CAPCO

JOURNAL

THE CAPCO INSTITUTE JOURNAL OF FINANCIAL TRANSFORMATION

CURRENCY

Economic simulation of cryptocurrencies

MICHAEL R. MAINELLI | MATTHEW LEITCH
DIONYSIOS DEMETIS

DIGITIZATION

#47
04.2018

JOURNAL

THE CAPCO INSTITUTE JOURNAL OF FINANCIAL TRANSFORMATION

RECIPIENT OF THE APEX AWARD FOR PUBLICATION EXCELLENCE

CONTENTS

ORGANIZATION

07 Implications of robotics and AI on organizational design
Patrick Hunger, CEO, Saxo Bank (Schweiz) AG
Rudolf Bergström, Principal Consultant, Capco
Gilles Ermont, Managing Principal, Capco

15 The car as a point of sale and the role of automotive banks in the future mobility
Zhe Hu, Associate Consultant, Capco
Grigory Stolyarov, Senior Consultant, Capco
Ludolf von Maltzan, Consultant, Capco

25 Fintech and the banking bandwagon
Sinziana Bunea, University of Pennsylvania
Benjamin Kogan, Development Manager, FinTxt Ltd.
Arndt-Gerrit Kund, Lecturer for Financial Institutions, University of Cologne
David Stolin, Professor of Finance, Toulouse Business School, University of Toulouse

35 Can blockchain make trade finance more inclusive?
Alisa DiCaprio, Head of Research, R3
Benjamin Jessel, Fintech Advisor to Capco

45 The aftermath of money market fund reform
Jakob Wilhelmus, Associate Director, International Finance and Macroeconomics team, Milken Institute
Jonathon Adams-Kane, Research Economist, International Finance and Macroeconomics team, Milken Institute

51 Costs and benefits of building faster payment systems: The U.K. experience
Claire Greene, Payments Risk Expert, Federal Reserve Bank of Atlanta
Marc Rysman, Professor of Economics, Boston University
Scott Schuh, Associate Professor of Economics, West Virginia University
Oz Shy, Author, How to price: a guide to pricing techniques and yield management

67 Household deformation trumps demand management policy in the 21st century
Iordanis Karagiannidis, Associate Professor of Finance, The Tommy and Victoria Baker School of Business, The Citadel
D. Sykes Wilford, Hipp Chair Professor of Business and Finance, The Tommy and Victoria Baker School of Business, The Citadel

CURRENCY

81 **Security and identity challenges in cryptotechnologies**
José Vicente, Chairman of the Euro Banking Association's Cryptotechnologies Working Group
Thomas Egner, Secretary General, Euro Banking Association (EBA), on behalf of the working group

89 **Economic simulation of cryptocurrencies**
Michael R. Mainelli, Chairman, Z/Yen Group, UK and Emeritus Professor of Commerce, Gresham College
Matthew Leitch, Z/Yen Group
Dionysios Demetis, Lecturer in Management Systems, Hull University Business School

101 **Narrow banks and fiat-backed digital coins**
Alexander Lipton, Connection Science Fellow, Massachusetts Institute of Technology (MIT), and CEO, Stronghold Labs
Alex P. Pentland, Toshiba Professor of Media Arts and Sciences, MIT
Thomas Hardjono, Technical Director, MIT Trust::Data Consortium, MIT

117 **Quantitative investing and the limits of (deep) learning from financial data**
J. B. Heaton, Managing Member, Conjecture LLC

SECURITY

125 **Cyber security ontologies supporting cyber-collisions to produce actionable information**
Manuel Bento, Euronext Group Chief Information Security Officer, Director, Euronext Technologies
Luis Vilares da Silva, Governance, Risk and Compliance Specialist, Euronext Technologies, CISSP
Mariana Silva, Information Security Specialist, Euronext Technologies

133 **Digital ID and AML/CDD/KYC utilities for financial inclusion, integrity and competition**
Dirk A. Zetzsche, Professor of Law, ADA Chair in Financial Law (Inclusive Finance), Faculty of Law, Economics and Finance, University of Luxembourg, and Director, Centre for Business and Corporate Law, Heinrich-Heine-University, Düsseldorf, Germany
Douglas W. Arner, Kerry Holdings Professor in Law, University of Hong Kong
Ross P. Buckley, King & Wood Mallesons Chair of International Financial Law, Scientia Professor, and Member, Centre for Law, Markets and Regulation, UNSW Sydney

143 **Digital identity: The foundation for trusted transactions in financial services**
Kaelyn Lowmaster, Principal Analyst, One World Identity
Neil Hughes, Vice President and Editor-in-Chief, One World Identity
Benjamin Jessel, Fintech Advisor to Capco

155 **Setting a standard path forward for KYC**
Robert Christie, Principal Consultant, Capco

165 **E-residency: The next evolution of digital identity**
Clare Sullivan, Visiting Professor, Law Center and Fellow, Center for National Security and the Law, Georgetown University, Washington D.C.

171 **The future of regulatory management: From static compliance reporting to dynamic interface capabilities**
Åke Freij, Managing Principal, Capco

Economic simulation of cryptocurrencies[1]

MICHAEL R. MAINELLI | Chairman, Z/Yen Group, UK and Emeritus Professor of Commerce, Gresham College
MATTHEW LEITCH | Z/Yen Group
DIONYSIOS DEMETIS | Lecturer in Management Systems, Hull University Business School

ABSTRACT

Cryptocurrencies have the potential to become effective currencies that give a higher level of macroeconomic control, thanks to the information that is available about holdings and transactions, and the potential for automated control mechanisms. However, these cryptocurrencies need to be designed properly and tested before launch. This paper reports the early results of an economic model that simulates a variety of behaviors by economic agents and some simple control mechanisms. An economic simulation model is likely to be a valuable tool in developing effective cryptocurrency systems and interacting with regulators.

[1] DasCoin, along with Z/Yen Group, supported this research financially. Michael Mathias and Terry O'Hearn of DasCoin provided comments on early drafts of the research. None of the authors have an interest in DasCoin or hold its cryptocurrency.

1. INTRODUCTION

Several hundred cryptocurrencies have been launched [Hileman and Rauchs (2017)], with others in the pipeline. Only a few have been successful enough to become widely known and easily exchanged for fiat currencies. Some of these currencies have had value for a while, then lost it. For reasons discussed below, even Bitcoin, the most famous of all, still does not fulfill all the traditional economic functions of money.

