1882-91**	**1886-91**	**1854-91**
Original	135.70	131.04	129.71	78.60	174.25
+ 0.3125%	112.15	104.58	95.89	53.00	103.91

Table 12: **Fundamentals of realignment expectations** ($E_t (dc_t) / dt$)

	(1)	**(2)**	**(3)**
Constant	-16.95713	-25.91386	-7.41287
	(15.10172)	(17.45975)	(15.95384)
Money	-0.73776	-2.00094	-1.18103
	(0.90746)	(1.72775)	(0.70945)
Income	-7.92340	-9.60244	-5.25278
	(6.58752)	(6.06364)	(6.52578)
Inflation	0.77835	-0.47746	3.38549
	(4.33819)	(3.75176)	(4.68858)
Trade	-3.58829	-4.09173	-3.37392
	(2.45225)	(2.88721)	(2.51774)
Fiscal	-6.02070	-9.35469	-4.02363
	(4.06161)	(4.55402)	(4.02363)
Reserves	-0.47669	-0.27223	-0.50040
	(1.04342)	(0.77183)	(0.17923)**
$E_{t-1} (dc_t) / dt$	0.64975	0.72546	0.60059
	(0.16732)***	(0.72546)***	(0.20176)***
R^2	0.398	0.5092	0.4519
F stat	2.36*	3.67**	3.95**
LM	0.01	0.932	0.001
Sample	1866-91	1871-91	1866-88

Robust standard errors in parenthesis. ***(**[*]) Statistics significant at less than 1%(5%[10%]).

Table 13: **Contingency Table - Gold flows/ gold points, 03/1861 - 05/1891**

		Direct estimates		**Indirect estimates**	
		Original	**+0.3125%**	**Mov. Average†**	**Smooth‡**
GX	Flows with violations	81	33	80	59
	Flows without violations	145	193	146	167
	Violations without flows	6	2	12	21
GM	Flows with violations	10	3	35	36
	Flows without violations	250	257	225	224
	Violations without flows	0	0	5	5

† Values counted relative to an interpolation of the gold points' estimates.

‡ Smooth trend estimates with 1886 dummy.

Table 14: **Regression estimates of gold exports, 1861-1891**

Variables	Monthly 1	Monthly 2	Annual 1	Annual 2	Annual 3
Constant	0.02361	0.00954	0.25759	0.10218	1.07964
	(0.00763)***	(0.03838)	(0.14904)*	(0.04155)**	(0.52331)**
Avg. GX viol.	-0.19800	0.07349	0.17469	0.48615	0.03925
	(0.27468)	(0.41999)	(0.33959)	(0.24491)**	(0.38166)**
lag Avg. GX viol.	0.22506	0.35303			
	(0.19140)	(0.41608)			
Crisis		0.12152		0.97712	0.82364
		(0.02596)**		(0.39115)**	(0.35185)**
lag Crisis		0.01460			
		(0.02669)			
lag Discount BP		0.00106			
		(0.00694)			
Trade Balance					-0.01311
					(0.00672)**
N	363	363	31	31	27
R^2	0.0012	0.0977	0.0065	0.5541	0.6429
F stat	4.02***	7.73***	2.62*	5.73**	9.09***
DW	1.90640	1.73159	1.83593	2.00969	1.79807

Robust standard errors in parenthesis. ***(**[*]) Statistics significant at less than 1%(5%[10%]).

Table 15: **Regression estimates of gold imports, 1861-91**

Variables	Monthly 1	Monthly 2	Annual 1	Annual 2	Annual 3
Constant	0.07529	0.06331	0.75675	0.68602	-4.56338
	(0.00986)***	(0.01332)***	(0.18742)***	(0.24362)***	(0.82893)***
Avg. GM viol.	-3.87102	-2.64765	6.13685	5.31698	3.79913
	(3.78737)	(2.36565)	(1.49589)***	(1.41545)***	(1.40483)**
lag Avg. GM viol.	6.95986	4.26245			
	(7.64382)	(4.18524)			
Crisis		0.55426		1.32309	1.53643
		(0.31295)*		(0.40819)***	(0.21366)***
lag Crisis		-0.38666			
		(0.29704)			
Avg. $E_t\left(dc_t\right)/dt$		-0.01056		-0.03961	-0.13994
		(0.00781)		(0.08022)	(0.09186)
lag Avg. $E_t\left(dc_t\right)/dt$		0.01326			
		(0.00595)**			
Hoarding					6.44723
					(0.81528)***
Trade Balance					0.00023
					(0.01177)
N	363	363	31	31	27
R^2	0.0195	0.1803	0.2762	0.5267	0.7568
F stat	20.85***	10.70***	21.85***	42.85***	50.32***
DW	2.07427	1.99866	2.01711	1.52530	1.81177

Robust standard errors in parenthesis. ***(**[*]) Statistics significant at less than 1%(5%[10%]).

