Gold and Trade:
An empirical simulation approach

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Abstract

The network externalities from international trade to the choice of exchange rate regimes have been invoked to explain the rise of the classical gold standard. In particular, gravity regressions have consistently shown large trade gains for countries on the same monetary regime (especially gold). However, causality probably runs in both directions, since more open economies would have a greater incentive to adopt stable exchange rate regimes, especially if they traded more with other countries already on gold. This raises an endogeneity issue for which conventional identification methods are not suitable. This paper uses empirical network analysis to model the co-evolution of trade and exchange rate regimes. Simulations of this evolution indicate the presence of a selection effect, monetary regimes influenced trade on the intensive thought not extensive margin, and a contagion effect, the monetary regimes of trade partners shaped countries' decisions to change their regime, during the First Globalization and classical gold standard era.

Early stage work
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1. Introduction

The global economy from the second half of the 19th century until World War I experienced two major trends in international trade and finance. The First Globalization led the fast growth of world trade, characterised by an expansion of the range of goods traded as well as the countries involved in the global system. Simultaneously, a gold peg became the monetary orthodoxy of the period, as many nations decided to adopt the gold standard. The link between these two developments has long been remarked and contemporaries were keenly aware of the advantages of adopting the monetary regime of their main trade partners. Because shared monetary regimes and enhanced trade relations are mutually reinforcing they create 'network externalities' which have been the object of intensive study in the literature on the late 19th century and our own wave of Globalization (Estevadeordal et al., 2003; Rose, 2000; Rose & Glick, 2016).

Several studies[1] have shown how network effects swayed countries' decisions to adopt gold. However, the identification of causal relations in networks with traditional statistical methods is very hard, in the absence of natural experiments. This project introduces a new estimation method that allows to account for possible endogeneity in these settings.

We investigate the relationship between trade and monetary arrangements and address the endogeneity issue by employing a RSiena simulation approach (Steglich et al., 2010). This method, recently developed in the sociology literature to address questions of influence and selection, utilizes a Stochastic Actor Oriented Model to simulate the development of network structures and behavioural characteristics (Snijders et al., 2010). The method requires a basic network setup, which in our case is based on trade relationships, and explains the changes in actor behaviour as optimal reactions to the contemporary network structure and the behaviour of other actors. In this paper we retain as behavioural variable the choice of monetary system and, in particular, the decision to adopt a gold peg.

We apply this method to the late 19th century in order to investigate the the role of trade in the development of the international monetary system as well as the impact of the international convergence onto the gold standard on the trade system of the First Globalization. We focus on a set of 32 independent countries with the ability to set their own monetary and trade arrangements. The time range covers little over five decades, from the 1860s until the disruptions of World War I.

The next section introduces the historical setting of trade and monetary

[1] In particular gravity studies like Meissner (2005)

arrangements between 1860 and 1911, as well as the literature on the subject. Section 3 then describes the details of the method, and its application to the historical case occupies section 4.

The preliminary results are presented and discussed in section 5 and the paper ends with some intermediate conclusions and directions for future research.

2. Historical Setting

The literature on the rise of the classical gold standard during the 19th century can still be usefully summarised in the three categories identified by Gallarotti (1995), namely, structural, proximate and permissive forces. Structural forces encompassed long-term trends that favoured the adoption of gold, while proximate sources acted as catalysts in particular periods. Finally, permissive forces determined whether individual countries could act on the previous two by joining (or remaining on) gold. Among the structural forces one can include the trends toward industrialisation and economic growth, or the ideology of gold, which persisted into the interwar (Eichengreen & Temin, 2010; Yeager, 1984). These explanations are the prime ground for political economy models of monetary regimes, which explore the distributional consequences of the adoption of a stable exchange rate regime. In these accounts, the gold standard had to be imposed by a combination of stable money interests (importers, banking/finance, industrial) against coalitions of indebted farmers, landowners, silver miners and exporters (Broz, 1997; Mitchener & Voth, 2011). These conflicts were played inside each country, but also in the international arena of a series of monetary conferences convened in the second half of the 19th century to solve the 'monetary question' (Reti, 1998).

In spite of these underlying structural forces and the efforts of international conferences to standardise the monetary regime, countries mostly joined gold in their own time (or not at all).[2] Moreover, the pattern of monetary regimes reproduced in Figure 1 reveals a number of clustered conversions to gold. The most famous is the so-called 'scramble for gold' of the early 1870s, when a number of European nations rushed to join once France and Germany had done so. Over the remaining decades a number of emerging

[2] In the absence of a agreement binding all countries to the same standard, some groups of nations formed common currency areas, the most successful being the Latin Monetary Union of 1865 and the Scandinavian Monetary Union of 1873.

nations also adopted gold, which became the predominant monetary regime by the early 20th century.

Among the proximate sources that aim to explain this staggered rhythm of adoption are the Franco-Prussian war and the defensive monetary strategy of France against the announced conversion of the new German Empire to gold (Flandreau, 1996), the demonetisation of silver by the US in 1873 (Friedman, 1990) and the rise in world silver production in the 1860s concomitant with a reduction in demand from Asia, one of its traditional markets (Flandreau, 2004).

The logic of network externalities is one of increasing returns. The larger the number of countries on gold and the more central they were to the trade and finance networks, the greater the gains to other nations from joining. The central role of France and Germany in the European trade and finance networks means that the scale of the move in 1873 is not entirely apparent from Figure 1, which only counts countries and abstracts from their size or importance. Most authors effectively date the start of the international gold standard from 1873, once the European core of nations had joined. Contemporaries were well aware of these externalities. For instance, the Swiss representative to the monetary conference of 1867 duly stated that although Switzerland itself preferred an international regime based on gold, its decision was conditioned by the preference of France, then still a bimetallic nation.[3] Broch, the Norwegian representative, equally stated that as 'the trade of the United Kingdoms [Sweden-Norway] was mainly done with Germany, especially through Hamburg, their joining a monetary union would be necessarily subordinated to a previous accession by the North of Germany.'[4]

Figure 1 here.