Nevertheless, cryptocurrencies have the potential to function as currencies, to revolutionize payments, and to transform finance for the better. From a macroeconomic point of view, cryptocurrencies offer the possibility of currencies whose exact supply is known at all times, along with the exact distribution of holdings of the currency and even the distribution of transaction values. It should be possible to exploit this information to manage the currency more effectively, mostly through automatic control mechanisms that operate quickly and free from political influence.

To achieve this, cryptocurrencies need more than just enthusiastic promotion. They need to be properly designed to function effectively as currencies. However, a cryptocurrency and its users form a complex system and design of its control mechanisms is difficult. To tackle this difficulty, simulation systems could be used. Many designers of complex systems (e.g., environmental, manufacturing, financial, economic) find simulation valuable. The value can derive from improved designs, anticipating problems, or rehearsing reactions to problems. Further, the ability of models to provide a predictive reference (at least short term) makes them useful within a control mechanism [Mainelli (2009)].

Increasingly, adoption of a cryptocurrency may depend on regulatory approval. Another motivation for the economic simulation model presented in this paper was to see if a cryptocurrency simulation might be of use in explaining to a wider audience, including regulators, how a cryptocurrency might perform. The model explored the design issues for cryptocurrencies and the value of using a simulation to test specific design features.

2. DEFINING SUCCESS FOR CRYPTOCURRENCIES

What should a cryptocurrency do well? The objectives could be defined in a number of different ways, but would surely include ideas like popularity, security, availability, efficiency, and speed. On top of those, the objective we focus on here is to be an effective currency.

A cryptocurrency should fulfill the traditional functions of money [Jevrons (1875)]. Exactly what those are has been a topic for scholarly debate for a long time. According to Mainelli (2015), "Money is a technology that communities use to trade debts across space and time." An old couplet breaks this down in more detail: "Money is a matter of functions four, a medium, a measure, a standard and a store." This has been analyzed by many authors, including Jevrons (1875).

Some very practical considerations underlie this theorizing. Money should be an effective medium of exchange, enabling two people to make a deal even though they do not have goods or services of equal value to exchange in a barter transaction. The money makes up the difference between what each person offers. This requires that it be accepted over a broad area and time. It should provide a reliable store of value so that if two people make two exchanges separated by a period of time neither feels cheated by the fact that money at one time is worth much more or less than it was at another. To be a standard means holding relative value to a basket of needs, but this is not easy as those needs change with technology, fashion, or scarcity. It should also be supported by a large community of people whose familiarity with the currency and what it can be exchanged for means that they can use it for mentally valuing objects and making decisions, even when the currency is not actually used in a transaction.

A crucial requirement, if a currency is to be effective, is that its value does not change, much, over time. A currency whose value changes greatly day by day cannot reliably store value over time. Losers will feel cheated by value movements. Buyers cannot learn the usual prices for goods they often buy, or shop for good bargains. Sellers cannot advertise prices for goods or services without constantly revising them. Nobody can use the currency in calculations as a proxy for utility.

A stable value in turn requires, among other things, that the money supply should match demand for money.

These requirements are all-embracing. It is difficult to think of any form of money that has achieved all four functions for a significant period of time. To be a store means holding firm over long periods of time, which by inspection has not been attained by fiat currencies nor gold. Fiat currency is a good medium of exchange within a tax zone, but has traditionally been a variable unit of account that leaks value with inflation.

However, these changes in value are slow compared to the rapid fluctuations typical of cryptocurrencies, including Bitcoin. This problem has been presented as a virtue, with cryptocurrencies offered as opportunities for speculation [Bouoiyour et al. (2014)]. Participants are encouraged to buy and hold for a while by prospects of appreciation. It is a game where the winners and losers balance out, except that operators of an exchange or mint take their cut. In theory, at least, a cryptocurrency could be a huge success as a speculative arena despite never being used to buy goods or services. In this role it is similar to online poker, not a currency.

3. AN ECONOMIC SIMULATION MODEL

3.1 Overview

To test ideas for economic control mechanisms for cryptocurrencies before committing them to a live cryptocurrency, it makes sense to build some kind of simulation model. The model described below was designed to focus on economic control, especially money supply and exchange rate mechanisms, not on other potentially relevant considerations, such as energy efficiency, community building, or commercial viability for participants.

It assumes that the cryptocurrency is designed and promoted as a payment system and currency, not as an opportunity for speculation, and that the exchange rate changes will be slow. This is very different to existing cryptocurrencies but realistic for a viable future cryptocurrency. The assumptions underlying the model's design are as follows:

- **A dominant fiat currency:** as the model is to simulate the early stages of a cryptocurrency, the assumption is that there is a dominant fiat currency that is widely used and whose prices are known to users. Everyone uses the fiat currency but they opt in and out of the cryptocurrency. For simplicity, the model assumes only one fiat currency and no inflation, making it a stable reference point for the cryptocurrency.
- **Relatively small scale:** even payments by Bitcoin are on a small scale compared to more established means of electronic payment, so the model assumes that IT costs are not a major factor and that there is no problem operating at the scale arising in the simulations [Croman et al. (2016)].
- **Payments and speculation:** cryptocurrencies are used to pay for goods and services, but users also buy and hold them, hoping to profit from exchange rate changes [Bouoiyour and Selmi (2015)]. This is probably common even among users who are not experienced, skilled currency traders. The model reflects both uses, but the sophistication of speculative trading strategies is very limited.
- **Easy choices between means of payment:** while the purchasing habits of currency users may be stable over time, driven by their basic needs (e.g., food, housing, transport), the choice between alternative payment methods is less constrained. Most users will have an array of alternative means of payment and can choose between them easily the moment before they pay. In the model, users choose between paying with the cryptocurrency and paying with a fiat currency on every transaction and their behavior is sensitive to price differences.
- **Two prices for the same good:** in a society where a cryptocurrency is used alongside a more established fiat currency, goods and services may be offered with prices in each. Sometimes, one of those prices will be a better bargain. For example, if a product is initially given two prices that are equivalent (according to the mid-point exchange rate at that moment), and those prices are not revised for a period of time, then one may become more attractive than the other as the exchange rate changes. This provides a very clear reason for users to pay with either fiat or crypto-currency on any particular occasion.
- **Unpredictable velocity:** the velocity of a currency is defined as the number of times, on average, that each unit of the currency is used in transactions to buy goods and services in a period of time. The velocity of cryptocurrencies is likely to be especially inconsistent over time because of the easy choice between means of payment and because electronic transfer of funds can be done very quickly. The velocity could be even higher if robots initiate transactions. The model tracks changes in velocity, calculated in both the conventional and in a distribution-adjusted way.