Table 16: **Results of the TAR(3,2,2) model**

		Lower	Middle	Upper
γ_0	-0.01085			
γ_1	0.01302			
Σ RSS	0.02175			
BIC	-29924.416			
		Lower	**Middle**	**Upper**
β_0		- 0.01289	0.00017	0.00414
		(0.00214)***	(0.00009)*	(0.00106)***
β_1		0.55443	0.72620	0.49122
		(0.08668)***	(0.02539)***	(0.04774)***
β_2		-0.51122	0.25366	0.20433
		(0.13634)***	(0.02783)***	(0.07117)***
n_r		94	1382	449
Steady-state		-0.01347	0.00831	0.01360
LST		0.15556	0.01221	0.13727
		(0.99952)	(0.99999)	(0.99965)

***(*) Values significant at less than 1%(10%).

Table 17: **Results of the smooth time trend models**

	Without dummy	With dummy
γ_{00}	-0.02101	-0.01507
	(0.00004)***	(2.61e-06)***
γ_{01}	0.00096	0.00102
	(1.46e-14)***	(6.19e-16)***
γ_{10}	0.048725	0.02714
	(0.00001)***	(0.07208)
γ_{11}	0.00096	0.00040
	(3.25e-14)***	(8.60e-12)***
γ_d		0.02373
		(10.0e-36)***
λ_0	0.48284	0.54318
	(0.08679)***	(0.03530)***
λ_1	0.37033	-0.00833
	(0.01074)***	(0.04012)
μ_0	0.00016	0.00006
	(8.43e-09)***	(8.88e-09)***
μ_1	0.95303	0.97426
	(0.00010)***	(0.00010)***
ΣRSS	0.02400	0.02373
# upper	263	197
# middle	1614	1569
# lower	48	159

*** Values significant at less than 1%.

Figure 1: **Exchange rate Pound/Real, 1854-1891**
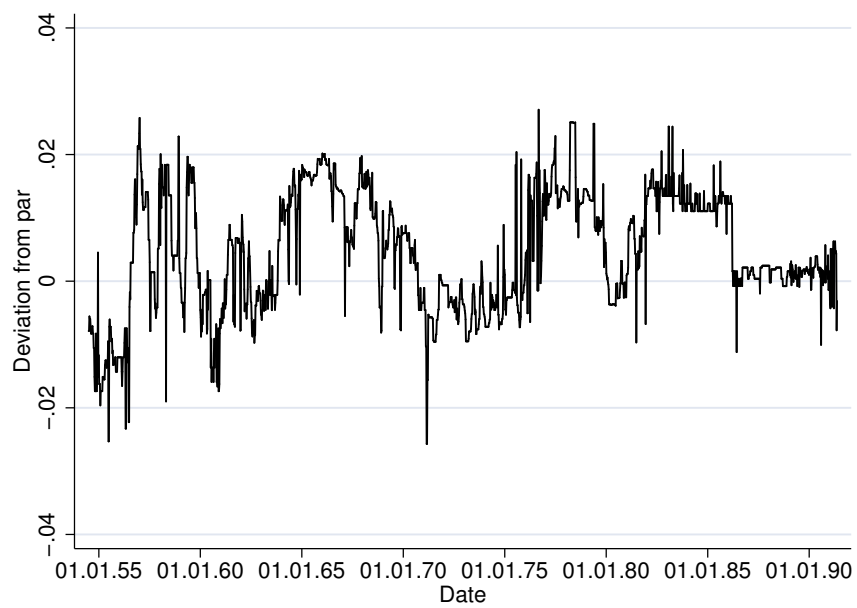
Figure 2: **Kernel density of Exchange rate**

