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Monetary regimes and statistical regularity: the Classical Gold Standard (1880-1913) through the lenses of Markov models

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Abstract: We aim at characterizing the Classical Gold Standard period (CGS) in order to verify if it is endowed with statistical regularity. We study the statistical properties of two-state annual transition matrices of countries switching from a sound state to a crisis state focusing on Reinhart and Rogoff 2009 dataset on external debt crises. The CGS period is governed by homogeneity both in time and across statistical units: the Homogeneous Markov Chain Model holds whereas the Mover Stayer Model does not. Our work is linked to the literature on the CGS and credibility (Bordo and Rockoff 1996). We follow a pure statistical approach to highlight two decisive channels of the credibility mechanism. The first is the stabilization of the probability of default of sound countries. The second is the fact that the CGS makes periphery/deficit countries homogeneous to the core with respect to the probability of default. Both channels are decisive because poor developing countries can borrow at favorable conditions and finance a level of investment greater than their capacity of saving.

JEL Classification: E42; N10; C130.

Keywords: Classical Gold Standard; Credibility; Time Homogeneous Markov Chain; Mover Stayer.

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1 Introduction

The approach we propose here aims at characterizing a particular monetary regime, the Classical Gold Standard (CGS) which ranges from 1880 to 1913, in order to verify if it is endowed with statistical regularity. In this light the Time Homogeneous Markov Chain model (HMC) and the Mover Stayer model (MS), which is an extension of HMC, are two useful tools apt to ascertain the presence of such regularity, with respect to three precise features which are particularly relevant for a monetary regime.

The first feature consists in time-homogeneity, i.e. the behavior of statistical units in a given temporal lag (for example one year) does not change as time goes by.

The second feature is spatial homogeneity, i.e. all the statistical units involved in the monetary regime under exam behave in the same way, independently from their individual traits.

The aforementioned HMC and MS models are particularly useful to check the presence of time and spatial homogeneity. Indeed these two features are both guaranteed by HMC, whereas MS is characterized only by time homogeneity and, contrary to the first model, presents an heterogeneous behavior across statistical units.

Once it is ascertained the temporal homogeneity of the monetary regime and the possibility to model it as a HMC or as a MS, it becomes possible to verify the third relevant feature, that is the presence/absence of an equilibrium distribution.

In this work we focus on the CGS where statistical units correspond to countries. We verify both forms of homogeneity on the basis of annual transition matrices, constructed on the Bernoullian variable sound/distressed for the considered countries.

It turns out that the CGS is HMC and thus governed by homogeneity both in time and across statistical units. We remind that if the period was characterized only by time and not spatial homogeneity we would have MS. Therefore, the conditional probability of default of sound countries is constant across time and binding for all the units. Such probability is reported in the estimated transition matrix, obtained as the maximum likelihood estimator based on the 33 observed annual matrices.

In addition we point out that the estimated transition matrix results to be irreducible and ergodic. This implies that the distribution of the unconditional probabilities of being sound/distressed varies with respect to time, but with a decreasing intensity until the equilibrium is reached (Grimmett Stirzaker, 1992).

These three properties are also relevant in terms of their economic implications.

The first is that in the CGS regime, contrary to previous monetary regimes, the probability of default of sound countries is constant across time. This property is a consequence of temporal homogeneity, i.e. the transition matrices observed through the different years tend to have the same structure. A stable default probability of sound countries across time implies a greater degree of trust among creditors and debtors and thus a greater capacity for deficit countries to attract foreign capital. According to our results the same regularity does not apply to another well studied monetary regime: the Interwar Gold Exchange Standard 1925-1933.

The second implication is that during the CGS' years homogeneity across countries in relation to the probability of default is observed.

In fact, if the regime was MS instead of HMC, the second characteristic would be absent, since MS implies that the whole set of statistical units (countries) can be divided into two sub groups with different transition matrices.

Relevance of homogeneity in time and across statistical units is not limited to the men-

tioned aspects. It is in fact worth to add that the hazard function is constant for all the statistical units belonging to the chain and consequently the probability of default is independent from the history of the single countries and dependent only on the most recent past. If we define Core those countries that have always been sound (as it is the case of the US and UK) and Periphery the countries which have been sound for a shorter time length and experienced some default in the past, then belonging to Core or Periphery does not influence the risk of default in the next period.

Finally the economic implication of the existence of the equilibrium distribution is the fact that the probability of default of all countries, independently of having been sound or distressed, tends to stabilize as time goes by. If the same monetary regime was not characterized by such a distribution, the percentage of default countries in the world would not show a clear and neat tendency to stabilize in time, but on the contrary it would fluctuate. Our work is then linked to the literature on the CGS and credibility and corroborates the thesis of the CGS as a ‘good housekeeping seal of approval’, according to which adherence to the convertibility rule by the Periphery, that heavily depended on access to international debt markets, would be viewed by lenders as evidence of financial probity. The good housekeeping seal of approval hypothesis for the Periphery is tested empirically in two subsequent articles by Bordo and Rockoff 1996 on the Classical Gold Standard, Bordo and Edelstein 1999 on the Interwar period and later by Obstfeld and Taylor 2003. These authors test the convergence between the risk premium of the periphery countries most committed to the gold standard with the risk premium charged on the loans in London. Differently from these studies we follow a pure statistical approach which highlights two decisive channels of the credibility mechanism. The first is the stabilization of the probability of default of sound countries which has necessarily a beneficial effect on the relations among debtors and creditors. The second is the fact that the CGS makes the Periphery homogeneous to the Core with respect to the probability of default. Both channels are decisive because poor developing countries can borrow at favorable conditions and finance a level of investment greater than their capacity of saving.