- **Consumer oriented currency exchange:** most people experience currency exchange when going on holiday or on a business trip. They buy the foreign currency they need at the advertised price rather than by putting more complex forms of order into an order-driven exchange. The model uses the simpler form of currency exchange between the cryptocurrency and a fiat currency.
- **Controlled money supply at a price:** the quantity of cryptocoins in issue at any time is precisely known and can be precisely controlled. This is different from the situation with fiat currencies today [McLeay et al. (2014)]. In the model, users can buy newly minted cryptocoins for a price, which approximately represents the situation with at least some cryptocurrencies at the time of writing. In the case of DasCoin, the cryptocoins can be acquired in exchange for Cycles, which themselves are bought with fiat currency or Bitcoin. Indirectly, this establishes an approximate cost of acquiring newly minted cryptocoins. The situation with Bitcoin is different. Bitcoin can be mined and so acquired at a price that reflects the investment in computing power. However, getting started at mining is a significant investment so Bitcoin users mostly do not mine sporadically when it is a cheaper option than going to an exchange. The model begins simulations with an initial stock of cryptocoins held by the exchange, and then tracks the quantity of cryptocoins in issue. The cost to acquire newly minted coins can be varied.

Clearly, a number of features of current and future cryptocurrencies and exchanges that are sometimes important are missing from this model. Some of these are mentioned below as opportunities for future development.

3.2 The simulation cycle

The economic model is stochastic and based on intelligent agents that interact over a sequence of discrete days, buying and selling goods, and adjusting their cryptocurrency holdings by exchanging for the fiat currency and buying newly minted cryptocoins. There have been several examples of agent-based models of currencies [Chatagny and Chopard (2000), Cocco and Marchesi (2016), Delage et al. (2010), Setzu (2007), Usami et al. (2006)]. The model is implemented as an R script. A wide range of parameters can be set to control the behavior of the model.

The agents in the model are: (1) merchants, who offer goods for sale; (2) customers, who buy those goods; and (3) an exchange market maker that buys and sells the cryptocurrency and fiat currency.

Each day follows the same pattern, as follows: (1) merchants decide if they will use the cryptocurrency and, if so, how often they will revise their prices; (2) merchants adjust some cryptocurrency prices; (3) customers decide if they will use the cryptocurrency; (4) customers make purchases of goods from merchants and, each time, decide if they will pay with cryptocurrency or fiat currency; (5) customers and merchants decide how much cryptocurrency they wish to hold and adjust their holding by buying from or selling to the currency exchange, or by buying newly minted coins; and (6) the currency exchange market maker decides what prices for the cryptocurrency to set for the next day.

> "To test ideas for economic control mechanisms for cryptocurrencies before committing them to a live cryptocurrency, it makes sense to build some kind of simulation model."

The fiat currency prices of goods remain fixed throughout each trial, but merchants can set cryptocurrency prices too. Merchants do this by using the mid-point exchange rate for the day to set a price that is equivalent to the given fiat currency price. They can either revise their prices daily, weekly, or every 30 days. The decision to start or stop using the cryptocurrency is randomized, as is the choice of frequency for revising prices. However, the decision to use the cryptocurrency is influenced by the apparent success of the currency and the amount of positive publicity around it. Once merchants have started to use the cryptocurrency they are encouraged to continue by their sales in the cryptocurrency.

Customers decide to use or not use the cryptocurrency in a similar, randomized way. Once they start using it they are encouraged to stay by the savings they make through cryptocurrency purchases.

Customers do not shop around for alternative suppliers of the same goods or services. However, customers who are cryptocurrency users will consider any cryptocurrency prices offered for goods they want to buy and will decide how to pay. This is based on choosing the cheapest way to pay given the two advertised prices, the day's midpoint exchange rate, and the cost of buying newly minted cryptocoins. (The midpoint exchange rate is the geometric mean of the bid and ask prices.)

Merchants and customers decide the amount of cryptocurrency they would like to hold at the end of each day by using the same basic strategy, but with parameters that are randomized between agents so that some heterogeneous behavior results. The users are assumed to have a cash amount (specified in fiat currency) that they hold at all times and allocate between fiat currency and cryptocurrency. Following the Kelly Strategy [Kelly (1956)], they allocate this cash amount according to their probability of each being the better investment. For example, if the user thinks that the cryptocurrency is 60% likely to appreciate relative to the fiat currency then the user will decide to hold 60% of the cash amount in cryptocurrency.

The perceived probability of cryptocurrency being the best investment is driven by several variables and in all cases the user considers the recent trend of changes in those variables [Izumi (2010)]. For example, if overall holdings of the cryptocurrency have been rising on most days recently then the user will take that as an encouraging sign and want to hold more.

The perception of commercial activity and exchange activity is tempered by knowledge of the distribution of that activity. This is modeled by having the agents react to market indicators multiplied by the relative entropy[2] of the distribution of the transactions or holdings involved. For example, if a lot of cryptocurrency is held, but only by one person, then this is little better than no cryptocurrency being held at all, while the same quantity of cryptocurrency equally distributed across many users is a much more encouraging sign of a viable community of users.

The model has several alternative strategies for revising the exchange rate of the cryptocurrency for each day. These are discussed in more detail below, where their effect is illustrated. However, the model does not fully reflect possible shortages of demand or supply that might mean the exchange cannot meet all orders.

Figure 1: Exchange rate (FC/CC) over time in a typical simulation trial (the rate is capped at 1.2 by the cost of minting).

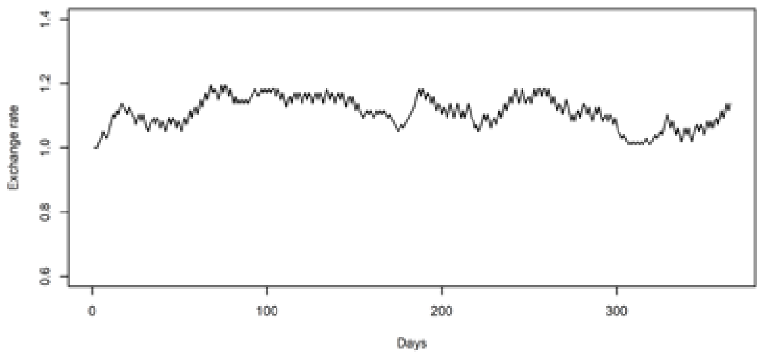


Figure 2: Minting is sporadic and occurs when the cost of buying newly minted cryptocoins is less than the cost of buying cryptocoins on the exchange.