In these statements we can see the logic of the trade gains from exchange rate stability invoked today about monetary unions (Rose & Glick, 2016). Indeed, the evidence about exchange rate volatility appears to confirm this association. Figure 2 represents a proxy for exchange rate stability: the coefficient of variation of monthly exchange rates against the central gold currency (sterling). We separated currencies by their regime and represent in the figure the median coefficient of variation by regime. This exercise has a couple of obvious biases with contradictory effects. First, by taking sterling as the *numéraire* it ignores that countries mostly trading outside the gold bloc could still attain exchange rate stability if sharing the same monetary

[3] International Monetary Conference (1867), p. 44.
[4] International Monetary Conference (1867), p. 22.

regimes of their trading partners. Nevertheless, it reveals a clear hierarchy in terms of stability of the four monetary regimes. Interestingly, gold gains ground against silver and bimetallic standards only after the scramble of the 1870s. The decreasing number of countries outside gold after that decade paid a clear price in terms of exchange rate uncertainty when trading with nations on gold. The volatility of paper regimes remains essentially unaltered throughout the period.[5] However, the volatility of silver currencies increases significantly since the early 1870s. In particular, the three spikes in 1890, 1893 and 1897 coincide with large changes in the market price of silver relative to gold. The second problem with Figure 2 is that it underestimates the underlying volatility of the different currency regimes due to the self-selection of countries into monetary regimes. Some of the countries that chose to remain outside gold were able to maintain relative stability through other means e.g. central bank intervention in the FX market, as in the cases of Austria-Hungary or Italy that remained on paper standards for substantial periods (Jobst, 2009; Tattara, 1999). This is even more obvious in the case of bimetallic regimes, which were abandoned by almost all countries by the turn of the century, with the exception of Venezuela and Bulgaria. Bulgaria was the last country to formally maintain this standard but despite that was able to retain a remarkable stability against foreign gold currencies thanks to a combination of good luck (positive trade balances) and domestic monetary measures (Dimitrova & Ivanov, 2014).

Figure 2 here.

The empirical literature on the gold standard has sought to quantify the magnitude of the network effects of trade gold pegs. The effect of sharing the same currency arrangements on trade between dyads has been measured in the context of gravity models. Both López-Córdova & Meissner (2003) and Flandreau & Maurel (2005) find that countries on gold traded by at least 30% more with each other than with nations not on gold. There is however also evidence of reverse causality, as countries that traded extensively with other countries on gold adopted the golden peg sooner (Meissner, 2005). Trade links were far from the only 'permissive' condition for countries to join gold, but this raises an endogeneity problem, which is only imperfectly addressed by the use of the exogenous (gravity-driven) component of trade. Meissner (2005) also shows that the resilience of domestic financial systems was crucial

[5] With the exception of an inflationary bout in 1898 concentrated in Portugal, Brazil and Spain.

to allow countries to peg to gold, whilst an excessive burden of debt delayed the adoption of this regime.[6]

The expected trade gains are not the only potential source of endogeneity. Another strand of the literature has focused on the stability properties of the bimetallic regime, which had been favoured by the main trading nations (with the exception of the UK) until the 1870s (Flandreau, 2004). This line of inquiry tends to show, based on GE models, that the bimetallic regime, contrary to the intuition from Gresham's law, was perfectly able to maintain a stable relation between the market prices of gold and silver and, more importantly, deliver domestic price stability as well (Flandreau, 1996; Velde & Weber, 2000). Notwithstanding, the same models show that the demonetisation of silver by three of the largest economies in the 1870s (France, Germany and the US) made the system unstable and accelerated the scramble for gold by other nations which could not afford the monetary instability from holding on to silver (Meissner, 2015; Morys, 2015).[7]

The conclusion that we can retain from this review is that, in the absence of natural experiments, identification is hard to argue. Mitchener & Voth (2011) focus on the trade relations of Asian colonies precisely because they had no choice but to adopt the monetary regime imposed by their European colonisers. Consequently, the choice of exchange rate regime for colonies should reflect less the expectation of the gains from joining a common currency regime. This comes as close to a natural experiment as has been found in this literature and the authors still find a large positive trade effect for colonies that changed to gold prior to World War I.

Apart from the 'large country' status, there are two further threats to identification of causal relations in networks with traditional statistical methods. The first is the already mentioned clustering of the timings when countries joined the peg. As the majority of nations in the European core joined during a relatively short interval in the 1870s, it is not clear whether the identification in the existing regressions comes from a timing effect (e.g. a

[6]An earlier literature also tried to establish a link between gold adoption and lower spreads on international borrowing (Bordo & Rockoff, 1996). Even though this direct link has been severely qualified since (Mitchener & Weidenmier, 2015), financial openness and the choice of exchange rate regimes were certainly connected, albeit in a more nuanced way. Bordo & Flandreau (2003) explain how only financially mature nations were able to borrow in foreign currencies and retain a credible peg to gold. Financially 'immature' countries were torn between the dangers of 'original sin' and the the 'fear of floating' (Hausman et al., 2001; Calvo & Reinhart, 2002).

[7]However, Fernholz et al. (2014) develop a DSGE model of the global economy, which when calibrated to 19th century conditions, implies that silver only stopped working as a global price anchor in the 1890s.

common shock) or from the fact that other nations were close, in economic terms, to these core countries (the network externalities). Figure 3 illustrates the problem by plotting the spatial autocorrelation measure devised by Moran (1948) and applied to the exchange rate regimes in our sample of nations with export trade shares as weights.[8]

Figure 3 here.

After being insignificant, or even slightly negative, leading up to the 1870's, there is a substantial jump to high and significant positive correlation[9] during the so-called 'scramble for gold in the early 1870's, demonstrating the strength of network externalities in shaping the realignment of monetary standards. That jump in the measure of spatial autocorrelation then dissipates and reverts back to insignificant values in the 1880s, before beginning an upward movement with stronger jumps during the late 1890's, another period with a number of states moving to the gold standard.

The final threat to identification comes from the very structure of the network of nations engaged in international exchanges through trade and finance. In a network, the probability of a country establishing a link with another nation clearly depends on the existence of ties between other countries. A practical example in this context is the inclusion of the Most Favoured Nation (MFN) clause in some of the treaties, which directly conditioned trade agreements and related trade relationships on the agreements the involved countries had with third parties. This then implies that the assumption of independently drawn country dyads must be violated, as the probability of a tie change is endogenous to the the current structure of the *whole* network. It is to try and address this issue that we turn to the methods of empirical network analysis, described in the next section.