The rest of the paper is structured as follows. Section 2 provides a survey of the literature. Section 3 describes the dataset and provides some descriptive statistics on the different monetary orders. Section 4 presents the three models used for the estimation: Markov Chain, Mover Stayer and also a non-homogeneous model. Section 5 presents the statistical tests and Section 6 supplies the main results. The last section contains the conclusions.

2 The Classical Gold Standard as a credible system

The Gold Standard was a commitment mechanism by adherent countries to fix their domestic currency in terms of a specified amount of gold. England was the first country to adopt it back in 1717 and the United States were on a de facto gold standard since 1834. Other major countries, namely Germany and France adopted it in the 1870s. We will investigate the period 1880-1913 which is known as the Classical Gold Standard (CGS). It is widely acknowledged in the literature (e.g. Bordo and Rockoff, 1996) that those countries that adhered to the CGS experienced a more stable money growth, lower inflation and lower fiscal deficits. On the other hand, member countries had to forgo monetary sovereignty and therefore some degree of flexibility to react to adverse supply shocks. It is clear that a fully operating CGS during which the government does not intervene to

alter the gold parity leaves little room for discretion in monetary policy. Whether this is beneficial or not has been largely debated in the economics literature⁵ and our paper does not want to contribute to this debate, instead we want to focus on the credibility debate of the CGS.

One of the most important features of stability of the CGS, apart from increasing the credibility of sovereign states, operated via the ‘absolute private sector credibility in the commitment to the fixed domestic-currency price of gold on the part of the center country (Britain)’ (Officer, 2010) and of some major other countries such as France, Germany, Belgium, Scandinavia and other European countries. This commitment mechanism was certainly in place since 1870 in Europe until 1914, whereas in earlier periods it operated under the implicit clause that convertibility might have been suspended during war times and restored after the end of the war at the pre-war parity. This involved a very low, at the limit zero, exchange risk.

According to Officer, credibility was due to the following factors: contracts were expressed in gold; shocks to domestic and world economies were infrequent; the strong commitment (‘ideology of orthodox metallism’) by political authorities to anti-inflation, balanced budget and stable money policy, which involved limited monetization of government debt; this policy option reflected the predominance of political interests favoring stable money (bankers, industrialists, etc.) as opposed to those favoring inflationary interests (farmers, landowners etc.). These elements have led Officer to define as ‘virtuous two-way interactions’ the interplay between credible commitment to convertibility and the underlying institutional and political environment which supported convertibility (stable ideological environment, the behavior of arbitrageurs and responsible and consistent policies by the authorities).

The environment thus far described was an important reason to explain why periphery countries wanted to join and maintain the gold standard. Adherence to the gold standard allowed access to the capital market of the core countries, because it signaled that periphery countries desired to follow and maintain a responsible monetary, fiscal and debt-management policy. As stressed in Bordo and Rockoff (1996), adherence to the gold standard was a ‘good housekeeping seal of approval’ which allowed countries to borrow at lower interest rates, by reducing the risk premium, and obtain high volume of credit to finance investment and growth.

Bordo and Kydland (1995, 1996) have analyzed the role played by the ‘commitment mechanism’ or ‘rule’ represented by adherence to CGS which, by minimizing the exchange rate risk and the possibility that liabilities might be inflated away, insured lenders against the risk of vanishing returns from their investments. Also, the contingency clause, applied during war time, was not to be seen as a break of the commitment but, following Grossman and van Huyck (1988), was seen as a temporary suspension to convertibility necessary to allow the country to follow a feasible fiscal path to smooth its revenue by financing its expenditures not only via taxes and bond finance, but also via seigniorage. Investors expected that after the emergency period the country would have restored the parity. Creditors viewed temporary suspension of gold convertibility as a signal of the

⁵Bordo (2008) has pointed out that output in the US has been more variable under the CGS with a coefficient of variation of 3.5 for real output between 1879 and 1913 as opposed to a coefficient of variation of 0.4 between 1946 and 2003. However White has stressed how comparisons in terms of output between the two periods may not be very reliable due to national statistics before WWI not being based on as broad an array of industry data as are post war statistics (see Romer (1986) on this) and the banking regulation in pre-WWI which may have favored banking instability.

adoption of an optimal mix of the three sources of finances to keep sound government finance and allow the future ability to service debt. Also according to McKinnon (1993) the operation of the rules of the game, according to which monetary authorities were supposed to alter the discount rate to allow the adjustment of the external balance, were an important part of the commitment mechanism. Though according to Bloomfield (1959) and De Cecco (1974) the rules of the game were frequently violated by many countries with the exception of England, McKinnon insisted that to the extent that the temporary abandonment of the rules of the game was not used extensively and that monetary authorities followed Bagehot's rule to prevent a financial crisis, this could have been seen as a strengthening rather than a weakening of the commitment mechanism.

Obstfeld and Taylor (2003) confirmed the credibility acquired by member countries adhering to the CGS (as opposed to the low credibility of interwar Gold Exchange Standard) and measured it as implying a reduction of borrowing spreads by 30 basis points. Thus during the CGS countries on gold are found to have more disciplined fiscal policies, lower public and more favorable treatment by financial markets.