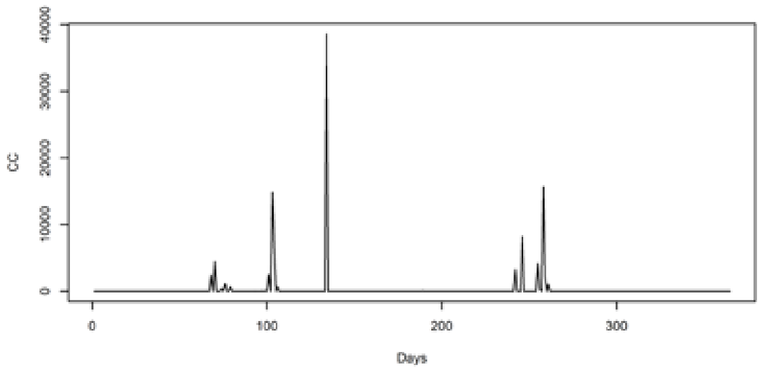
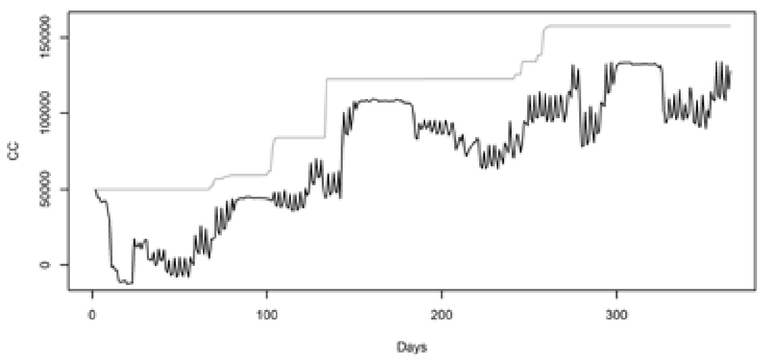


Figure 3: When cryptocoins are minted, the total quantity of cryptocoins in existence increases (the grey line) and this tends to allow the pool of cryptocoins held by the exchange market maker (black line) to increase.



[2] Relative entropy was defined as the entropy of the distribution divided by the entropy of a uniform distribution of the same total value. For a sequence of N non-negative values bi, i = 1..N, Relative Entropy = $-\frac{\sum_{i=1}^{N}\frac{b_i}{N}\times\log_2(\frac{b_i}{N})}{\log_2(N)}$, with 0 x $\log_2$ (0) = (0)

3.3 A typical trial

As discussed later in this article, many aspects of the behavior of a new cryptocurrency are unpredictable and sensitive to details of agents' decisions. However, some features of trials with the model are fairly consistent and are visible in the following, typical example. This provides some context for understanding the variations and effects of control mechanisms discussed later.

This was a trial simulating 365 days with 10 merchants, 40 customers, and a cost of minting that was 1.2 times the initial exchange rate of the cryptocurrency (CC), which was 1 unit of the fiat currency (FC). The exchange rate evolved as shown in Figure 1, clearly capped by the minting cost of 1.2. Minting occurs when the rate to buy CC rises and hits the minting cost, as shown in Figure 2.

Although minting is only sporadic, it has a great effect on the total quantity of CC that exists, relieves pressure on the exchange's pool of cryptocurrency, which was becoming depleted, and constrains the exchange rate.

With the minting cost set much higher the exchange rate tends to rise much further before being capped, but exactly what happens depends on other features of the system. If new cryptocoins were to be mined continuously in a way that was largely unrelated to demand rather than purchased from the mint then the effects would depend on many features of the system but would be less controlled.

The demand for CC is largely driven by the gradual rise in users, as seen in Figure 4.

The holdings of users (excluding the exchange market maker) also rise, but not as smoothly. Figure 5 shows these holdings, but multiplied by the relative entropy of the holdings. Relative entropy is a number between 0 and 1 that reflects inequality in the distribution. A relative entropy of 1 occurs when all holdings are of equal value. A relative entropy of 0 occurs when only one user holds CC. (The model also tracks this quantity using the Gini Index[3] as a measure of inequality.)

Use of CC to buy real goods also increases, but is sporadic, as shown in Figure 6. Comparison with the exchange rate time series reveals that the activity corresponds to periods of falling or stable prices.

Figure 4: The total number of users (both merchants and customers) rises rapidly at first, then slows down and may decrease.

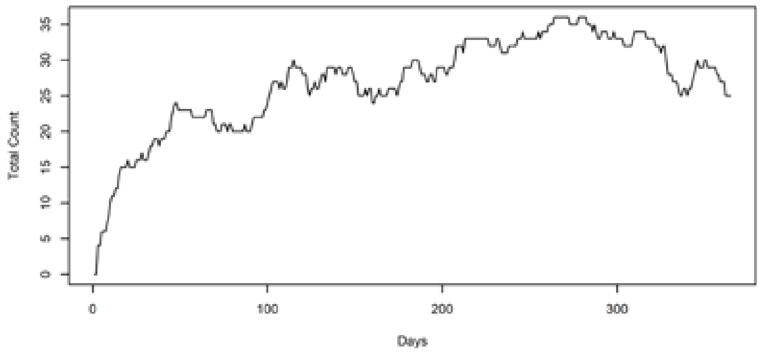


Figure 5: Holdings of CC (excluding the exchange market maker) rise, but not smoothly. The plot shows the total holdings of CC by merchants and customers multiplied by the relative entropy of those holdings so that both the quantity and distribution of CC holdings is considered.