3. Method

The SIENA, Simulation Investigation for Empirical Network Analysis, methodology has been recently developed by Steglich et al. (2010) to address situations of endogeneity involving network structures between actors. The main idea is to simulate the co-evolution of network and behaviour over

[8]If weights are defined by geographic proximity as in contiguity or by binary trade relations, either trade partnerships or treaty arrangements, the patterns do differ somewhat.

[9]The coefficient is bounded between -1 (perfect negative spatial autocorrelation) and +1 (perfect positive spatial autocorrelation). The dashed lines in Figure 3 represent the confidence interval of the coefficient.

time and use this to conduct statistical analysis of repeated observations of networks according to the Stochastic Actor-oriented Model.[10]

We estimate the model with a routine written for R, RSiena, which uses a method-of-moments procedure operationalized through repeated computer simulation to perform estimation. The basic starting point is to incorporate a wide range of mechanisms into the formation and development of the network structure to identify their respective effects onto tie formation and dissolution. This is expanded by incorporating behaviour changes, i.e. specific actor characteristics, to the set-up which adds a potential mutual dependence between ties and behaviour. To address this endogeneity problem the approach shifts the conceptual model from treating the observations over time as a series of discrete choices to a continuous process whose state is observed at specific time points. The network and each actor's behaviour are therefore taken as evolving continuously over each time period, and their simultaneous modelling allows to account for mutual dependencies and multiple changes between the points in time at which the states of the network and the behaviour are observed. An important restriction of this method, at the moment, is that it can only deal with count ordered variables for behaviour and binary definitions of the network. So long as the behaviour under investigation can be ranked, the first issue is not a great limitation. In our case, we will work with a ranked definition of exchange rate stability to define behaviour as the choice of exchange rate regime (see Figure 2). The definition of the binary trade links will be more restrictive, as discussed below in section 4.

Structurally, the modelling of mechanisms includes actor, dyadic and network structure effects. The first are based on particular characteristics of the actors, e.g. GDP in the context of countries as actors, which makes them equivalent to regular explanatory variables in a standard regression set-up. Dyadic effects are based on characteristics and covariates of pairs of actors. These can be direct tie variables, for example distance between two countries, or interacted actor variables, as the ratio of two countries' GDP. These links between actors can be ordered and directed, consequently allowing these dyadic effects to be potentially asymmetric. Finally, network structure covariates state the structural position of each actor within the network, for example the number of countries one is linked to.

Changes in the network as well as the behavioural status of individual actors are modelled as the outcome of a two-step process comprising two

[10] The description in this section is closely based on the exposition in Manger & Pickup (2016) as well as in the underlying works of Steglich et al. (2010) and Snijders et al. (2010).

sub-processes; the first process governs when the possibility to change the network or behaviour arises for an actor, while the second then determines whether an actual change happens, once the opportunity arises. The first is governed by a rate function while the second is determined by an objective function. The rate function is similar to a hazard rate function in a survival analysis set-up and determines the probability that the actor can make a change at any given point in time. Once the possibility of a change arises the objective function determines whether a change increases the utility of the actor and will consequently be implemented. There are separate rate functions for network and behaviour, which are assumed independent from each other, such that the opportunity to change a behaviour will never arise at exactly the same moment as the opportunity to change the network.

Formally, the rate functions, which determine the waiting times until the next opportunity for change, are modelled by an exponential process with the following density function:

$$g_i(t) = \lambda e^{-\lambda t}, t > 0 \tag{1}$$

where $\lambda = \sum_i(\lambda_i^Z + \lambda_i^X)$ with λ_i^Z and λ_i^X as actor-specific (and possibly period-specific) parameters for the behaviour rate and network rate functions, respectively. This formulation implies that the probability that the next possible change actor i can make is a behavioural one is λ_i^Z/λ, and for a tie change λ_i^X/λ.

Once an actor gets an opportunity to make a change, the respective objective function determines which change (if any) maximizes the utility of the actor.[11] Starting from the current network structure, the actor has three possible actions with respect to each other actor in the network: initiate a new tie, dissolve an existing tie or retain the existing network without making a change. If there are n actors this then implies n possible actions consisting of changes in $(n-1)$ ties to other actors plus the retention of the existing structure. Formally, the network objective function, which includes the mechanisms modelled with network structure, actor and dyadic covariates, is given by:

$$f_i^X(\beta, \mathbf{x}, \mathbf{z}) = \sum_{\mathbf{k=1}}^{\mathbf{m_1}} \beta_k^X \mathbf{s}_{ik}^X(\mathbf{x}, \mathbf{z}) \tag{2}$$

Following generalized linear statistical models, this function is assumed to be a linear combination of a set of *effects*, $s_{ik}^X(\mathbf{x}, \mathbf{z})$, which are functions defined on the state of the network and behavioural variables. Particular examples

[11] Consequently, the objective function in each case takes the state of the network or the behavioural values as given.

will be discussed in a later section. Statistical parameters β_k represent the importance of the respective effects so $f_i^X(\beta, \mathbf{x}, \mathbf{z})$ is the value of the objective function for actor i depending on the states $\mathbf{x}$ of the network and $\mathbf{z}$ of the behavioural variables.

Similarly to a multinomial logistic regression, this allows to calculate the probability of any single tie change shifting the network status from $\mathbf{x}$ to $\mathbf{x}'$. Given the parameters of the objective functions this probability is:[12]

$$P(x) = \frac{exp(f_i^X(\beta, \mathbf{x}', \mathbf{z})}{\sum_{x' \in C} exp(f_i^X(\beta, \mathbf{x}', \mathbf{z})} \tag{3}$$

In the case of a potential change in behaviour, the actor has three choices, namely increase, decrease or retain the value. As the behavioural variable is required to be discrete, the potential increase or decrease is limited to exactly one step up or down. This restriction to a single step change is similar to the restriction to a single tie change in the case of the network structure. Furthermore, the behaviour objective function is also similar in structure to its network counterpart:

$$f_i^Z(\beta, \mathbf{x}, \mathbf{z}) = \sum_{\mathbf{k=1}}^{\mathbf{m_2}} \beta_k^Z \mathbf{s}_{ik}^Z(\mathbf{x}, \mathbf{z}) \tag{4}$$