Meissner (2005) by using duration analysis estimates the association between some key explanatory variables and the time conditional probability (i.e. the hazard rate) of periphery countries making a transition to the gold standard. His findings show that, whereas exchange rate volatility and inflationist agricultural interests did not matter for the timing of adoption, the desire to decrease borrowing costs on international capital markets was one of the key elements inducing periphery countries to adhere to the gold standard. By comparing domestic long-term government bond yields and British consol rate, Meissner (2005) finds that the 'good housekeeping' hypothesis is confirmed.

By adopting a target zone interpretation of the gold standard, focusing specifically on the issue of credibility in the classical and interwar gold standard, Hallwood, MacDonald and Marsh (1996) find evidence of very fast and significant mean reversion of the sterling-franc exchange rate, which supports the hypothesis of the CGS as a credible target zone. On the other hand some authors have questioned that adherence to the gold standard led to a significant effect on borrowing spreads.

Indeed, contrary to most existing literature, Mitchener and Weidenmier (2009) analyze country risk and currency risk on sovereign risk spreads during the CGS. They find that the CGS reduced currency risk spreads, but had no significant impact on sovereign risk spread, and that gold standard adherence for many emerging market countries was not very credible⁶.

Also, Ferguson and Schularick (2006, 2012) have pointed to the 'Empire effect' according to which there were 'no credibility gains in the volatile economic and political environments of developing countries' and investors were able to discern behind the 'thin film' of gold the fiscal stance of countries adhering to the CGS.

With respect to the existing literature on the stability and credibility of the CGS, we intend to explore the role played by sovereign debt crisis focusing on the probability of default of countries during the CGS and the credibility acquired by the periphery through the operating mechanism of the same monetary regime.

In a series of papers Bordo and co-authors have investigated the role played by foreign currency denomination and debt crisis during the CGS. Bordo and Meissner (2005) study the role of foreign currency debt in precipitating a debt crisis by comparing the CGS with

⁶In another paper on why Japan had adopted the gold standard, Mitchener, Shizume and Weidenmier (2009) stress the relevance of political factors and more specifically gains in trade flows, rather than a reduction in country's risk.

the present (1972-1997) period. A key finding is that exposure to foreign currency is not per se leading to financial fragility, but the latter will occur only if foreign currency debt is mismanaged. In particular, a strong reserve position or high exports towards the hard currency (i.e. gold during the CGS) may decrease the likelihood of a debt crisis. By investigating the first era of globalization (corresponding to the CGS), Bordo and Meissner (2011) find that countries with credible commitments were able to avoid major financial crises despite the potential of facing sudden stops of capital inflows, major current account reversals and currency crises that accompanied international capital markets free of capital controls.

Finally, Bordo Meissner and Stuckler (2010) analyze the link between foreign currency debt and debt crisis during the period 1880-1913 and find that certainly greater ratios of foreign currency debt to total debt are associated with increased risks of currency and debt crises, however the link crucially depends on the level of reserves and policy credibility. By policy credibility the authors mean credible adherence to hard pegs (i.e. gold during the CGS) and this significantly decreased the probability of a debt crisis.

3 The Dataset

The empirical exercise is based on the construction of a two-state annual transition matrix of countries switching from a ‘sound’ state to a ‘crisis’ state. Each transition matrix provides information on the percentage of countries in the sample that, from period t to period $t+1$, have remained in their ‘beginning of period’ state, either ‘sound’ or in ‘crisis’, or have moved to a different state ‘crisis’ or ‘sound’ respectively.

In order to construct and eventually study the properties of the transition matrices, we use a dataset drawn from Reinhart and Rogoff 2009. The dataset is rich in terms of countries covered (we focus on a list of 70 countries that cover all the five continents) and it goes back to the historical period we are interested in: the Classical Gold Standard period (1880-1913)⁷ and the interwar Gold Exchange Standard (1925-1933)⁸.

For each of the periods considered we construct a panel of countries that enter the sample only after their independence year. We focus only on external debt crisis events defined as the ‘outright default on payment of debt obligations incurred under foreign legal jurisdiction, repudiation or the restructuring of debt into terms less to the lender than in the original’ (Reinhart and Rogoff 2009). In the appendix we report the list of countries considered.

Before turning to the models that describe the relationship between successive transition matrices, we intend, at first, to analyze the characteristic of the countries in terms of soundness/default in the period in exam.

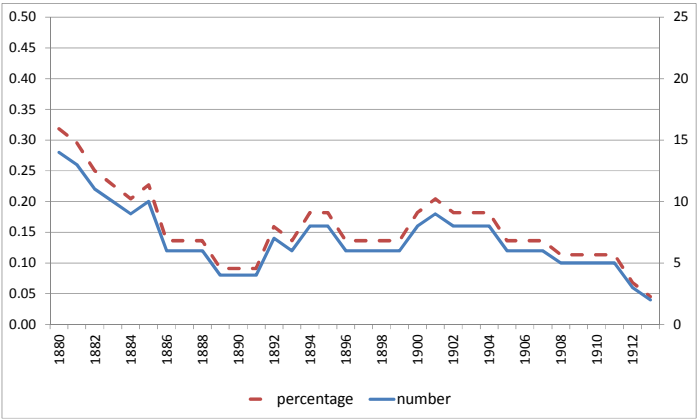
Figure 1 reports for each year the number (left axis) and the percentage (right axis) of countries in default. We immediately notice that the percentage of default in both periods can be at times high and at times low, but in the interwar period the fluctuations are much larger.