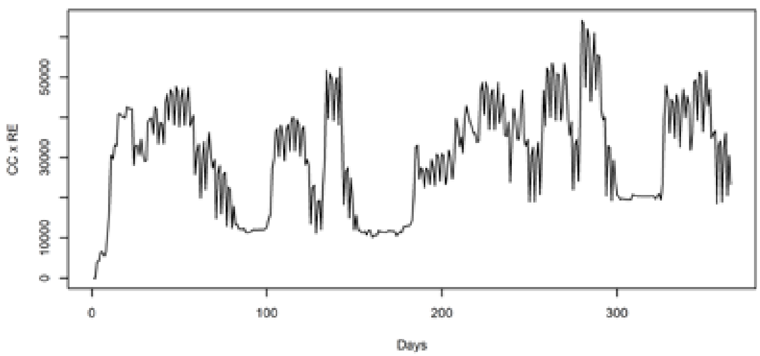
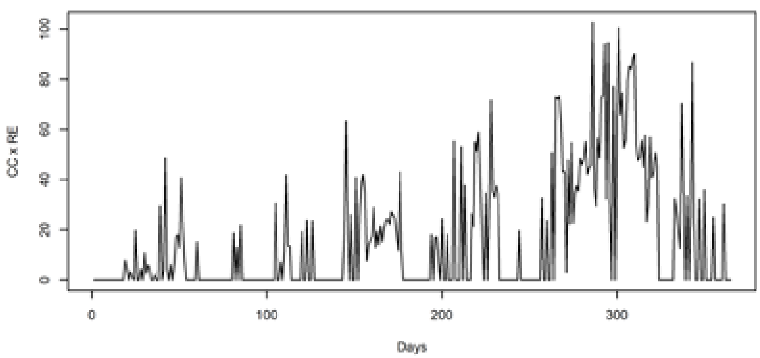


Figure 6: Use of CC to buy real goods and services increases but is sporadic.



[3] The Gini Index is 1 for complete inequality and 0 for complete equality, which is the opposite of Relative Entropy. The model tracks and uses 1 - G, where G is the index.

Commercial activity is driven by a falling rate, as shown by a scatter plot of the moving average of daily exchange rate movements against commercial activity. In Figure 7, it is clear that commercial activity appears most strongly when the trend is flat or negative.

If the model was more sophisticated and customers shopped around for the best deal on identical products from alternative suppliers then the effect of these flurries of CC spending would be stronger, with merchants offering CC prices making more sales.

3.4 Different behavior from varying assumptions about agents' decisions

Future cryptocurrencies may attract, and prompt, different behaviors among users. They might vary in being market followers or contrarians, in having a long- or short-term perspective, or in being more or less susceptible to hype. This probably means that it is not feasible to predict, accurately, the evolution of a particular cryptocurrency. However, it should be possible to simulate a variety of plausible behaviors and study how the control mechanisms perform in the face of challenging patterns.

To accommodate this, the simulation model has a large number of parameters that affect its behavior. Many of these concern the decisions of agents. Two important examples are assumptions about decisions to get involved with the cryptocurrency and decisions on how much of it to hold each day.

A very common feature of simulation trials with the model is a rapid initial uptake of the CC as merchants and customers decide to use it and begin to hold stocks of the CC. This demand alone drives the price up.

However, after an initial rise the pressure is reduced as the number of customers and merchants opting in reduces to match the increasing number opting out. Although the total population of merchants and customers in the model is intended to represent only those people who would ever be interested in using a cryptocurrency, this is still not realistic. In the real world, there are billions of potential users but only a relatively tiny proportion of them become actual users. A cryptocurrency could perhaps rise as a result of recruiting new users for a long period of time.

Figure 7: The trend of exchange rate changes (represented by the exponentially weighted moving average of daily differences) is linked to purchasing real goods and services. It is most common when the currency falls, making prices quoted in CC more attractive than FC prices, until prices are adjusted.

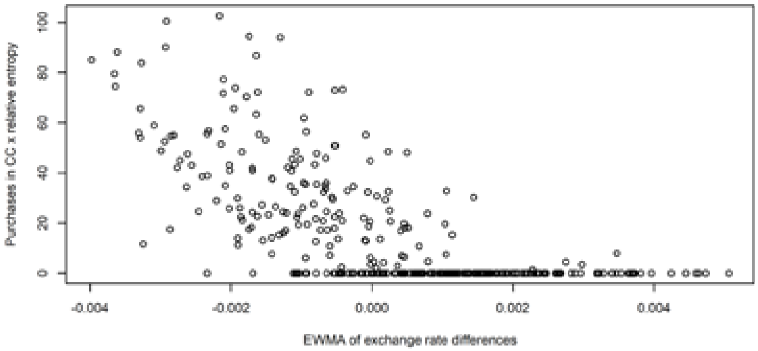


Figure 8: Increasing the population of potential customers from 40 to 400 and reducing the propensity to become users gives a smoother growth of user numbers, reaching a plateau determined by assumptions about joining and leaving.

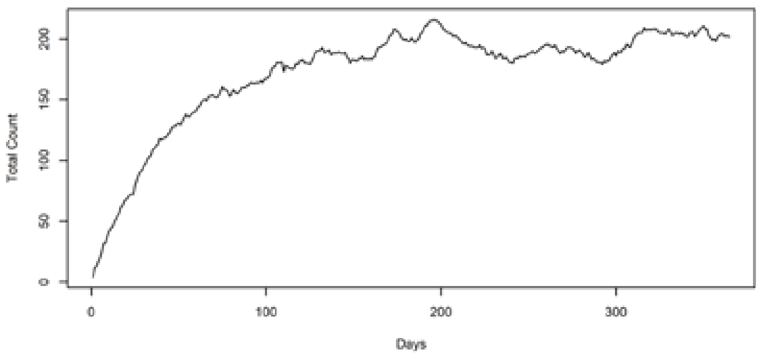
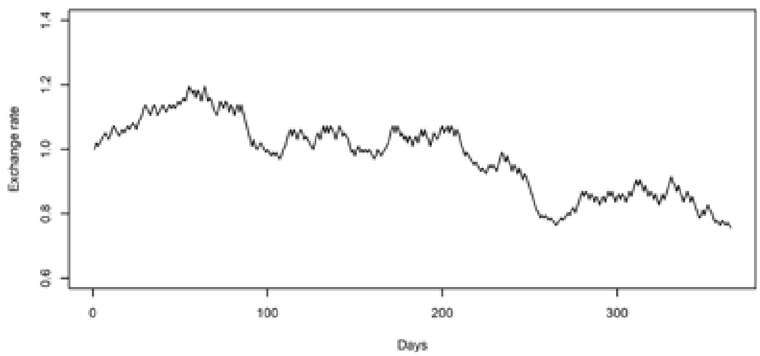


Figure 9: With relatively unreactive, users the exchange rate tends to hover in between sudden jumps.



Increasing the pool of potential users, but decreasing the proportion of them that join each day, produces simulations that are more predictable in percentage terms because of the larger numbers involved (e.g., Figure 8). However, the total fraction of the population that become users depends entirely on the assumptions made about how people will respond to promotional activity, news of the progress of the cryptocurrency, and so on.

