Economic Thought 6.2: 14-26, 2017

A Quantum Theory of Money and Value, Part 2: The Uncertainty Principle

David Orrell, Systems Forecasting, Toronto, Canada
dorrell@systemsforecasting.com

Abstract

Economic forecasting is famously unreliable. While this problem has traditionally been blamed on theories such as the efficient market hypothesis or even the butterfly effect, an alternative explanation is the role of money – something which is typically downplayed or excluded altogether from economic models. Instead, models tend to treat the economy as a kind of barter system in which money's only role is as an inert medium of exchange. Prices are assumed to almost perfectly reflect the 'intrinsic value' of an asset. This paper argues, however, that money is better seen as an inherently dualistic phenomenon, which merges precise number with the fuzzy concept of value. Prices are not the optimal result of a mechanical, Newtonian process, but are an emergent property of the money system. And just as quantum physics has its uncertainty principle, so the economy is an uncertain process which can only be approximated by mathematical models. Acknowledging the dynamic and paradoxical qualities of money changes our ontological framework for economic modelling, and for making decisions under uncertainty. Applications to areas of risk analysis, forecasting and modelling are discussed, and it is proposed that a greater appreciation of the fundamental causes of uncertainty will help to make the economy a less uncertain place.

Keywords: forecasting, prediction, uncertainty, risk, money, quantum theory

JEL codes: B41, B50, E40, E47, G01

1. Introduction

The profession of economic forecasting has come under widespread criticism in recent years, particularly for its inability to foresee major crises, such as the one from which the world economy is still struggling to extricate itself. As Adair Turner (2014) noted, 'Modern macroeconomics and finance theory failed to provide us with any forewarning of the 2008 financial crisis.' That was the case even *during* the crisis of 2008 (Ahir and Loungani, 2014): a study that year by IMF economists showed the consensus of forecasters was that not one of 77 countries considered would be in recession the next year (49 of them were). Central bankers, who were heavily influenced by mainstream economic theory, were caught equally unawares (White, 2013).

This problem has often been blamed on theories such as the efficient market hypothesis, which states that market fluctuations are random and therefore cannot be predicted (Fama, 1965; Lucas, 2009), or even the butterfly effect from chaos theory

(Ormerod, 2000; Bernanke, 2009). However neither efficiency nor butterflies is the first thing that comes to mind when contemplating what became known as the Great Financial Crisis.[1]

A more reasonable explanation for the failure of standard economic models, as pointed out by a number of economists, is that they do not properly take into account money, debt, or the massive financial sector (White, 2013; Keen, 2015). Instead, they treat the economy as a kind of barter exchange system, in which money plays little role except as an inert medium of exchange, and a metric of economic activity. Many of the key results of economics, such as the Arrow-Debreu (1954) theory of general equilibrium, rely on models which exclude money altogether; and, as discussed below, even the modern dynamic stochastic general equilibrium models, used to predict the effect of policy changes, do not usually include a financial sector.

In particular, risk models that are designed to assess uncertainty treat the economy as an essentially static system, unaffected by the dynamics of money. This omission is particularly glaring given the fact that the financial sector dominates the economic power structure, produces most of the money through credit creation, and was at the heart of both the 2008 crisis, and its aftershocks – for example in the eurozone crisis.

This paper will argue that the catastrophic misunderstanding of risk, which paved the way for the financial crisis, is driven by our failure to properly account for the properties of money. Bringing money back into the picture does far more, though, than tweak the way we model the financial sector; it alters our most basic understanding of how the economy works, and therefore upends our ontological framework of commonly accepted (and often unspoken) assumptions and working practices for things like risk, forecasting and decision making under uncertainty. This affects even areas that seem far removed from finance.

The paper begins by looking at traditional theories of money, and shows that the Newtonian, mechanistic approach favoured by mainstream economics leads to the view that money has little importance. We then recap, from a preceding paper, an alternative perspective on money and value, inspired by non-Newtonian physics, which argues that money is an intrinsically dualistic phenomenon which binds precise number with the fuzzy concept of value. Money gains its power by forging this link, but the result frequently shows paradoxical behaviour. We show how these properties of money feed into the behaviour of the economy as a whole. The link between price and value is unstable, and this drives much of the uncertainty in the economy. The paper discusses implications for risk assessment, forecasting applications, economic modelling and decision-making under uncertainty; and concludes by arguing that a better understanding of the nature of money is a necessary first step to understanding the causes of uncertainty in economic forecasting.