The difference between the two periods is in the variability. This is confirmed by the summary statistics reported in Table 1 where the variance is much smaller in the former period compared to the latter. During the Classical Gold Standard period the lowest percentage of distressed countries is at the end of the sample and the highest at the beginning, for the

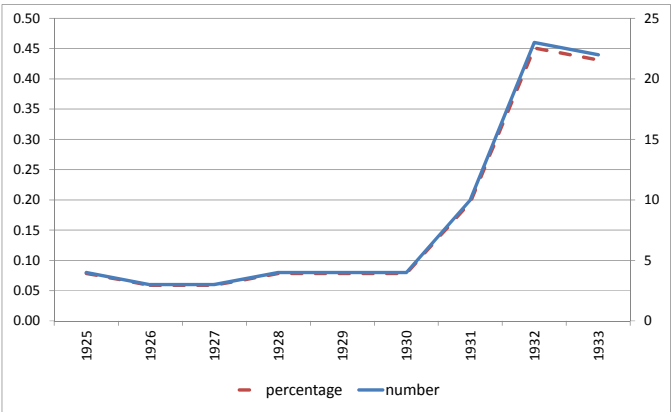
⁷We study what in the literature has been considered the Classical period see Bordo (1981)

⁸Germany, UK and Japan abandoned the Gold Standard in 1931 and the US in 1933.

interwar period (1925-1933) the lowest proportion of distressed is in 1926 and just a few years later, in 1932, it reaches its highest peak.



a) Classical Gold Standard Period (1880-1913)



b) Interwar Gold Exchange Standard (1925-1933)

Figure 1: Number and percentage of default countries

Table 1: *Summary statistics of the percentage of countries in default*

	Regime	years	min	1q	median	3q	max	mean	st.dev.	var.
1880-1913	CGS	34	4.3	11.2	12.8	17.0	29.8	14.6	5.6	31.2
1925-1933	interwar GES	8	5.7	7.1	7.5	10.4	43.4	16.1	15.4	238.6

4 The models

In this section we describe three statistical models that we will use in order to provide a classification of the countries' behavior during the spans of years belonging to the monetary regime in exam. In particular we focus on the HMC model, the MS model and a third model which is not homogeneous with respect to time (Frydman, Kallberg and Kao, 1985).

Let X be the random binary variable such that $X_t(l) = 0$ if the l -th country is having a crisis at time t , 1 otherwise. The sequence $X_0(l), X_1(l), \dots, X_t(l), \dots$ can be modeled with a discrete stochastic process. When we assume the spatial homogeneity, the value of X does not depend on l , since all the statistical units have the same behavior. For this reason we will use the notation X_t instead of $X_t(l)$. It is worth recalling some basic definitions related to stochastic processes:

Definition 1: The stochastic process $\{X_t\}_{t=0,1,\dots}$ satisfies the Markov property if and only if:

$$Pr(X_t | X_{t-1}, X_{t-2}, \dots, X_1, X_0) = Pr(X_t | X_{t-1}) \quad (1)$$

that is, the next state depends only on the current state, and not on the previous path (the process is memoryless).

Definition 2: The process $\{X_t\}_{t=0,1,\dots}$ is said to be time-homogeneous if and only if:

$$Pr(X_{t+s} | X_t) = Pr(X_s | X_0) \quad (2)$$

that is, the movements within a given interval of time $[t, t+s]$ do not depend on the initial value t but only on the temporal lag s .

4.1 Description of the models and their properties

4.1.1 Time Homogeneous Markov Chain Model

The most famous model satisfies both the Markov property and time-homogeneity. The behavior of X is ruled by the transition matrix $P = \{p_{ij}\}_{i,j=1,\dots,k}$ such that:

$$p_{ij} = Pr(X_{t+1} = j | X_t = i) \quad (3)$$

The spatial homogeneity derives from the fact that every individual is supposed to evolve according to the same transition matrix P . Note that time-homogeneity implies that the conditional probability p_{ij} does not depend on t . Having P , we can also easily evaluate the

m-steps transition probability

$$p_{ij}^{(m)} = Pr(X_{t+m} = j | X_t = i) \quad (4)$$

since $P^{(m)} = \{p_{ij}^{(m)}\} = P^m$ (the m-th power of P). More generally the HMC model satisfies the *Chapman-Kolmogorov equation*: $P^{(m+n)} = P^{(m)} \cdot P^{(n)}$.

In some cases the chain admits an equilibrium distribution, in particular when the transition matrix is irreducible and ergodic (see Grimmett and Stirzaker, 1992). When it happens, the equilibrium distribution π can be evaluated as follows:

$$\pi = \eta \cdot \lim_{n \rightarrow \infty} P^n \quad (5)$$

Where η is the starting distribution, that is $\eta_i = Pr(X_0 = i)$.

4.1.2 Mover-Stayer Model

This model, proposed for the first time by Blumen, Kogan and McCharty (1955), belongs to the class of *Mixture Models*, since countries are supposed to be subdivided in two groups, the *Movers* and the *Stayers*. The former group is ruled by a classical Markov chain with transition matrix M, the latter contains individuals never moving from their starting state, and then following a degenerate chain with transition matrix equal to the identity I. The spatial homogeneity decays, since the behavior of individuals depends on the group they belong to (in any case it is worth noting that individuals in the same group have the same behavior). Let s_i be the probability of being a Stayer in state i, and let S be the diagonal matrix $diag\{s_1, \dots, s_k\}$, then the global transition matrix is given by

$$P = S + (I - S) \cdot M \quad (6)$$

where I is the identity matrix. The Markov property and the time-homogeneity still hold, but the transition probabilities have the following form:

$$p_{ij} = \delta_{ij} \cdot s_i + (1 - s_i) \cdot m_{ij} \quad (7)$$

where δ_{ij} is the Kronecker Delta, equal to 1 if $i=j$, 0 otherwise. The transition matrix after m steps is no longer equal to a product as before, but it is given by the following rule:

$$P^{(m)} = S + (I - S) \cdot M^{(m)} \neq P^m \quad (8)$$

In the MS the equilibrium distribution, when it exists, can be calculated similarly to the HMC model:

$$\pi = \eta \cdot \lim_{n \rightarrow \infty} P^n = \eta \cdot [S + (I - S) \cdot \lim_{n \rightarrow \infty} M^n] \quad (9)$$