In these early model simulations, the time taken to reach the approximate equilibrium level where joiners equal leavers does not change much as the total population is increased. This is a surprise, but perhaps reflects the assumption that the entire population is exposed to information about the cryptocurrency at the same time. In reality, perhaps people pay attention to this news only occasionally and there is some kind of spreading awareness that slows the process. Alternatively, it may be that salespeople promoting cryptocurrencies and services related to them take time to work through the population of potential buyers.

Another example of sensitivity to assumptions is the effect of making users more reactive to recent information. In the model, the extent to which users react to the latest information rather than wait to see if trends persist is controlled by the individual recency factors of each user and each variable. However, by constraining those into narrow ranges it is possible to see the effect of making everyone generally more or less reactive.

Figures 9 and 10 contrast the typical appearance of the exchange rate time series with low and high reactiveness, respectively. With low reactiveness, the series has periods of small rises and falls, with rapid changes of direction, interrupted by occasional big rises or falls. With high reactiveness, the series is more often characterized by a more even see-saw rise and fall with few dramatic changes. This change is not reflected much in the change in standard deviation of daily differences, which goes from 0.1534 to 0.1555, nor in the Fractal Dimension[4] of the time series, which rises from 1.676 to 1.699. However, it is clear that the distribution of runs up and down has changed, with many more movements of around 0.05 in size.

Figure 10: With relatively reactive users the exchange rate tends to rise and fall more continuously, giving the plot a serrated appearance.

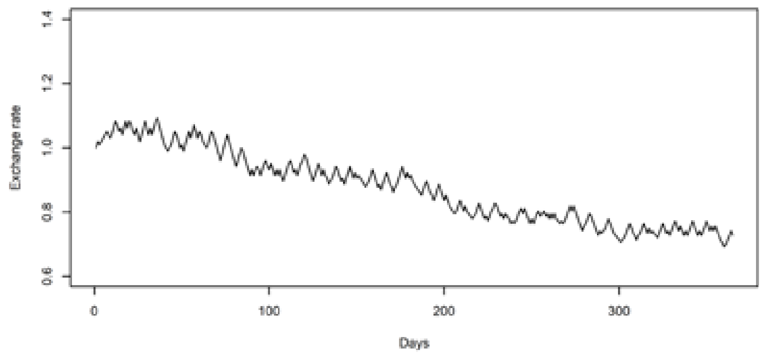


Figure 11: With fairly even distribution of goods, purchasing, and money, the time series of CC holdings multiplied by relative entropy has a complex shape with many rises and falls.

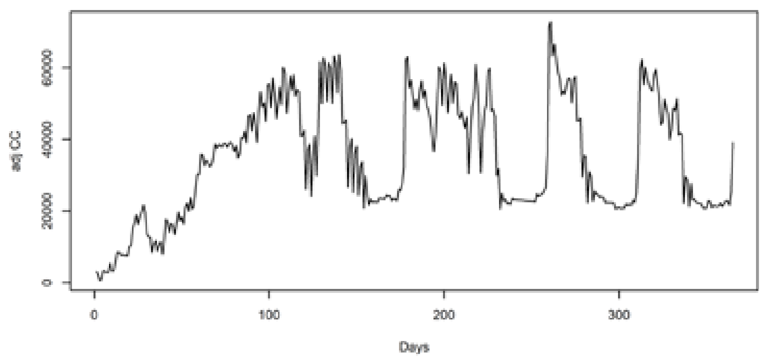
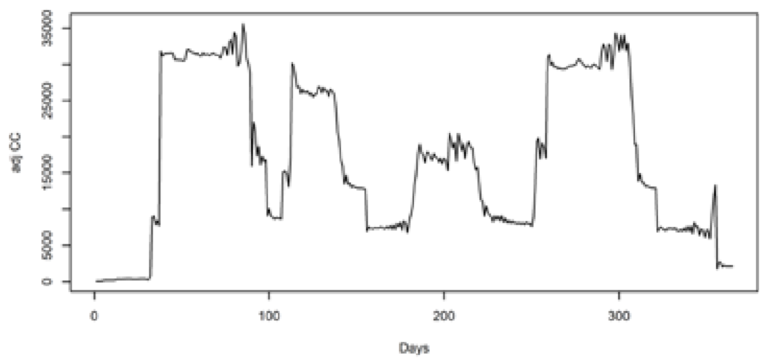


Figure 12: With unequally distributed goods, purchasing, and money, the time series of CC holdings multiplied by relative entropy has a simpler shape, dominated by large rises and falls.



[4] The Fractal Dimension values were calculated using a refinement of Higuchi's algorithm [Cervantes-De la Torre et al. (2013)].

The distribution of holdings and activity is also important. It is possible to vary this while keeping the total number of merchants, customers, and goods constant, and keeping the average number of purchases per customer per day constant along with the average price of goods. With the goods and money fairly evenly distributed, the relative entropy of holdings of CC emerges at around 0.9 and the graph of CC holdings multiplied by relative entropy typically shows a fairly complex shape with many periods of rapid alternating rises and falls, mixed with some large jumps (Figure 11).

In contrast, with very unequal distributions of goods, purchasing, and money, the relative entropy emerges at around 0.2 and the plot of CC holdings multiplied by relative entropy is simpler, with sudden jumps but less other activity (Figure 12).

3.5 Control mechanisms

The rule used by the exchange market maker to update the exchange rate for each next day is a highly influential control mechanism. It is not true to say that any rule that adjusts the rate up a bit when demand exceeds supply, and adjusts it down when supply exceeds demand, will have roughly the same effect thanks to a natural negative feedback loop.

With the same starting conditions but changing only the rule for updating the exchange rate, very different results are obtained. A further series of plots illustrates the effect on exchange rate using a simulation in which the cost of minting is set very high so that the exchange rate is not capped and the money supply is fixed. With a minimal rule that adjusts the rate up by 1% or down by the same multiple the result is shown in Figure 13.

With a rule that adjusts the rate more when the absolute value of the net demand for CC is larger, a visibly different time series results (Figure 14). Bursts of demand for CC are met by a rapid increase in the rate that then subsides, nearly as rapidly.

The same rule but with a weaker reaction to differences between supply and demand produces a more stable exchange rate (Figure 15) with a narrower range but similar characteristics. Note the slight upward trend.

