Rise of the Machines: Algorithmic Trading in the Foreign Exchange Market

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Executive Summary

The use of algorithmic trading (AT), where computers monitor markets and manage the trading process at high frequency, has become common in major financial markets in recent years, beginning in the U.S. equity market in the 1990s. Since the introduction of algorithmic trading, there has been widespread interest in understanding the potential impact it may have on market dynamics, particularly recently following several trading disturbances in the equity market blamed on computer-driven trading. While some have highlighted the potential for more efficient price discovery, others have expressed concern that it may lead to higher adverse selection costs and excess volatility. In our study, we analyze the effect algorithmic ("computer") trades and non-algorithmic ("human") trades have on the informational efficiency of foreign exchange prices. In particular, we look at two distinct aspects of (in-)efficiency in the foreign exchange market: triangular arbitrage opportunities and "excess" volatility in high-frequency returns.

We rely on a novel data set consisting of several years (September 2003 to December 2007) of minute-by-minute trading data from Electronic Broking Services (EBS) in three currency pairs: the euro-dollar, dollar-yen, and euro-yen. The data represent a large share of spot interdealer transactions across the globe in these exchange rates, with EBS widely considered to be the primary site of price discovery in these currency pairs during our sample period. A crucial feature of the data is that, on a minute-by-minute frequency, the volume and direction of human and computer trades are explicitly identified, allowing us to measure their respective impacts at high frequency. Another useful feature of the data is that it spans the introduction and rapid growth of algorithmic trading in an important market where it had not been previously allowed. Figure 1 below illustrates the rapid rise in algorithmic trading on EBS in the three currency pairs that we analyse.

The theoretical literature highlights two main differences between computer and human traders. First, computers are faster than humans, both in processing information and in acting on that information. Second, there is the potential for higher correlation in computers' trading actions than in those of humans, as computers need to be pre-programmed and may react similarly to a given signal. There is no agreement, however, on the impact that these features of algorithmic trading may have on the price discovery process.

Some theoretical studies argue that the speed advantage of algorithmic traders over humans -- specifically their ability to react more quickly to public information -- should have a positive effect on the informativeness of prices: Once price inefficiencies arise, AT quickly makes them disappear by trading on posted quotes. Importantly, however, in this case algorithmic trades are a source of adverse selection for those who provide liquidity. In addition, one could also advance that better informed algorithmic traders who specialize in *providing* liquidity make prices more informationally efficient by posting quotes that reflect new information quickly, thus preventing arbitrage opportunities from occurring in the first place.

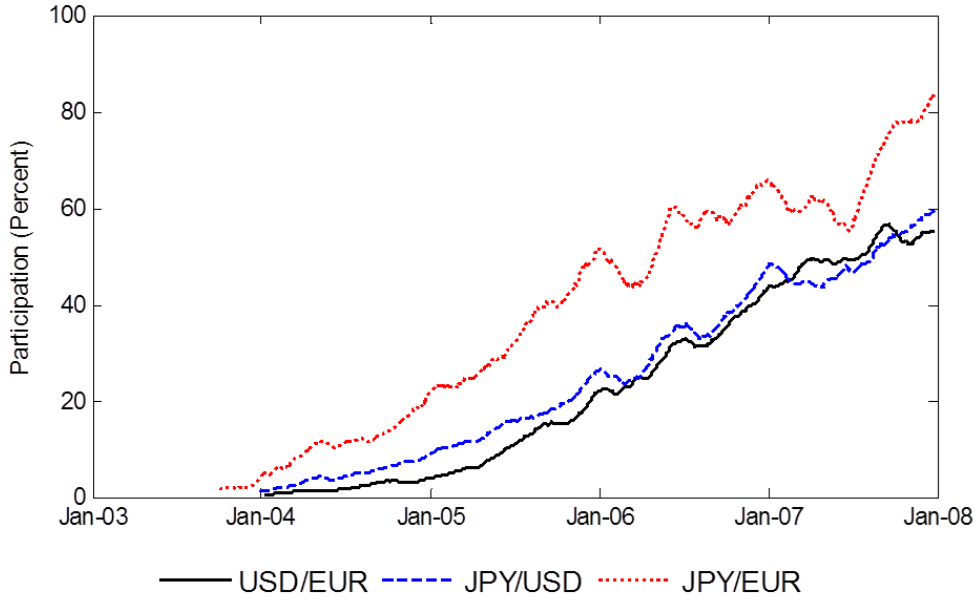

Figure 1: 50-day moving averages of the percent of total transacted volume that involves at least one algorithmic counterparty. (USD/EUR, JPY/USD and JPY/EUR denote the euro-dollar, dollar-yen and euro-yen currency pairs, respectively.)