4.1.3 Non Homogeneous Markov Chain Model

In this model the Markov property is still valid, as well as the spatial homogeneity, whereas the time-homogeneity assumption is discarded. The transition matrix is a func-

tion of time and for every value of t we have transition probabilities defined as

$$p_{ij}(t) = Pr(X_{t+1} = j | X_t = i) \quad (10)$$

and a transition matrix $P(t) = \{p_{ij}(t)\}$, such that $P(t) \neq P(s)$ if $t \neq s$. Note that the conditional probabilities depend on t , the time in which the transition happens. The m -steps transition matrix is still given by the product

$$P^{(m)} = \prod_{t=1}^m P(t) \quad (11)$$

which is a generalization of the Chapman-Kolmogorov equations.

4.2 Additional properties of HMC and MS models

We highlight now two additional features of the HMC and MS models which can be relevant in the analysis of the monetary regime under exam: *the holding time*, or *persistence*, in a given state and the *hazard function*. As a consequence of time-homogeneity, it is possible to provide an explicit probability distribution of the number of consecutive years spent by countries in the same state (the holding time) and to point out that the hazard function is constant. These properties do not hold when time-homogeneity is discarded.

4.2.1 Holding time distribution

Persistence means the tendency to remain in the same state, which can be measured by the holding time, that is the number of consecutive years across which a country is always sound or distressed. More in detail we consider the random variable T describing the number of consecutive steps spent in the same state. Assuming that a country is distressed at a given time t , that is $X_t = 0$, then under the HMC model, the probability of being distressed for the next k years is given by

$$Pr(T = k | X_t = 0) = Pr(X_{t+1} = \dots = X_{t+k} = 0, X_{t+k+1} = 1 | X_t = 0) = (p_{00})^k p_{01} = (1 - p_{01})^k p_{01} \quad (12)$$

for $k=0, 1, 2, \dots$

This is exactly the form of the geometric distribution with parameter $p = p_{01}$. If we assume that $X_t = 1$, we obtain a similar result with $p = p_{11}$. That is the holding time in the state sound/distressed follows a geometric distribution with parameter given by the corresponding transition probability. Finally if we consider the MS model, we obtain that the holding time in the state of sound/distressed has again a geometric distribution with parameters respectively equal to $(1 - s_0) \cdot m_{01}$ and $(1 - s_1) \cdot m_{10}$.

4.2.2 Hazard function

Generally speaking the hazard function is the probability that a country switches from sound to distressed (or vice versa) at time t , knowing that it has never switched before t .

More formally, when the holding time T has a discrete distribution the hazard function is

$$\lambda(t) = Pr(T = t | T > t - 1) \quad (13)$$

In Xekalaki (1982) it is proved that when T has a geometric distribution with parameter p , as in the HMC and MS models, then the hazard function is constant, in particular $\lambda(t) \equiv p$. As a consequence of this result, the probability of a sound country to become distressed and vice versa does not depend on the past history of the same country, since it does not depend on the time spent as sound/distressed.

4.3 Estimation

In order to adapt the models on our empirical data, we need to estimate the parameters. Suppose we are given the following quantities: T is the total numbers of observed steps (that is countries are observed for T consecutive years); $n_0 = (n_1(0), \dots, n_k(0))$ is a vector such that the value $n_i(0)$ corresponds to the number of individuals starting from the state i ; $n_{ij}(t)$ is the number of individuals being in state i at time $t-1$ and in state j at time t , for every $t = 1, \dots, T$ and let $N(t) = \{n_{ij}(t)\}$; $n_t = (n_1(t), \dots, n_k(t))$ be the vector containing the number of individuals in every state at time t ; finally $n_s = (n_{s1}, \dots, n_{sk})$ is the vector containing the number of individuals never moving from their starting state. As in Anderson and Goodman (1957), the estimated transition matrix for the classical Markov chain is given by \hat{P} such that

$$\hat{p}_{ij} = \frac{\sum_{t=1}^T n_{ij}(t)}{\sum_{t=0}^{T-1} n_i(t)} \quad (14)$$

In the case of a non-homogeneous chain, every $P(t)$ has to be estimated by means of the matrix \hat{P} such that

$$\hat{p}_{ij} = \frac{n_{ij}(t)}{n_i(t)} \quad (15)$$

(Anderson and Goodman, 1957).

The Mover Stayer Model is more difficult to pin down because of the lack of information about the actual number of Stayers in every state. As in Frydman (1984), the parameters are recursively estimated, starting from the solution \hat{n}_{ii} of the equation

$$[n_{*i} - Tn_i(0)] \cdot x^{T+1} + [Tn_i(0) - n_{ii}] \cdot x^T + [Tn_{si} - n_{*i}] \cdot x + n_{ii} - Tn_{si} = 0 \quad (16)$$

where $n_{*i} = \sum_{t=0}^{T-1} n_i(t)$.