Finally, another less reactive rule, but this time with a tendency to avoid the market maker's pool becoming depleted or excessive (Figure 16). The exchange rate now keeps returning to the original value of 1, even though this is not an explicit part of the rule used.

Figure 13: The exchange rate over time with a minimal rule for adjusting the rate each day.

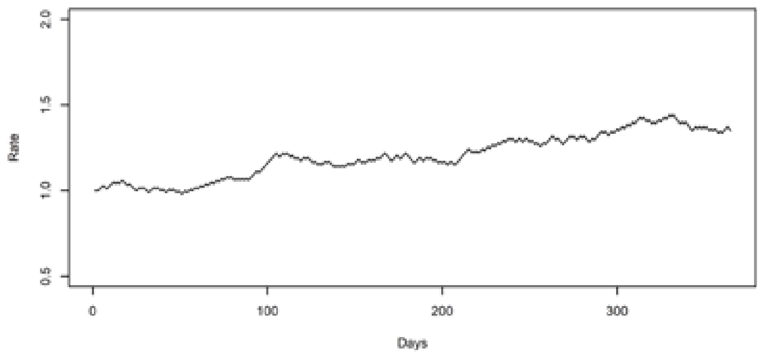


Figure 14: With a rule that adjusts the rate more as the difference between demand and supply for the CC increases, a greater overall variation in rates is produced, and with a different quality of variation.

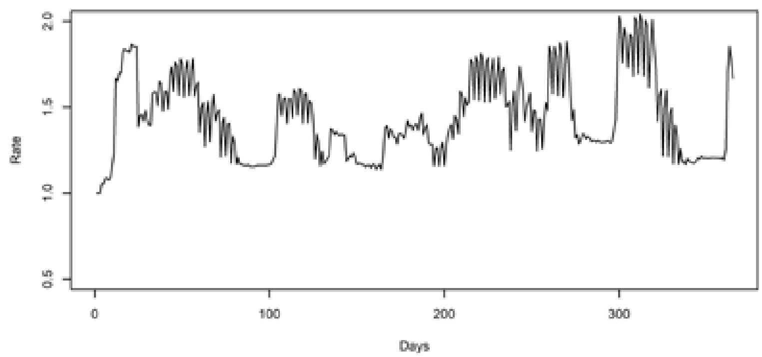
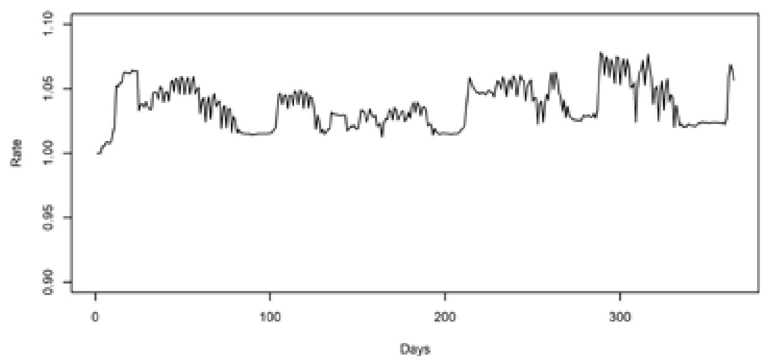


Figure 15: With a rule that reacts less strongly to an imbalance between demand and supply the variation in rates is much less, though the patterns of variation appear similar. Note the narrower scale on the vertical axis compared to Figure 14.



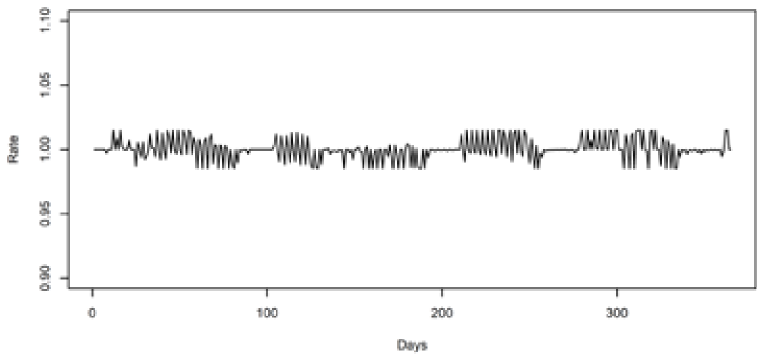
4. AREAS FOR FUTURE RESEARCH

The sensitivity of the model to different assumptions about agents' decision making and other factors that are unlikely to be predictable before a cryptocurrency is launched strongly suggests that exact prediction of cryptocurrency behavior is unlikely to be feasible before going live. However, it might be valuable later and could even be a part of a control mechanism. However, by simulating a variety of plausible behaviors it is possible to test adaptive management strategies for managing cryptocurrencies and demonstrate the information that could be available to regulators and governments. The model needs to be able to simulate a variety of behaviors, including potentially destructive loops and catastrophic changes, and allow alternative control rules to be tested.

A number of potentially interesting effects and features of cryptocurrencies and their environments could be incorporated into future developments of the simulation model. These include the following:

- Transaction costs
- International use, where the cryptocurrency might be an alternative to two or more fiat currencies
- Very rapid transactions within a single day, perhaps also driven by algorithmic trading, that might lead to large movements in exchange rates within a single day
- Any increased tendency to set and advertise prices in the cryptocurrency when the exchange rate is stable
- Other reasons for using the cryptocurrency, such as social display, to feel up-to-date, or to facilitate crime
- The influence of social networks in deciding who gets enthused about a cryptocurrency and when
- The impact of focused, energetic sales effort that persuades particular subgroups of the population to participate rather than just pushing sales information at everyone
- Highly damaging news stories, such as stories of hacking and arrests, that might deter people from using the cryptocurrency
- Complex, idiosyncratic features of cryptocurrency designs, whose effect is often to complicate decision making for users and increase the uncertainty involved for all participants.

Figure 16: With a rule that also tries to keep the market maker's pool within a range the exchange rate is also constrained and repeatedly returns to the original value of 1.



The economic usefulness of a cryptocurrency depends to a large extent on how evenly distributed it is. If a handful of people own nearly all of it, then, even if there are many people with non-zero holdings, its usefulness will be limited.

A particular feature of CCs going forward may be their ability to test empirically the Quantity Theory of Money, taking distribution into account. The distinction between "distribution of activity" and "distribution of holdings" suggests an extension to the Quantity Theory of Money, where MV = PT, the "Fisher Equation" [Fisher (1922)], where M = money supply; V = velocity of circulation (the number of times money changes hands), P = average price level, and T = volume of transactions of goods and services.