In contrast to these mostly positive views on algorithmic trading and price efficiency, others argue that (in a world with no asymmetric information) the speed advantage of algorithmic traders would not increase the informativeness of prices but would still increase adverse selection costs. In addition, potential commonality of trading actions amongst computers may have a negative effect on the informativeness of prices. The large losses that occurred for many quantitative long-short equity strategies at the beginning of August 2007, highlight the possible adverse effects on the market of such commonality in behavior across market participants (algorithmic or not) and provide empirical support for this concern.

Guided by this literature, our paper studies the impact of algorithmic trading on the price discovery process in the foreign exchange market. We first use our data to study the impact of algorithmic trading on the frequency of triangular arbitrage opportunities amongst the euro-dollar, dollar-yen, and euro-yen currency pairs. These arbitrage opportunities are a clear example of prices not being informationally efficient in the foreign exchange market. We document that the introduction and growth of algorithmic trading coincided with a substantial reduction in triangular arbitrage opportunities (see Figure 2 below). We then continue with a formal analysis of whether algorithmic trading activity *causes* a reduction in triangular arbitrage opportunities, or whether the relationship is merely coincidental, possibly due to a concurrent increase in trading volume or decrease in price volatility. Our formal statistical model shows that algorithmic trading activity does cause a reduction in the number of triangular arbitrage opportunities. In addition, we find that algorithmic traders reduce arbitrage opportunities more by acting on the quotes posted by non-algorithmic traders than by posting quotes that are then traded upon. This result is consistent with the view that algorithmic trading improves informational efficiency by speeding up price discovery, but that, at the same time, it increases the adverse selection costs to slower traders, as suggested by some theoretical models.

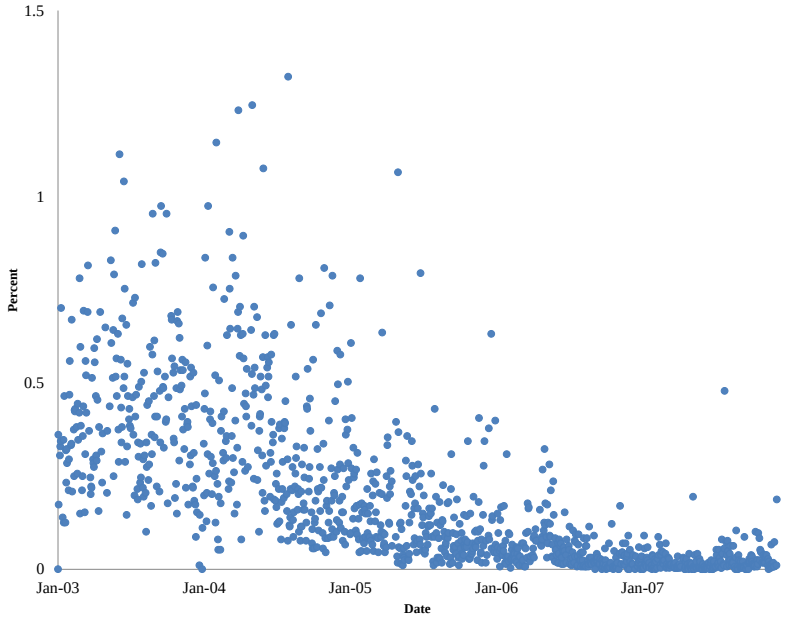

Figure 2: Percent of seconds with a triangular arbitrage opportunity with a profit strictly greater than 1 basis point.

The impact of algorithmic trading on the frequency of triangular arbitrage opportunities is, however, only one facet of how computers may affect the price discovery process. More generally, we investigate whether algorithmic trading contributes to the temporary deviation of asset prices from their fundamental values, resulting in excess volatility, particularly at high frequencies. In our formal statistical tests, we find that, on average, an increase in algorithmic trading participation in the market causes a *reduction* in excess volatility. Interestingly, we find that the improvement in the informational efficiency of prices now seems to come predominantly from an increase in the trading activity of algorithmic traders when they are providing liquidity---that is, posting quotes which are hit---not from an increase in the trading activity of algorithmic traders who hit posted quotes. In other words, in this case, in contrast to the study of triangular arbitrage, algorithmic traders appear to increase the informational efficiency of prices by posting quotes that reflect new information more quickly.

Finally, to address another concern highlighted in the literature---namely that the trading strategies used by computers are more correlated than those used by humans, potentially creating excess volatility---we propose a novel way of indirectly inferring the correlation among computer trading strategies from our trading data. The primary idea behind the measure that we design is that traders who follow similar trading strategies will trade less with each other than those who follow less correlated strategies. Empirically, we find evidence that algorithmic traders do not trade with each other as much as our simple benchmark would predict, which we view as consistent with their trading strategies being highly correlated. However, the analysis shows that this high degree of correlation does not appear to cause a degradation in market quality.