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Transition in the waiting-time distribution of price-change events in a global socioeconomic system

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HIGHLIGHTS

- We quantify the distribution of waiting times between currency price changes.
- A gradual transition is observed between short and long waiting times.
- Longer waiting times show a power-law tail with exponent near 3.5.
- Shorter waiting times can be explained using a model of boundedly rational agents.

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ABSTRACT

The goal of developing a firmer theoretical understanding of inhomogeneous temporal processes – in particular, the waiting times in some collective dynamical system – is attracting significant interest among physicists. Quantifying the deviations between the waiting-time distribution and the distribution generated by a random process may help unravel the feedback mechanisms that drive the underlying dynamics. We analyze the waiting-time distributions of high-frequency foreign exchange data for the best executable bid–ask prices across all major currencies. We find that the lognormal distribution yields a good overall fit for the waiting-time distribution between currency rate changes if both short and long waiting times are included. If we restrict our study to long waiting times, each currency pair's distribution is consistent with a power-law tail with exponent near to 3.5. However, for short waiting times, the overall distribution resembles one generated by an archetypal complex systems model in which boundedly rational agents compete for limited resources. Our findings suggest that a gradual transition arises in trading behavior between a fast regime in which traders act in a boundedly rational way and a slower one in which traders' decisions are driven by generic feedback mechanisms across multiple timescales and hence produce similar power-law tails irrespective of currency type.

1. Introduction

From human communications and conflicts to protein production, a wealth of studies has recently appeared in the physics literature concerning the underlying dynamics of complex processes across the biological and socioeconomic sciences [1–8]. The task of developing a theory for the timing of events in socioeconomic systems is a particularly daunting one, since

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inherent feedback processes operate across multiple timescales; yet it is precisely this complexity in time which makes the problem such an attractive one for the statistical physics community, and one in which the statistical physicist's toolbox may prove useful in practice. Indeed, many important everyday problems can be reduced to predicting the timing of the next event in a series of such events. This situation is particularly acute in the world's global markets, since a decision to buy or sell can rapidly turn bad if the collective action of the other market participants produces an unfavorable price change either before or during the fulfillment of the trade.

Here, we pursue this physics-driven goal of developing a mechanistic understanding of intermittent collective processes, by focusing on arguably the world's largest socioeconomic system—the foreign exchange (FX) market [1,2,9,10]. This market handles an average daily trading volume of over four trillion US dollars. Moreover, it is a decentralized market in which financial centers around the world act as trading hubs for the buying and selling of currencies, with continuous operation from 20:15 Greenwich Mean Time (GMT) on Sunday until 22:00 GMT Friday [11]. The FX market consists of a diverse collection of buyers and sellers: diverse both in trading behavior and geographic location. It is their collective activity which determines the relative value of currencies at any point in time [1,9,2,10]. We specifically investigate the time between price changes across multiple currencies. This is an easily measurable characteristic of a price series. Furthermore, being able to accurately model such a variable has significant practical value. Any trader who has placed a resting order at the best price has a dilemma: Should they cancel their resting order and aggress the resting liquidity on the opposite side of the book? If they do so, they incur a known transaction cost; if they do not, their resting order may be filled (resulting in a zero transaction cost) but the price may also move against them—potentially resulting in a significantly greater transaction cost. The respective merits of the two options will be strongly influenced by how long the trader believes it will be until the best price changes. A better understanding of the characteristics of this waiting-time distribution would enable this decision to be better informed.

In addition to the practical interest in this particular question within the finance industry, and the rapidly growing interest within the physics community concerning waiting times in collective processes, other applications include manufacturing where the distribution of failure times has proved to be an important risk control tool [12]. In particular, fat-tailed distributions can give rise to large fluctuations in the waiting time which exceed the mean value by many standard deviations. However, modeling the fine-grained details of human trading systems poses significant problems. There are strong and poorly understood feedback effects inherent in the system, since each decision to place or cancel an order by one market participant can influence the future behavior of all other market participants. This complex feedback remains only partially understood, both within physics and in the wider finance community. As a result, accurate models for the microstructure of such markets have so far eluded researchers. (See Ref. [13] for a detailed review.) However, there is still significant value in a model which, while known to be imperfect, is a quantitatively reasonable approximation to reality—particularly if this model is mathematically tractable. Clearly, how good a model needs to be will depend upon what the model will be used for. For example, those engaged in ultra-high-frequency trading will need to have a more sophisticated and in-depth understanding of the complex feedback mechanisms between orders placed within milliseconds of each other than will a trader who places orders at a much lower frequency.

Pinning down the precise form of the waiting-time distribution for different currencies requires reliable trading data on a fine-grained timescale. This is made difficult by the fact that the 'price' shown in commercially supplied data may actually be a hybrid of quoted prices, instead of something truly representative of supply and demand, such as best bid–ask executable prices. Here, we avoid this issue using a unique dataset of best bid–ask executable prices on a second-by-second scale for all the major currencies, captured by the global FX trading desk at HSBC Bank, which is one of the world's largest FX trading institutions. We consider three commonly suggested waiting-time distributions: the exponential distribution, the Weibull distribution, and the lognormal distribution. Of these candidates, the lognormal distribution gives the best fit to the observed data. By contrast, if we restrict our study to longer waiting times, the distribution is well described statistically by a power law, with each currency pair exhibiting a power-law exponent α which is clustered around 3.5. For the regime of short waiting times up to approximately 11 s, the waiting-time distribution takes on a different form, which can be reproduced by a modified version of Arthur's El Farol bar problem, an archetypal complex systems model in which boundedly rational agents compete for limited resources [14]. Taken overall, our findings suggest that there is a crossover in trading behavior between the scale of a few seconds and the scale of minutes and beyond. We speculate that this crossover accompanies a transition between the fast second-to-second regime in which traders act in a boundedly rational way (hence generating El Farol-like dynamics [14]), and a slower regime in which feedback drives more considered decisions across multiple timescales (hence generating a power law).

Our paper is structured as follows. Section 2 briefly reviews the literature related to financial market activity and the waiting-time distribution, while Section 3 describes the source of our data. Section 4 briefly discusses the statistical methods and corresponding models adopted in the paper, while Section 5 provides the results of the distribution fitting process and the statistical tests. Section 6 introduces a multi-agent model which mimics the market dynamics for short waiting times. Section 7 provides concluding remarks and a perspective for future work.

2. Background

There have been a number of studies looking at the statistics of different types of waiting time in financial data [10,6–8,15]. For example, the waiting time between two consecutive transactions of bond futures traded at LIFFE (London