The extension might be along the lines of d(H)MV = d(A)PT where d is a distribution or entropy measure for "holdings" and "activity."

Management strategies need not be restricted to minting and exchange rules. Action could also be taken to link the currency to real goods and services by, for example, offering a catalogue of products with stable cryptocurrency prices.

Other important issues for further research include:

(1) Comparison with alternative electronic payment methods, many of which are highly efficient and more secure than credit and debit cards.

(2) The economic arguments for and against currencies with a small user base, such as the local currencies of Germany discussed by Rösl (2006) and by Z/Yen (2011).

5. CONCLUSION

Cryptocurrencies in the future have the potential to contribute efficiency and economic control, but better designs are needed and these will need to be tested. Simulation is a good way to do this before committing to a live cryptocurrency and might also help with control once the cryptocurrency is live.

Exploring such a model's behavior has confirmed that results are sensitive to the detailed characteristics of agents' decisions, and are unpredictable. This is seen in the response to changing the number of customers, the reactiveness of users to routine news of the cryptocurrency, and the way goods, purchases, and money are distributed across users.

Powerful controlling effects can be achieved by adjusting the cost of newly minted cryptocoins and by adjusting the exchange-rate price revision rule. Almost certainly, other sources of unpredictability and of control can be found. This is just the start of an exciting line of research.

All this suggests that designers of cryptocurrencies should develop and test their design (through simulation and mathematical analysis), including any exchange facilities, and should focus on rules that adapt to events rather than being fixed, based on initial assumptions. It may never be possible to predict in advance the evolution of a cryptocurrency, but it should be possible to develop a model that can be used to test control mechanisms against a wide range of factors and effects.

References

Bouoiyour, J. and R. Selmi, 2015, "What does Bitcoin look like?" Annals of Economics and Finance 16:2, 449-492

Bouoiyour, J., R. Selmi, and A. Tiwari, 2014, "Is Bitcoin business income or speculative bubble? Unconditional vs. conditional frequency domain analysis," MPRA, http://bit.ly/2GC0SVp

Cervantes-De la Torre, F., J. I. González-Trejo, C. A. Real-Ramírez, and L. F. Hoyos-Reyes, 2013, "Fractal dimension algorithms and their application to time series associated with natural phenomena," Journal of Physics: Conference Series 475:1

Chatagny, R. and B. Chopard, 2000, "A parallel model for the foreign exchange market," Parallel Computing 26:5, 587-600

Cocco, L. and M. Marchesi, 2016, "Modeling and simulation of the economics of mining in the Bitcoin market," PLoS ONE 11:10, http://bit.ly/2ogTHuY

Croman, K., C. Decker, I. Eyal, A. E. Gencer, A. Juels, A. Kosba, A. Miller, P. Saxena, E. Shi, E. G. Sirer, D. Song, and R. Wattenhofer, 2016, "On scaling decentralized blockchains," in Clark J., S. Meiklejohn, P. Ryan, D. Wallach, M. Brenner, and K. Rohloff, (eds.), Financial cryptography and data security. Lecture notes in computer science, vol. 9604, Springer

Delage, V., C. Brandlhuber, K. Tuyls, and G. Weiss, 2010, "Multi-Agent based simulation of FOREX exchange market," Maastricht University, Department of Knowledge Engineering, the Netherlands Teramark Technologies GmbH, Munich, Germany

Fisher, I., 1922, The purchasing power of money, its determination and relation to credit, interest and crises, assisted by Harry G. Brown, New and Revised Edition, Macmillan, original publication 1911

Hileman, G. and M. Rauchs, 2017, "Global cryptocurrency benchmarking study," working paper, doi:10.2139/ssrn.2965436

Izumi, K., 2010, An artificial market model of a foreign exchange market, Economic Web Institute, http://bit.ly/2HDrNRJ

Jevrons, W. S., 1875, Money and the mechanism of exchange, D. Appleton and Co.

Kelly, J. L., 1956, "A new interpretation of information rate," Bell System Technical Journal 35:4, 917-926

Mainelli, M., 2009, "Environmental consistency confidence: scientific method in financial risk management," in Tarantino, A. and D. Cernauskas (eds.), Risk management in finance: six sigma and other next-generation techniques, John Wiley & Sons, 273-288

Mainelli, M. R., 2015, Unblock the shared economy, Duke Corporate Education

McLeay, M., A. Radia, and R. Thomas, 2014, "Money creation in the modern economy," Bank of England Quarterly Bulletin 2014 Q1

Rösl, G., 2006, "Regional currencies in Germany – local competition for the Euro? No. 43." Deutsche Bundesbank Discussion Paper, Series 1: Economic Studies, Frankfurt

Setzu, A., 2007, "A framework for financial markets modeling and simulation," Exchange Organizational Behavior Teaching Journal

Usami, A., R. Tsuya, T. Iba, and H. Takayasu, 2006, "Building a simulation model of foreign exchange market," The 5th International Conference on Computational Intelligence in Economics and Finance (CIEF2006), Taiwan

Z/Yen, 2011, "Capacity trade and credit: emerging architectures for commerce and money," report prepared for the City of London Corporation, ESRC, and Recipco

ABOUT CAPCO

Capco is a global technology and management consultancy dedicated to the financial services industry. Our professionals combine innovative thinking with unrivalled industry knowledge to offer our clients consulting expertise, complex technology and package integration, transformation delivery, and managed services, to move their organizations forward. Through our collaborative and efficient approach, we help our clients successfully innovate, increase revenue, manage risk and regulatory change, reduce costs, and enhance controls. We specialize primarily in banking, capital markets, wealth and investment management, and finance, risk & compliance. We also have an energy consulting practice. We serve our clients from offices in leading financial centers across the Americas, Europe, and Asia Pacific.

To learn more, visit our web site at **www.capco.com, or follow us on Twitter, Facebook, YouTube, LinkedIn and Xing.**

WORLDWIDE OFFICES

Bangalore	Frankfurt	Pune
Bangkok	Geneva	São Paulo
Bratislava	Hong Kong	Singapore
Brussels	Houston	Stockholm
Charlotte	Kuala Lumpur	Toronto
Chicago	London	Vienna
Dallas	New York	Warsaw
Dusseldorf	Orlando	Washington, DC
Edinburgh	Paris	Zurich

CAPCO.COM

CAPCO