50
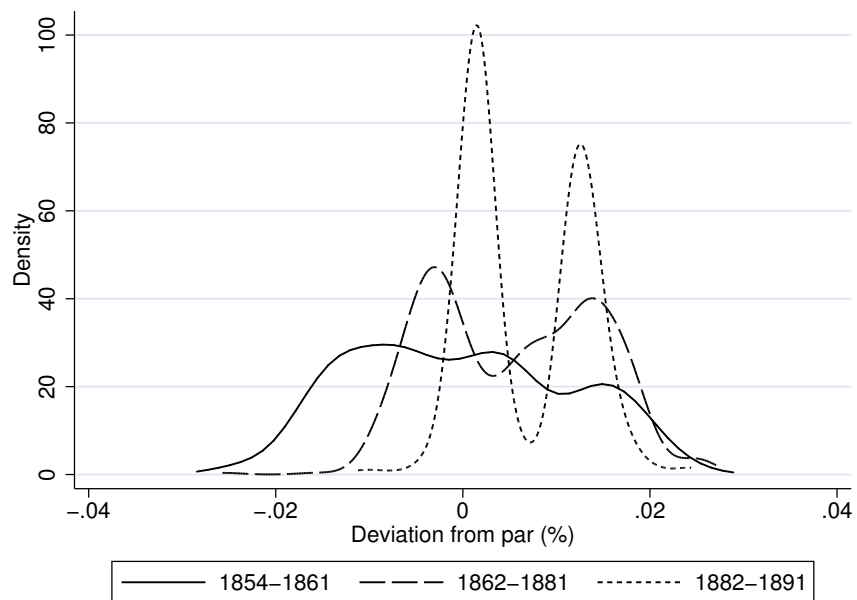
Figure 3: **Main direct expenditures of gold shipment, 1857-1891**