Indeed, it is possible that the s_{ik}^Z are the same as those in the network objective function, but this implies that the same effects and covariates drive the change in network ties and behaviour values. This is clearly not a reasonable assumption, so the two sets of effects will normally differ between the objective functions. Although the included effects differ, the probability for a particular change is formulated in the same way:

$$P(z) = \frac{exp(f_i^Z(\beta, \mathbf{x}, \mathbf{z}')}{\sum_{z' \in C} exp(f_i^Z(\beta, \mathbf{x}, \mathbf{z}')} \tag{5}$$

These functions are used in the simulation algorithm to execute the estimation. The idea is to sample parameter values with the goal of matching the characteristics of the simulated networks with those of the actual observed network. This estimation utilizes a Method of Moments approach, although a Maximum Likelihood as well as Bayesian alternative are also feasible. The

[12] C is the set of all $n-1$ possible tie changes. This probability is defined for a directed network with a behavioural variable so tie x_{ij} can take the value 1 while x_{ji} is 0 (and vice versa). There are a number of possibilities to force the symmetry between x_{ij} and x_{ji} such that the network is undirected and ties are simple links between two actors.

algorithm converges to an estimate for each parameter value and associated standard error as well as a t-statistic for its convergence.[13]

The sign of the parameter values and the standard error indicate the direction of the effect of the associated mechanism as well as its statistical significance. The estimated parameters for each effect should be interpreted as log-odds ratios. The explanatory covariate variables are centred on their mean, so if they are held at this rate, the parameter estimates give the effect of an one-unit change in the mechanisms on the probability of an increase (or decrease) in the network (i.e. the number of ties) or of the behavioural value.

The intention behind the application of this methodology is to disentangle the mutual feedback between network structure and behaviour variables. We will use the empirical network methodology to study the relation between trade links and monetary regime change described in the previous section. As already mentioned, the issue here is that countries that share the same monetary regime (e.g. the gold standard) are likely to trade more, what is usually referred to as a *degree* effect; but, at the same time, a country more involved in international trade may be more likely to adopt the gold standard (a *selection* effect), especially if it trades with countries already on gold (an *influence* or *contagion* effect). The incorporation of specific mechanisms involving the network, behaviour, and additional external factors is designed to clarify the structure of the influence in each direction. It does not, however, guarantee that the estimation results are causal in the face of the underlying endogeneity problem. Nevertheless, it is indeed possible to interpret the results causally under a relatively mild set of assumptions about the nature and timing of the evolution of network and behaviour, which should be easily fulfilled in our case. They are:

- The observed network and behaviour are the outcomes of an underlying Markov process in continuous time. This is reasonable to assume as transition probabilities between states of the network (trade) or behaviour (monetary regimes) should depend on the starting state.

- The actors act independently of each other at any moment, conditional on the observed network, behaviour and covariates. This requires that there are no coordinated (simultaneous) changes in the network or behaviour by two or more actors.[14] Although not strictly impossible, this

[13] The latter provides a check whether the simulated values converged sufficiently close to the observed network values.

[14] The requirement of a reciprocal agreement to form a tie does not violate this assumption.

kind of joint action by two or more nations has little historical relevance. Indeed, as described in section 2, nations did not coordinate their choices of trade partners or of exchange rate regimes, despite all the effort of the several international monetary conferences gathered in the second half of the nineteenth century.

- The changes in the network are conditionally independent from the changes in behaviour, which implies that there cannot be simultaneous changes in network ties and actor behaviour. This is more disputable, but it should be noted that the models are based on continuous time, so we do not make much harm to reality by assuming this condition.

- At any given time only one single tie can be changed and similarly behaviour can only be increased or decreased by one unit. This is also not a restrictive condition for the same reason. To wit: it does not preclude the possibility of a country changing its monetary standard by more than one level or creating or cancelling trade relations with more than one nation, since the rate functions are defined in continuous time, while we observe the left- and right-hand side variables only at annual frequency.

The particular nature of our research questions fits well within the described set-up of the methodology, including the assumptions required for causality. Trade relations provide a natural network structure between actors (countries). In this paper we characterise trade in two ways, as the network of formal trade treaties and as bilateral trade flows. The first variable implies a non-directed network since, by definition, trade treaties are a reciprocal tie between two nations. For the purpose of the second network, we measure trade as exports from one country to each of its trading partners, a directed network.The behaviour variable in our model is the choice of exchange rate regimes. This is coded as a count variable, and the panel nature of the data provides repeated observations of the evolving network and behaviour.

4. Estimation

4.1. Data

We run our model for a sample of 31 independent nations over 51 years (1860-1911). This long panel is not balanced because some countries only enter the analysis at independence. We concentrate exclusively on sovereigns because the model assumes that actors have autonomy to act in accordance with their own national interest. The full list of nations and their inclusion dates are listed on Table 1.

Table 1 here.

We do not run the model at a yearly frequency because there is a trade-off between precision of estimates and frequency of data. Similarly to a regression, if the left-hand side variable has small variance the model will not have a good fit. To increase the variance of trade link changes and monetary regime changes, we ran the model with triennial observations (17 time periods). Our model includes four dependent variables. The first is the exchange rate regime adopted by each country and, in particular, whether it joined the gold standard (behaviour). We then include three network variables: whether each pair of countries is connected by a trade agreement (Treaty), whether there is an actual trade flow from one country to the other (Partner) and whether one country is a major export destination for the other as measured in the export share (Major Partner).

The inclusion of two definitions of trade networks serves two purposes. First, it allows quantifying the relative strength of formal trade ties and actual trade flows in influencing the choice of exchange rate regimes. Second, it provides a natural testing ground for the mutual relation between trade agreements and actual trade. In particular, we will be able to test whether trade treaties created trade or, as argued in the recent literature, the wave of trade agreements in the 1860s came after the majority of unilateral trade liberalisation had been accomplished (Accominotti & Flandreau, 2008; Tena et al., 2012).

We classify the exchange rate arrangements into four possible values: paper currencies (without a formal metallic backing), silver standards, bimetallic standards and gold standards. We then coded these four regimes into our behavioural variable, which is ordinal and takes values increasing in the degree of exchange rate stability: 1 for paper regimes, 2 for silver, 3 for bimetallic and 4 for gold. The underlying classification was done by the authors based on the following sources: Accominotti et al. (2011), Bae & Bailey (2003), Esteves (2007), Ferguson & Schularick (2006), Leavens (1939), Meissner (2005), Pick & Sédillot (1971), Vv.Aa. (2014), and Young (1925). Even though this ordering of exchange rate stability is time-varying (see Figure 2) and depends on country idiosyncratic characteristics (e.g. frequency of real shocks), we believe that it gives a good representation of the order of monetary choices facing countries in the 19th century, especially after the

1870s.[15] Moreover, we also ran the model with a tripartite classification of exchange rate regimes (paper – silver or bimetallism – gold) and the results were very similar.