5 Test of hypothesis

As in Anderson and Goodman (1957) and Frydman, Kallberg and Kao (1985) we can use the estimated parameters to test the assumption of time homogeneity and the presence of Stayers. We note that the HMC model is nested in both the MS and non-homogeneous models. We then apply a *likelihood ratio test* which is a statistical test used to compare two models, one of which (the *null model*) is a special case of the other (the *alternative*

model). The test statistic is given by $-2\log\left(\frac{L_n}{L_a}\right)$, where L_n is the likelihood for the null model, and L_a is the likelihood for the alternative model. Such statistic is approximately distributed as a χ^2 distribution, with degrees of freedom depending on the kind of models we are comparing. Following Frydman et al. (1985) the likelihoods for the three models are: HMC: $L_{hmc} = c \cdot \prod_{i,j} (\hat{p}_{ij})^{n_{ij}}$

MS: $L_{ms} = c \cdot \prod_i \hat{s}_i^{n_{si}} (i - \hat{s}_i)^{n_i(0) - n_{si}} \cdot \hat{m}_{ii}^{n_{ii} - T n_{si}} \cdot \prod_j \hat{m}_{ij}^{n_{ij}}$

Non-homogeneous model: $L_{ns} = c \cdot \prod_{t=1}^T \prod_{i,j} (\hat{p}_{ij}(t))^{n_{ij}(t)}$

with $c = \prod_i \left(\frac{n_i(0)}{n}\right)^{n_i(0)}$.

The first test regards the HMC (null model) against the non-homogeneous chain (alternative model).

The test statistic is $-2\log\lambda$, where λ results to be equal to $\frac{L_{hmc}}{L_{ns}} = \prod_t \prod_{i,j} \left(\frac{\hat{p}_{ij}}{\hat{p}_{ij}(t)}\right)^{n_{ij}(t)}$.

Such statistic is approximated by a χ^2 distribution with $T \cdot k \cdot (k - 1)$ degrees of freedom (Anderson and Goodman, 1957).

The second test regards the same null model against the alternative MS model. In this case λ is equal to L_{hmc}/L_{ms} and the statistic $-2\log\lambda$ is approximated by a χ^2 distribution with k degrees of freedom. In both cases we assume that the null hypothesis is true and we supply the p-value.

In addition to the aforementioned tests of hypothesis, we propose here a goodness-of-fit test in order to support our results. As in Cipollini, Ferretti, Ganugi (2012) this test is based on the comparison between the estimated and the observed distribution of sound and distressed countries. Let $p(0)$ be the starting distribution (provided by the percentage of sound/distressed countries in the first observed year), and let $p(t)$ be the observed distribution in the t -th year, then we can compare $p(t)$ with $\hat{p}(t)$, the estimated distribution for the same year, provided by the model we are working with. The goodness-of-fit test is based on the following statistic:

$$C = n \sum_{i=1}^k \frac{(p_i(t) - \hat{p}_i(t))^2}{\hat{p}_i(t)}, \quad (17)$$

where t is fixed and n is the number of statistical units. This test statistic is distributed as a χ^2 distribution with $k-1$ degrees of freedom.

6 Results

6.1 Results on the statistical tests

The empirical stylized facts introduced in the descriptive statistics section show that during the CGS the proportion of countries in default has a more stable behavior, across time, compared to the interwar period. In the following section our aim is to test whether the CGS is governed by a HMC or by a MS process or even by a process which is not homogeneous across time, applying the statistical tests described in the previous section. In a first step we apply the log-likelihood test to compare HMC with the non-homogeneous chain: in this way we check the presence of time-homogeneity. Secondly we test HMC against the MS model to verify if we can assume the presence of homogeneity among countries. The results are reported in Tables 2, 3. The statistical test reported in Table

Table 2: *Log-likelihood test: HMC versus non-homogeneous model*

Period	Regime	Observed test statistic	d.f.	p-value
1880-1913	CGS	89.71	64	0.0187*
1925-1933	interwar GES	55.11	12	0.0000 ⁺

Significance level : '****' 0.1, '**' 0.05, '*' 0.01, '+' 0

Table 3: *Log-likelihood test: HMC versus MS*

Period	Regime	Observed test statistic	d.f.	p-value
1880-1913	CGS	1.01	2	0.6040***

Significance level : '****' 0.1, '**' 0.05, '*' 0.01, '+' 0

2 confirms homogeneity of the CGS period and non homogeneity of the interwar period with a confidence level of 99%. This is a satisfying result, since the CGS corresponds to a 33-year-long span of time and usually matrices observed across shorter intervals of time are probably more homogeneous. The test thus supports also the fact that the transition matrices are homogeneous across time only during the CGS and the HMC prevails over the MS (Table 3), then there is no heterogeneity across countries. Having ascertained that the CGS can be fitted with a Markov Chain, we support this result by means of the goodness of fit test. The starting distribution is the percentage of sound/distressed in 1880. The estimated transition matrix of the HMC is called \hat{P} and it is showed in Table 4. For example we consider $p(1)$, the observed distribution among sound and distressed after one year (i.e. in the year 1881), and we compare it with the estimated $\hat{p}(1)$, given by the formula $\hat{p}(1) = p(0) * \hat{P}$. The same test can be repeated for every year from 1880 to 1913, knowing that the estimated distribution for the t -th year is given by $\hat{p}(t) = p(0) * \hat{P}^t$. Table 4 reports the value of the statistic C for every year, and the corresponding p-value evaluated using a χ^2 distribution with one degree of freedom. As we can see the goodness of fit test supports our results.