Values in percentage of amount shipped
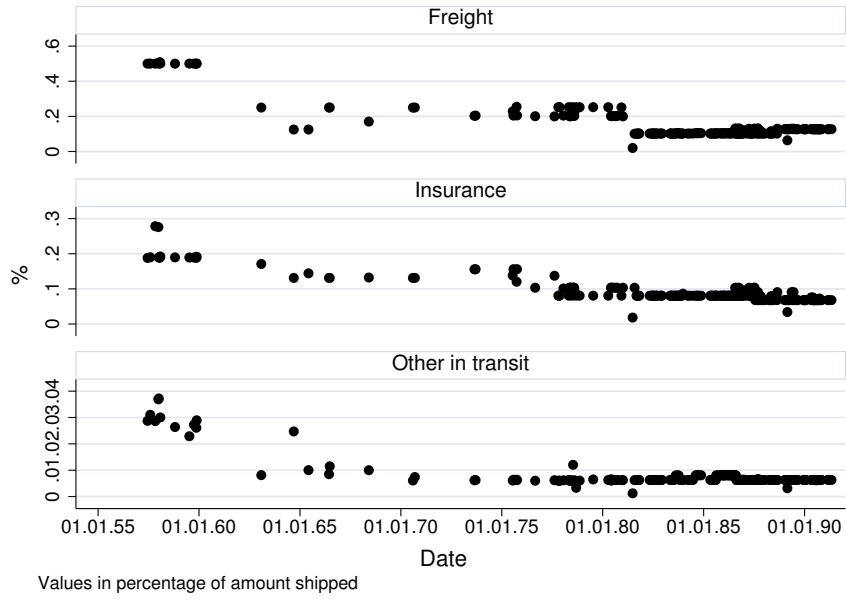
Figure 4: **Gold points (direct reconstruction), 1854-1891**
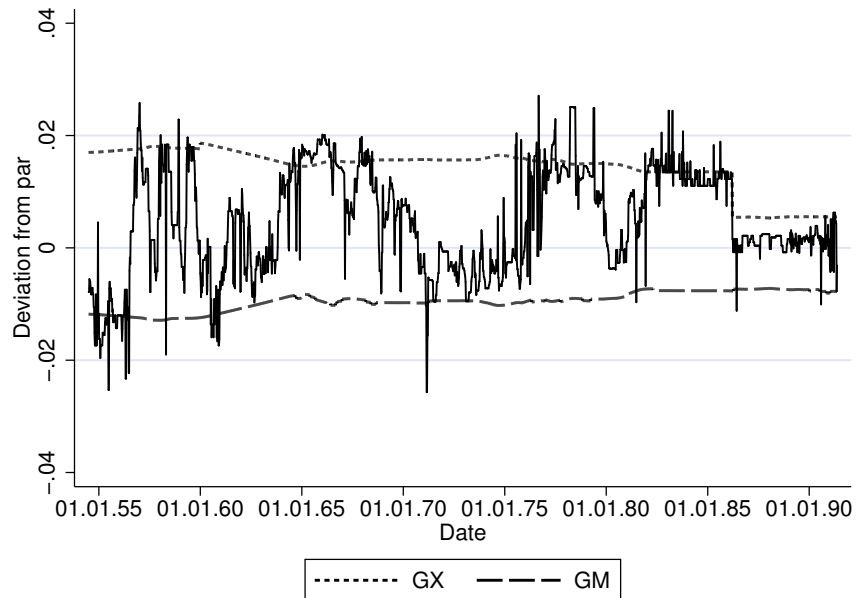
Figure 5: **5-year moving window gold points' estimates**
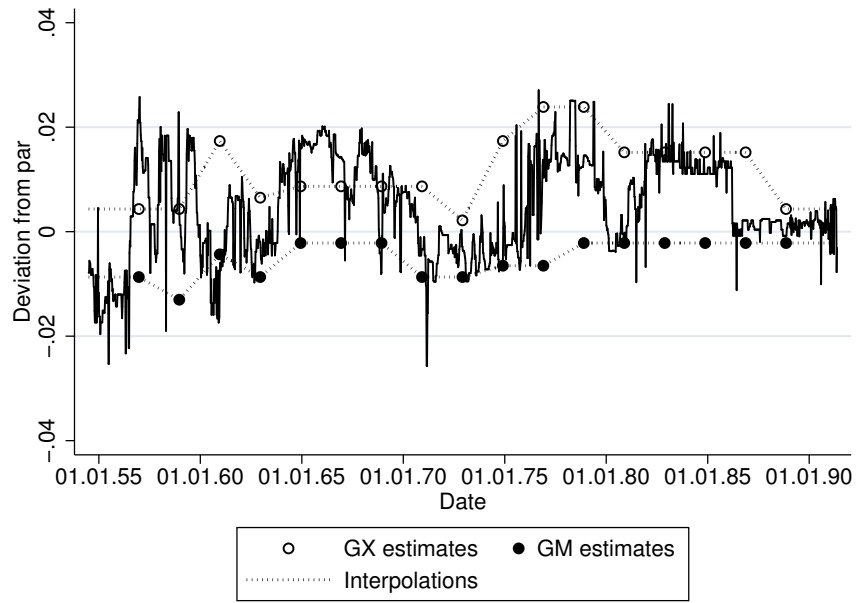
Figure 6: **Smooth trend gold points' estimates**

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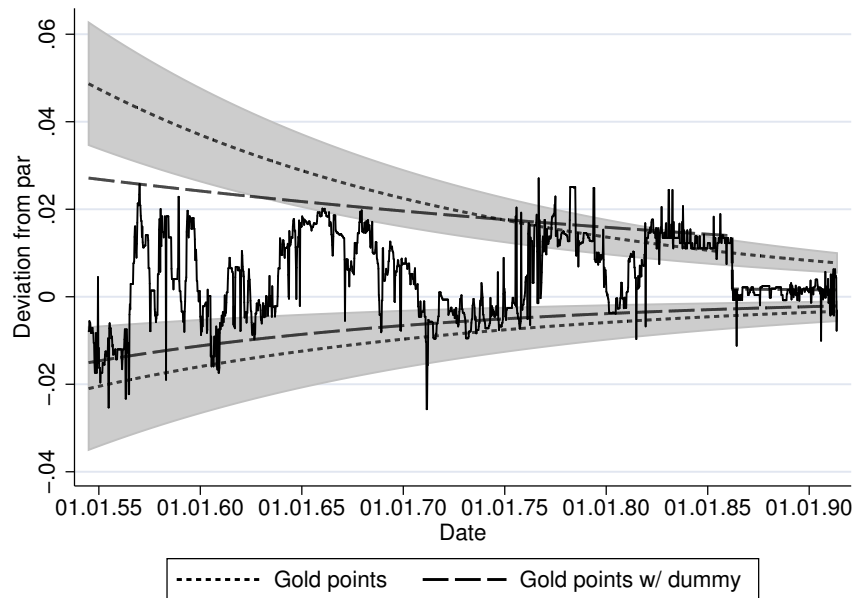
Figure 7: **Interest rate differentials - deviation from parity**