The information on the treaty agreements network comes from Robert Pahre's trade agreement database, which covers the full time period (Pahre, 2007). It contains treaties between sovereign nations which directly concern trade arrangements between the two involved countries. The range of matters addressed in these treaties is fairly wide, ranging from shipping rights, small import concessions, most-favoured nation arrangements to free trade treaties. In turning the data set into the variables used in the network part of our model, we make two simplifying, related assumptions. First, we only record whether a trade treaty was in force between two states, the actual content does not influence the coding of the binary variable. Second, we also do not distinguish whether the treaty was an arrangement clearly benefiting both sides or whether it was just one side making concessions. This implies that we do not distinguish between regular trade treaties among mutually consenting nations and the so-called 'unequal treaties' that were imposed on a number of developing and emerging nations in the course of the 19th century (Findlay & O'Rourke, 2007).

The data on actual trade flows comes from two large repositories of bilateral trade flows: the RICardo and the TRADHIST databases (Dedinger & Girard, 2016; Fouquin & Hugot, 2016).[16] Coding these trade flows into networks of dyadic relations also involved a restriction on the use of the original data. Since the model requires that the network links be entered as binary values (link, no link), we censored the data on exports to only cover trade relations that cleared a certain threshold of trade intensity. For the Partner network this threshold was set at 0.5% of the origin country's exports. This means that we only code a trade link from country A to country B in a given year, if A sells to B at least 0.5% of its exports on that year. The threshold was not arbitrarily fixed, but corresponds to the median of bilateral trade shares in our database. As is well known, the distribution of trade shares is very skewed to the right, so that in setting such a low bar we are effectively

[15]The retention of bimetallism by large countries until then effectively stabilised the gold/silver price ratio minimising the destabilising impact of large gold or silver discoveries according to Gresham's law. After 1872, the double shock of widespread demonetisation of silver and large silver discoveries, which quadrupled world production, meant that holding on to a silver standard implied a systematic tendency toward currency depreciation accompanied by greater exchange rate volatility.

[16]Available at, respectively, http://ricardo.medialab.sciences-po.fr/#/ and http://www.cepii.fr/cepii/en/bdd_modele/presentation.asp?id=32.

capturing the extensive margin of trade, rather than its intensive margin.[17] For the Major partner network the threshold was set at 5%, representing a trade-off between focusing on destinations that clearly dominate a country's export structure and capturing more movements across the threshold as a representation of changes in the intensive trade margin.

As the dependent variables, the covariates can be in two forms, either using dyadic data resembling network ties or monadic (country-specific) data. Dyadic variables include time-invariant geographic factors, in particular the distance between two countries and whether they are contiguous to each other. Distance is measured as the distance in kilometres between (modern) capitals and is taken from the CEPII's GeoDist database (Mayer & Zignano, 2011). Contiguity is a binary indicator based on the classification by the Correlates of War project (Stinnet et al., 2002). Another time-invariant dyadic covariate is based on the languages spoken in each country pair. The variable is coded as one if both countries have the same official language, and zero if not from the data in in the CEPII's language dataset (Melitz & Toubal, 2012). The final two dyadic covariates are time-variant binary indicators for whether two countries were in a formal political alliance or were at war with each other, as coded by the Correlates of War project (Sarkees & Wayman, 2010; Gibler, 2009).

The monadic variables include time-variant country characteristics as well as common time effects.[18] Our choice of variables is driven by the several drivers of monetary unification during the 19th century identified in section 2. To capture long-term structural forces[19] we include real GDP per capita taken from Barro & Ursúa (2008) and other sources.

Among the proximate drivers of gold adoption, we include a measure of the fiscal space of individual governments and the annual global production of gold (a time effect). The fiscal variable controlling for the 'fiscal maturity' of each nation is the share of external debt (or debt repayable in FX) in

[17] The Hirschman-Herfindhal index of bilateral trade shares averages 0.297, with a minimum of 0.076 (Great Britain) and a maximum of 0.81 (Honduras). Alternatively, the top ten trade partners absorbed on average 97% of all exports of each nation, with a minimum of 75% in the case of Britain, the country with most diversified trade network in this period.

[18] To estimate a common effect we need to drop at least one country-period observation. We chose to do drop Cuba and Bulgaria.

[19] In robustness checks we also include levels of industrialisation and urbanisation in each country.Information about the level of industrialisation is incorporated by including the share of secondary sector employment as given by Banks (1976). The degree of urbanisation is measured as the share of the total population living in cities above 100,000 also from Banks (1976).

the total debt stock of each country. The data on these variables[20] were compiled by the authors. Finally, we also include the number of external disputes a country was involved in as a control variable for political and exogenous threat factors [21]. The data is taken from the Correlates of War project. Table 2 lists the summary statistics for all left- and right-hand side variables included in the model.

Table 2 here.

4.2. Specification

We now incorporate the variables described in the previous section into a number of mechanisms, which then constitute eight separate functions. For each of the outcomes (three trade networks and monetary standard), we estimate two functions: one rate function determining the opportunity to make a change in the respective outcome and the objective function, which determines which change (if at all) should be made when the opportunity arises.

4.2.1. Monetary Standard

The *rate function* for changes to the monetary standard contains the basic setup of any rate function, namely, a constant for each period between observations. As we did not include any further mechanisms in the rate function, the estimates for the time-varying rate represent the expected number of opportunities for changing the monetary standard during the respective time period. We will not report the estimate of this parameter λ^Z, because it does not have a natural economic interpretation.

The *objective function* underlies the decision once the opportunity to make a change to the monetary standard arises. The options are the retention of the existing standard, a change 'up' and a change 'down'. Up and down refer to the ordering of the different standards, from paper (1) to silver (2), bimetallism (3) and gold (4). If, e.g., a country is on a silver standard, the options are to retain that standard, move 'up' to bimetallism or 'down' to a paper standard.