Table 4: *Goodness-of-fit test*

t	1	2	3	4	5	6	7	8	9	10	11
year	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891
C	0.033	0.003	0.001	0.007	0.336	0.543	0.304	0.153	1.202	0.985	0.816
p-value	0.855***	0.953***	0.970***	0.936***	0.562***	0.461***	0.581***	0.696***	0.273***	0.321***	0.366***

t	12	13	14	15	16	17	18	19	20	21	22
year	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902
C	0.2531	0.0182	1.2234	1.365	0.0892	0.1137	0.1366	0.1574	1.8515	3.4406	1.9634
p-value	0.615***	0.893***	0.269***	0.243***	0.765***	0.736***	0.712***	0.692***	0.174***	0.064**	0.161***

t	23	24	25	26	27	28	29	30	31	32	33
year	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913
C	2.0068	2.0434	0.2382	0.2458	0.2521	0.0009	0.0011	0.0014	0.0016	0.8373	1.9387
p-value	0.156***	0.153***	0.625***	0.620***	0.615***	0.976***	0.973***	0.970***	0.968***	0.360***	0.164***

Significance level : '****' 0.1, '**' 0.05, '*' 0.01

Table 5: *Estimated one-year transition matrix*

	sound	distressed
sound	98.1%	1.9%
distressed	15.1%	84.9%

Table 6: *Estimated ten-year transition matrix*

	sound	distressed
sound	90.6%	9.4%
distressed	75.1%	24.9%

6.2 Conditional probabilities

The results showed in the previous section are not only interesting from a statistical point of view, but have relevant implications in economic terms and help characterize the CGS from other monetary regimes. Time homogeneity during the CGS implies that the conditional probabilities, i.e. the probability of sound countries of defaulting in the next period, remains constant throughout the years covering the CGS. It is worth to note that the inter-war Gold Standard is not characterized by this kind of regularity. Then time homogeneity implies that the CGS generated a virtuous mechanism that helped stabilizing the probability of default for sound countries and that the same mechanism could not be restored after WWI.

Time homogeneity makes it possible to calculate the estimated transition matrices at different time horizons.

Table 5 shows the estimated one-year transition matrix for the CGS, which contains the estimated probabilities of being sound or distressed in the next year, conditional on the fact of being sound or distressed in the current year. Table 6 shows the estimated ten-year transition matrix, obtained as the 10th-power of the one-year matrix. The percentage of distressed becoming sound after 10 years is around 75%, corroborating the credibility hypothesis of the Classical Gold Standard.

6.3 Unconditional probabilities and the equilibrium distribution

The conditional probability, reported in the transition matrix, corresponds to the probability of switching to a determinate state, conditioned on the starting state. A different matter is to evaluate the unconditional probability, i.e. the probability of defaulting or the probability of remaining sound, after a fixed time length, independently from the starting state.

This proportion of sound and distressed on the whole set of countries during the CGS years is not constant but, in our case, changes in time with decreasing intensity until the

Table 7: *Estimated unconditional probabilities of distressed and sound countries*

	0	I	II	III	IV	...	XXIX	XXX	XXXI	...	ss
distressed	31.8	28.3	25.4	23.0	21.0	...	11 ^a	11 ^a	11 ^a	...	11
sound	68.2	71.7	74.6	77.0	79.0	...	89 ^a	89 ^a	89 ^a	...	89

^a Rounded to nearest whole number

equilibrium distribution is reached⁹.

Given this result for the CGS we are able to calculate how the proportion of distressed and sound countries varies in time according to the model, until the steady state is attained. We can see from Table 7 that the steady state would be reached within 29 years with 89% of sound countries and 11% of distressed. Figure 2 shows graphically the theoretical transitions from sound to crisis states and the period of time in which this equilibrium is reached.

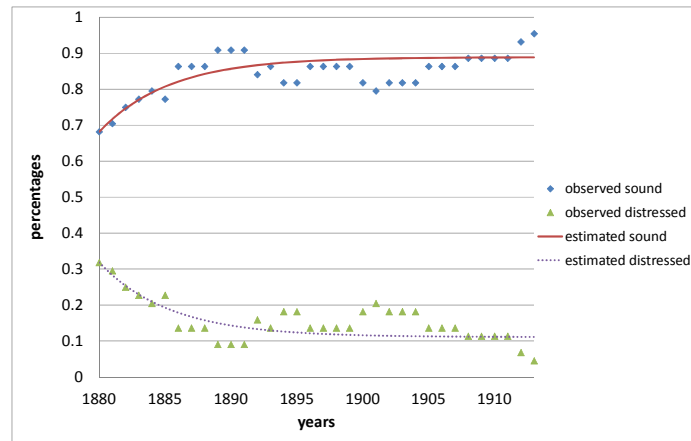


Figure 2: Estimated and observed unconditional probabilities of distressed and sound countries

⁹The existence of the equilibrium distribution is assured by the irreducibility of the estimated one-year matrix (which in other words means that it is possible to go from any state to any state) and by its ergodicity (for details see Grimmet and Stirzaker, 1992). In any case we can easily verify that the one-year matrix satisfies the statements of the Perron-Frobenius theorem, i.e. it is irreducible and it has only one eigenvalue equal to one (the eigenvalues are respectively $\lambda_1 = 1$ and $\lambda_2 = 0.83$). As a consequence the equilibrium distribution exists and is unique.

6.4 Constant hazard function

Finally the HMC model implies a geometric distribution for the holding time and consequently a constant hazard rate. One of the main properties of the geometric distribution is the lack of memory, which is reflected also in the implied constant hazard rate: the time until the next occurrence of an event (in our case ‘default’) does not depend upon past history.