Figure 8: **Expected realignment rate (Svensson's "simplest test")**
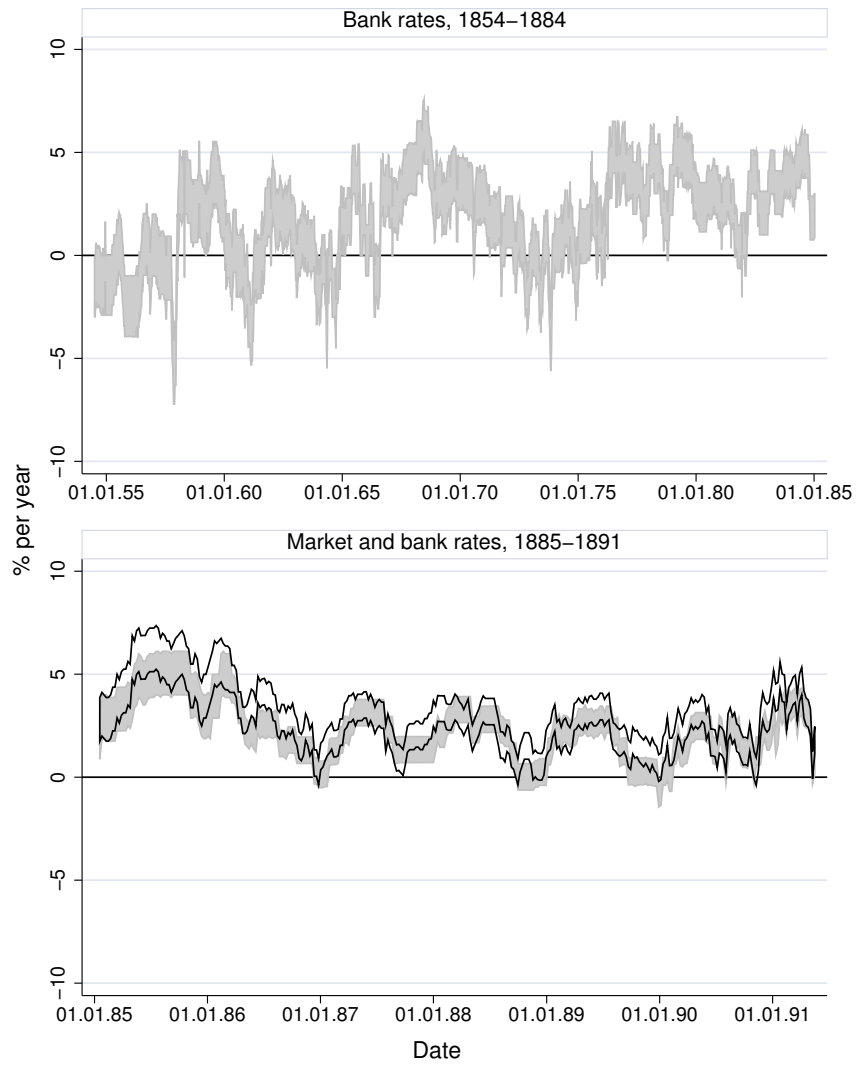
Figure 9: **Expected realignment rate (Svensson & Bertola's "credibility test")**
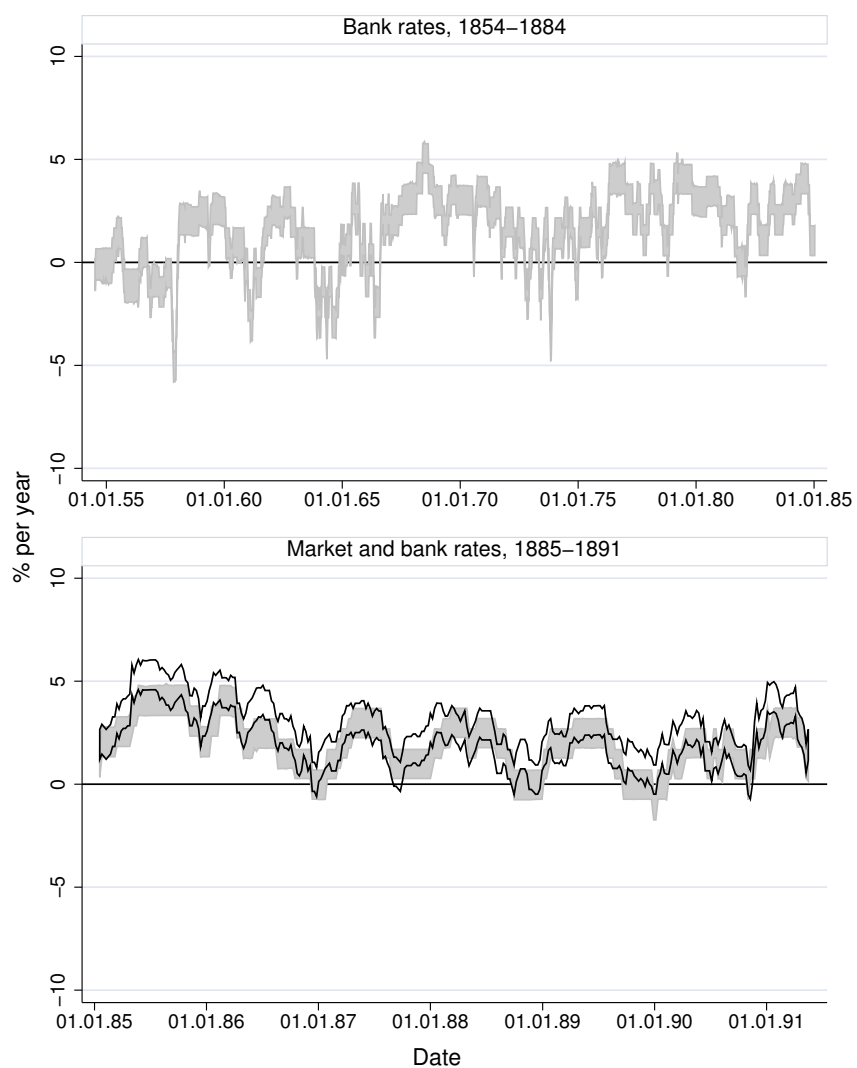