[20]In robustness checks we also used the ratio between debt service payments and total government revenue as well as the ratio of the market prices of gold and silver (a time effect). The first was compiled by the authors while he market prices of gold and silver bullion in London were taken from Officer & Williamson (2016) and NBER (n.d.).

[21]In a robustness check we also control for the political system as proxied by the PolityIV score (Marshall et al., 2014). We include this variable to control for the political economy theories about the adoption of gold, particularly the prevalence of restricted franchises in the prewar (Eichengreen, 1992)

We include two types of mechanisms in the objective function. The first type of mechanisms combines the existing trade and the monetary standards of each nation's trade partners. We include two effects of this type, the first of which measures the average monetary regime of trade partners weighted by the respective trade share. The second effect focuses more directly on the impact of large export destinations as it measures the lowest monetary regime of all major trade partners.

These two effects are our main variables of interest in the behavioural side of the model, as they test whether trade links were influencing countries to change their monetary standards based on those of their trading partners. The third type of mechanisms includes the country-specific monadic variables: *GDP*, the *number of disputes*, and the *foreign debt share* as well as a common time effect: the *global gold production*.

4.2.2. Trade Networks

The rate functions of each of the three trade networks incorporate the same period effects as the monetary standard and yields a parameter λ^X, which we do not report.

The objective function expresses three options for change (given the chance), namely, to retain the existing network, to add one link with another country or to sever an existing one. In total this adds up to 31 possible actions consisting of retaining the status quo and changing one of the 30 dyads with other countries. We include four types of mechanisms in this function. The first type is again based on the outcome itself, and includes four effects. The first is the *degree* of involvement in the network, i.e the number of trade agreements or trade links a country has in force at the time. The second, only present in the trade flows network, tests for the impact of *reciprocity* in trade flows, i.e. whether countries tend to establish bilateral ties when a unilateral trade tie already exists. The third effect is whether changes in the number of *indirect trade partners*, countries that are only linked through a third country, matter for signing a further trade treaty with or exporting goods to an additional nation (or for dissolving a treaty / reducing exports) . The fourth effect tests for network closure. Practically, this mechanism tests whether a country is more (or less) likely to open up a trade link (or sign a treaty) with another country if the two are already connected through a common third country. If these *Transitive triads* were inferior to direct links we would expect this effect to have a positive impact on the establishment of direct trade connections.

The second type of mechanisms is based on the monetary standards of other countries, our main variables of interest, in combination with a country's current standard. The first of four effects in this category tests whether the *monetary system (domestic)* of each nation matters absolutely, i.e. whether a country is more (or less) likely to establish a trade link with another nation if it has a 'higher' monetary standard. The second effect tests whether the difference between two *monetary systems (difference partner - domestic)*, i.e. it tests whether a nation's trade network is influenced by the relative currency arrangements of its potential trade partners. The third effect is very similar to the second, but tests whether the absolute value of the difference between the two *monetary systems* ($|partner - domestic|$) matter. Similarly, the fourth effect interacts the plain difference with the country's own standard, *monetary system domestic*(difference partner - domestic)*, to test whether the effect of the difference is contingent on the current arrangement.

The third type of mechanism tests for the reciprocal effect of pre-existing trade flows on the likelihood of establishing new trade agreements and of trade agreements on the likelihood of starting to trade with the signatories or to elevate a destination country to a major partner. As mentioned, recent literature has found more evidence of the former effect (trade leads to treaties) than of the latter. As the impact of treaties might not symmetric, we split the mechanism into two parts, one testing whether treaties affect the likelihood of a new trade link or elevation of an existing link and the other testing whether a treaty affects the likelihood that an existing trade link gets dissolved or reduced.

Finally, we include as fourth class of mechanisms, the direct effect of dyad-specific covariates: *contiguity* between each pair of countries, *distance*, common *language* and whether the countries were part of a political *alliance* or were at *war*.

5. Results

Table 3 provides the estimates of each mechanism included in the objective functions. The results for the mechanism parameters of the three objective functions can be interpreted similarly to the coefficients resulting from a logistic regression. In the case of the behaviour objective function, the exponentiated coefficients define the multiplicative increase in the probability of 'moving up' one level in the order of monetary regimes given a one-unit increase in the respective covariate.

Table 3 here.

Starting with the factors shaping the evolution of the monetary system the pattern of results for the impact of the two network-based mechanisms is interesting. The average monetary regime of all trade destinations, weighted by the respective export share, has a noticeable, statistically significant, positive impact on a country's likelihood to move towards a higher monetary standard. The move of another country, which receives 10% of a country's exports, from silver to gold increases the likelihood for the origin country to increase its monetary standard by 9.7%, similarly if that same country drops from gold down to paper the likelihood of a down-shift is 24.2% higher. The effect of the lowest monetary regime of major trade partners is statistically not significant, any such effect likely already caught be through trade share weighting of the average regime effect.

The included monadic covariates have a statistically significant influence on the odds of changing monetary standards.The share of debt held abroad has a strong negative influence, shifting countries from gold towards silver and paper. To put this estimate in perspective, a one standard deviation increase in the foreign debt share (69 percentage points, see Table 2) makes the retention of the existing standard 62.1% less likely than a down-shift of the monetary standard. Any dispute a country was involved made an upward shift 22% less likely than just retaining the status quo. Finally, wealthier nations rushed faster toward gold. A one standard deviation increase in per capita GDP made an upward shift in monetary regimes about 2.1 times more likely than a retention or downward shift, similar a 10% growth starting from sample mean increases the likelihood by 12.3%.

The estimated parameters for the objective function underlying the three trade networks similarly compare the relative probabilities for no change in the network with the addition (or removal) of a particular network tie.[22]

Starting with the trade agreements network, the negative degree effect indicates that the more trade treaties a country has in force, the less likely it is to add another one. The positive effect of the 'transitive triads' mechanism however implies that the probability of adding a particular tie increases by 35% if that tie creates a triad, i.e. if the two countries have already existing trade treaties with a common third country. A similar effect is evident in the third effect: countries are more likely to seek a trade agreement with nations that have more trade partners, with each additional partner adding 15% . This effect is consistent with the logic of MFN clauses, the more concessions a country makes towards third countries the more interesting as a treaty partner the country becomes. While there is no statistically significant direct

[22]It is consequently also feasible to compare the relative probabilities between two potential ties or any other combination of two changes of the network involving a single modification.

effect of contiguity the effect of distance is consistent with standard gravity arguments. The relative probability of adding a particular tie increases if the countries were geographically closer. Sharing the same language, political alliances as well as war seemingly had no significant impact, with the somewhat surprising non-effect of the last one likely due to the very low incidence of open warfare between the included countries in the sample. As expected the total GDP of potential trade treaty partners mattered positively, again following the logic of the gravity literature. Comparing two otherwise identical potential trade partners with a one standard deviation difference in GDP implies a 51.5% higher likelihood for starting to export to the country with the larger GDP than entering the market of the smaller one.