What we intend to point out in our work is that a constant force of mortality characterizes the CGS. Indeed the same does not apply if we consider the interwar Gold Exchange Standard.

The outcome of our analysis goes in the direction of proving that the poor industrializing countries made the right choice when adhering to the Gold Standard during its heyday. The chance of a country experiencing default in the next period does not depend on the number of years that country has been sound in the past: whether it has always been sound (as in the case of core countries such as Britain, US, France and Germany) or whether it had already experienced a certain number of years in default (as is the case of some periphery countries such as Argentina, Mexico, Brazil, Portugal). The Classical Gold Standard was, according to our analysis, a credible system. Creditors believed that the poor countries, once they decided to adhere to the system, would conduct a probe and credible public finance policy regardless of their past as defaulting countries. For this reasons, the periphery managed to attract capital and their country risk converged to the risk of the core. This finding is further corroborated by the fact that in the CGS period the HMC model prevails over the MS.

7 Conclusions

The last decades have experienced many financial turmoils at the international level and the movement towards common currency areas, such as the Eurozone, on the one hand, and the problem of reserve accumulation and current account imbalances on the other hand, have given rise to various debates calling for a different international system. At the academic level, an important debate has centered around the role played by the Classical Gold Standard. Some authors like Bordo and Rockoff (1996), and Bordo and Kydland (1995, 1996) have highlighted the role of credibility that adherence to the Gold Standard could provide to its members. These authors by taking stock of the ‘rules vs discretion’ debate of the ‘80s have stressed that widespread adherence to the CGS, despite the loss of flexibility to react to adverse supply shocks, could guarantee lower risk premia and therefore long-run growth prospects. On the other hand, some authors like Ferguson and Schularick (2006, 2012) have questioned the beneficial effect that adherence to the CGS may have had on member countries. They have pointed to the Empire effect as more relevant during the CGS era, and, crucially, to the ability of investors to look behind the ‘thin film’ of gold in order to discern the true fiscal stance of countries adhering to the CGS. Therefore they have called into doubt the hypothesis of the ‘Good Housekeeping Seal’.

Our paper has looked at this debate by focusing on a different aspect, the transition from a sound state to a crisis state, by using a dataset constructed by Reinhart and Rogoff 2009, and has adopted a different technique, based on a pure statistical approach. Indeed Time Homogeneous Markov Chains and the Mover Stayer Model have allowed us to investigate time-homogeneity, spatial homogeneity and the presence or absence of an

equilibrium distribution.

Our findings are that, during the CGS, countries could stabilize their probability of default, with respect to which there was no difference between periphery and core countries. The statistical homogeneity, with respect to the probability of default, detected within the group of core countries may suggest that, to some extent, poor developing countries or, more in general, peripheral countries were prepared to accept lower flexibility in responding to supply shocks by forgoing monetary independence, because adherence to the CGS could provide a 'Good Housekeeping Seal'.

Though our analysis has focused mainly on the Classical Gold Standard period (1880-1913) with some comparisons for robustness check purposes to the interwar Gold Exchange Standard (1925-1932), we aim at extending, in a future work, the application of Markov Chains to investigate more closely the credibility of alternative monetary regimes such as the Gold Exchange Standard and the Bretton Woods System (1946-1971). This project will allow to establish whether adhering to different international monetary regimes may have been more or less beneficial for peripheral countries and the world economy in general.

In conclusion, we can still confirm the last part of the very last sentence in Bordo and Rockoff (1996): 'whether a 'Good Housekeeping Seal' as transparent and durable as the gold standard can be recreated today, is an open question', though we think that to some extent we shed further light on the first part of it concerning the CGS as a 'Good Housekeeping Seal'.

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Appendix. Countries, Gold Standard adherence, Default years

countries	GS dates*	Default dates**
Argentina	1867-1876;1883-1885;1900-1914	1890-1893
Australia	1852-1915	-
Austria-Hungary	1892-1914	-
Belgium	1872-1914	-
Bolivia	1908-1914	-
Brazil	1888-1889;1906-1914	1900-1910
Bulgaria	1906-1914	-
Canada	1854-1914	-
Chile	1895-1898	1880-1883
China	-	-
Colombia	-	1880-1904
Costa Rica	1896-1914	1880-1885;1901-1911
Denmark	1872-1914	-
Dominican Republic	-	1880-1888;1892-1907
Ecuador	1898-1914	1880-1890;1900-1904;1906-1911
Egypt	1885-1914	1880
El Salvador	-	-
France	1878-1914	-
Germany	1871-1914	-
Greece	1885;1910-1914	-
Guatemala	-	1880-1888
Honduras	-	1880-1913
Indonesia	-	-
Italy	1884-1894	-
Japan	1897-1917	-
Mexico	1905-1913	1880-1885
Netherlands	1875-1914	-
Nicaragua	-	1911-1912
Norway	1875-1914	-
Paraguay	-	1880-1885;1992-1993
Peru	1901-1914	1880-1889
Portugal	1854-1891	1892-1901
Romania	1890-1914	-
Russia	1897-1914	1885
Spain	-	1880-1882
Sweden	1873-1914	-
Switzerland	1878-1914	-
Thailand	-	-
Tunisia	-	-
Turkey	1881-1914	1880-1881
UK	1821-1914	-
Uruguay	1876-1914	1991
US	1879-1917	-
Venezuela	-	1880-1881;1892;1900-1905

* according to Officer 2010; ** according to Reinhart and Rogoff 2009