Figure 10: **Exchange market interventions of the Bank of Portugal, 1880-83**
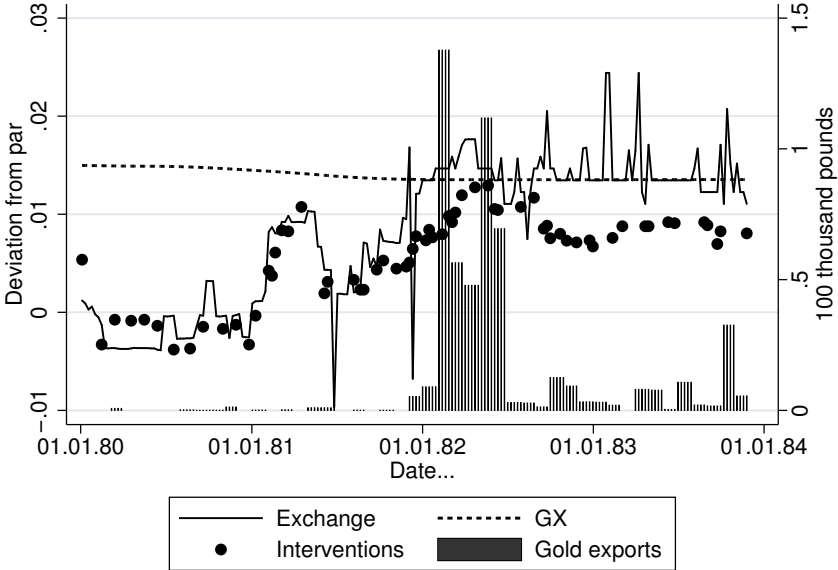
Interventions from Banco de Portugal (1883: 34–35).

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