The final group of mechanisms involves the other outcome variables including the monetary standard of of the potential partners as well as existing trade relationships. Apparently, the monetary standard of potential signatories did not matter nor did any pre-existing trade relationships,even major ones. As other authors have shown, trade liberalisation through treaties is an imperfect predictor of trade growth before 1913 (Accominotti & Flandreau, 2008; Tena et al., 2012), consequently the insignificance of monetary regimes and pre-existing trade relationships is not completely unexpected.

In the trade partner networks the regular covariates show significance and direction mostly according to expectation. Contiguity now matters strongly with an effect size of 65% respective 126%, as does distance again. Language appears to have had a positive effect on the intensive, but not extensive, margin, Political alliances seemingly had no significant impact. Following the predictions of the gravity framework, the size of a trade partner in terms of GDP mattered strongly along both margins, increasing not only the likelihood that a country exported to that particular market, but also the extent of that trade relationship. The degree effect is again negative, consistent with the stylized fact that international trade networks tend to be concentrated in relatively small number of partners. Moreover, there is a strong effect of reciprocal trade flows, suggesting that most nations were not able to retain unbalanced trade relations permanently. As the reciprocity effect is substantial stronger for the existence of trade in both directions (471%) than for the status as major trade partner (33%) it appears to have been substantially easier to maintain an unbalanced trade relationship along the intensive margin rather than the extensive one. This difference is also visible for the effect of transitive triads, which is positive for basic trade relationships but insignificant for major partner status. Similar to trade treaties the pre-existing relationship with a third country matters whether a country enters a new market with an effect size of 11%, but not so much for the intensity of the relationship. In contrast to the effect on trade treaties, the number of trade partners of a potential new export destination does not affect the likelihood to enter that particular market.

The impact of monetary standards on trade relationships affected the extensive margin but not intensive one. The decision to enter a particular market seemingly was independent of its own monetary standard as well as that of the potential decision. The intensive margin however was influenced, similar to the effects of the gold standard on trade flows found in the gravity literature. The found pattern, shown in table 4, however is not as straightforward. The results for countries on the Gold standard show that they are more likely to be major trade destinations than comparable countries on any of the other three standards, likely catching a wealth effect not fully captured by destination GDP. Countries on the gold standard may be more likely to be destinations, but they are also less likely to have major trade partners as the relative effect size for any potential destination country is lower than if the country were on a different monetary regime. As these countries were more likely to be more developed they also had a more diversified geographic trade pattern with a lower number of export trade shares above the 5% threshold. The pattern becomes more puzzling for countries either on silver or a bimetallic standard. Major trade partners are more likely, relatively speaking, to be either on gold or on a paper standard.

The results for the impact of trade treaties on trade flows are mostly in line with the existing literature on 19th century trade liberalisation, as there is no significant effect on the extensive margin and the likelihood to trade with another country (Accominotti & Flandreau, 2008; Tena et al., 2012). The impact of treaties on the intensive margin, in this case having an export share over the 5% threshold, shows a split impact. While there is no effect of a trade treaty on lifting the export share above the threshold, there is evidence that treaties reduced the likelihood that an above the threshold share falls below it. The effect size is substantial, indicating a 60% higher likelihood to retain that major trade partner status. Treaties apparently did not lead to more trade, but solidified existing trade relationships.

6. Conclusion

The importance of strategic externalities in the network of currencies in the gold standard has been established in the literature (Flandreau & Jost, 2009). This paper introduces a novel methodology to identify the nexus of externalities between trade links and exchange rate regime choices during the rise of the classical gold standard. Dynamic network models are a natural setting to estimate the co-evolution of networks and behaviours and allow for a causal interpretation of the mutual feedback effects under a relatively mild set of assumptions.

The evidence is suggestive of feedback effects in both direction, with monetary standards affecting the intensive margin of trade and trade flows acting as a conduit for the externalities imposed by other countries' monetary standards on the domestic regimes. The results in this paper expand on the consistent evidence from gravity studies about the large and significant effect of monetary standards (and especially gold) on trade by pointing out a more complex pattern of interactions contingent on the regimes in both origin and destination countries. Similarly it identifies the existence of spillovers from other countries' monetary regimes on a country's domestic monetary arrangements through trade flows as conduits. In network analysis these results indicate the existence of selection and contagion effects in the relationship between monetary regimes and trade relationships and point towards a more nuanced understanding of the interactions between different economic aspects of the classical gold standard period.

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Table 1: **Countries Included in Analysis**

Argentina	Colombia	Japan	Spain
Austria-Hungary	Cuba (1898)	Mexico	Sweden
Belgium	Denmark	Netherlands	Switzerland
Bolivia	France	Norway	Turkey
Brazil	Germany	Portugal	United States
Bulgaria (1879)	Great Britain	Romania (1879)	Uruguay
Canada	Greece	Russia	Venezuela
Chile	Italy (1862)	Serbia (1879)	

Table 2: **Summary Statistics**

Variable	Mean	St.Dev	Median	Min	Max
Monetary Standard	2.75	1.23	3	1	4
Treaties†	4.19	3.55	3	0	18
Trade links†	12.93	7.83	12	0	30
Contiguity	0.09	0.28	0	0	1
Distance	6.13	4.34	6.48	0.17	18.6
Language	0.10	0.30	0	0	1
War	0.01	0.10	0	0	1
Disputes	1.148	1.76	0	0	8
GDP	43.5	69.2	11.5	0.46	452
GDPpc	2.28	1.47	2.02	0.55	8.81
Foreign Debt Share	42.9	69.3	11.8	0	388
Debt Service	2.30	1.17	2.35	0.03	6.37
Gold Production	8.75	4.91	6.17	4.95	21.2

†Average over country/year observations. Note: PolityIV has been shifted by 10 to a range of 0 to 20. Urbanization and Industry are defined in 1/1000*s* so 100 equals 10%.

Table 3: **Estimation Results**

Behaviour - Money Standard	Log.odds	S.E.
Ave. Standard Partner (trade weighted)	0.925***	(0.276)
Minimum Standard Major Partner	0.075	(0.204)
GDP (per capita)	0.506***	(0.172)
Disputes	–0.248**	(0.105)
Foreign Debt	–0.014***	(0.004)
Gold Production	0.131***	(0.049)
Network - Treaties	Log.odds	S.E.
Network degree	–1.288***	(0.139)
Transitive triads	0.303***	(0.066)
Number indirect partners	0.141***	(0.049)
Contiguity	–0.029	(0.241)
Distance	–0.030*	(0.018)
Language	–0.147	(0.237)
Alliance	0.282	(0.387)
War	–0.306	(0.599)
Money (Partner)	–0.023	(0.087)
GDP (Partner)	0.004***	(0.001)
Partner trade link	0.173	(0.254)
Major Partner link	0.095	(0.355)

Table continued on next page

Table 3
continued

Network - Trade partner	Log.odds	S.E.
Network Degree	–2.197***	(0.097)
Reciprocity	1.551***	(0.077)
Transitive triplets	0.100***	(0.010)
Number indirect partners	–0.075	(0.094)
Contiguity	0.505***	(0.122)
Distance	–0.048***	(0.008)
Language	0.153	(0.103)
Alliance	0.178	(0.254)
GDP (Partner)	0.006***	(0.001)
Money (domestic)	–0.000	(0.041)
Money (difference)	0.046	(0.032)
Money (abs. diff)	0.067	(0.095)
Money (dom * diff)	0.027	(0.062)
Treaty (existing)	0.199	(0.190)
Treaty (new)	0.202	(0.142)
Network - Major partner	Log.odds	S.E.
Network Degree	–0.891***	(0.152)
Reciprocity	0.283**	(0.120)
Transitive triplets	0.050	(0.034)
Contiguity	0.814***	(0.148)
Distance	–0.013	(0.015)
Language	0.378**	(0.157)
Alliance	0.159	(0.233)
GDP (Partner)	0.006***	(0.001)
Money (domestic)	0.086	(0.066)
Money (difference)	0.284***	(0.053)
Money (abs.diff)	0.586***	(0.149)
Money (dom* diff)	0.387***	(0.095)
Treaty (existing)	0.475**	(0.215)
Treaty (new)	0.150	(0.190)

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 4: **Monetary Standard effect on Major Trade partner network**

Origin\Destination	Paper	Silver	Bimetal	Gold
Paper	0.86	1.04	1.26	1.53
Silver	1.70	0.94	1.67	2.99
Bimetal	1.54	1.25	1.02	2.69
Gold	0.65	0.77	0.93	1.11

The table shows the relative effect sizes for combination of origin country standard (rows) and destination country standard (columns).

Figure 1: **Monetary Regimes, 1850-1913**

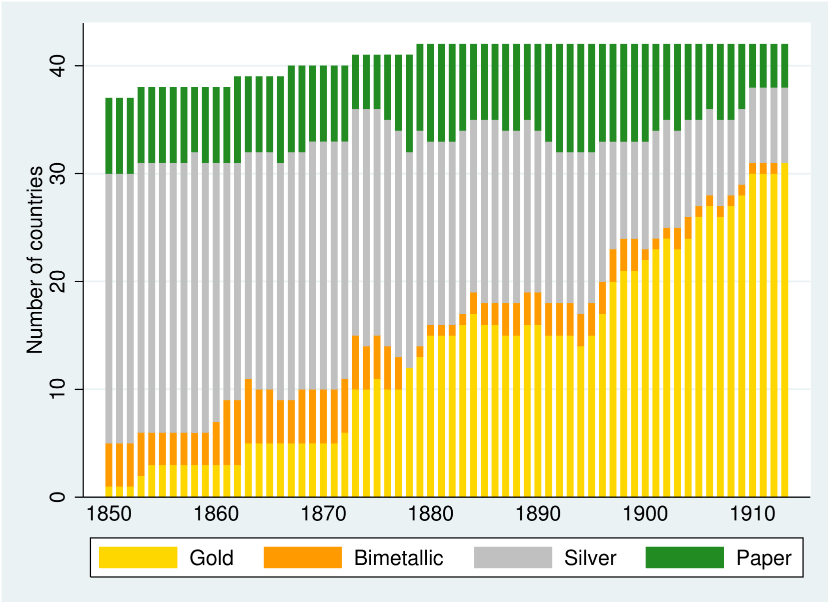

Figure 2: **Exchange Rate Volatility, 1850-1913**

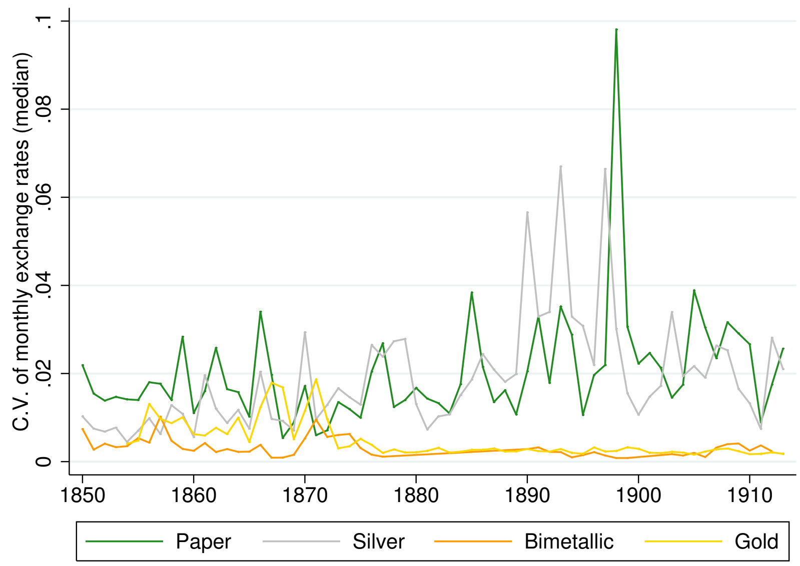

Figure 3: **Moran's I, 1860-1913**