2. The Role of Money

Since probably the time of its invention, a debate has raged over whether the value of money is intrinsic (a measure of inherent value), extrinsic (something assigned by the state), or a mix of the two (see, e.g., Kiyotaki and Wright, 1989). Bullionists, for example, argue that money needs to be based on a weight of precious metal, which gives it intrinsic value; while chartalists emphasise the role of the government, which backs the value of its money by accepting it for payments such as taxes (Knapp, 1924, pp. 38-39). Most mainstream economists, meanwhile, take a neutral position, which says that money has no unique or special qualities, but instead is defined by its roles, e.g. as a medium of exchange, a store of

[1] Sensitivity to initial conditions (the 'butterfly effect') is certainly a factor in nonlinear models, but a more relevant cause of forecast error is usually drawbacks in the model itself (Orrell, 2012, pp. 205-208).

value, and a unit of account (Jevons, 1875). In particular economists tend to emphasise the first: Samuelson and Nordhaus (2001, p. 511), for example, defined money as '*anything that serves as a commonly accepted medium of exchange*' (their italics). One consequence of this approach is that economic questions are reduced to abstract calculations of utility, which is assumed to be directly related to price. As we'll see, this has shaped our approach to economic modelling and decision making.

An alternative approach to the subject of money, described previously (Orrell, 2016; Orrell and Chlupatý, 2016; Orrell, 2017), is to begin with the concept of number, and its relation to the world of things. To summarise, we first define money objects to be transferable entities, created by a trusted authority, which have the special property of a *defined monetary value* – specified by a number and a currency unit. They can be a coin, a sheet of paper, or a piece of electronic information sent over a phone (as in quantum physics, with its virtual particles, the distinction between real and virtual objects is blurred). Money is treated as a fundamental quantity, and its unit specifies the currency framework, which involves political and legal factors such as the range of acceptance and other rules. The trade of money objects for goods or labour in a market means that those things also attain a numerical value (in the money's units), namely the price, in a sort of measurement process. In this 'quantum' view, market prices are therefore an *emergent property* of the system, in the sense that they emerge from the use of money objects.

Note this is not to say that money *itself* is best seen as an emergent property. Indeed, a distinguishing feature of any form of money seems to be that it is very carefully designed. Money originated in ancient Mesopotamia as a credit system in a highly-centralised urban society run by temples; coin money in ancient Greece was initially used by the army as a payment system and a means for obtaining supplies. One might argue whether cybercurrencies, such as Bitcoin, are a particularly good or stable form of money, but a great deal of effort was certainly spent in designing them in such a way that they might serve as money. Indeed, the quantum theory of money was in part motivated by the need to describe such cybercurrencies, where the 'trusted authority' backing the currency is the computer algorithm, combined with continuous network surveillance, rather than the state (Orrell, 2016). The function of money is also dependent on the exact design of legal and financial institutions, such as the banking network.

While such a definition – money objects are things with a fixed monetary value – may appear obvious to the point of truism, the objects thus described have some remarkable properties which feed into the economy as a whole. In particular, money objects have both a physical aspect and a virtual aspect which is expressed through interactions, in the same way that a subatomic object like an electron or photon has a dual wave/particle nature. The dualistic, two-sided nature of money means that it frequently shows paradoxical behaviour.

The dual properties of money also resonate with human psychology and make it a strongly psychoactive substance which elicits powerful responses. On the one hand, the fact that money involves ownership makes it an effective emotional and motivational tool; but on the other hand, the fact that it is based on number encourages analytical thinking and the tendency to reduce complex social exchanges to a one-dimensional computation. It is not surprising then that money has conflicting effects, or that our response to it is far from being purely mechanical, rational, or predictable, as behavioural economists (and, for that matter, most humans) have long noted. The idea of rational economic man, central to the utility maximisation assumed in orthodox models, seems anachronistic when money is involved, which is one reason money has been excluded from models.

Another effect of money and debt is to act as a sort of entanglement device. One of the more puzzling aspects of quantum physics is that particles can become linked so that a measurement of one instantaneously affects the behaviour of the other, even if it is on the other side of the universe. A similar (if less mysterious) phenomenon occurs in the economy, where the creation of money entangles the user of the currency with the issuer, so, for example, users of the euro currency are affected by events in the eurozone. Most money today is created by private banks through issuing loans, which entangle the debtor and creditor so that a change in the status of one (such as bankruptcy) instantaneously affects the status of the other. Financial instruments, such as derivatives, create a complex web of entanglements which sits above the financial system.

Of course, the comparison of economics with physics should not be taken too far, and our aim here is by no means to further mathematicise the subject, or produce a quantum mechanics of the economy – but at least if we are going to draw on physics, as economists routinely do, we should draw on the right kind of physics. Economics is steeped in scientific metaphors whose roots are in Newtonian or Victorian science. The idea of 'utility' for example was envisaged by its Victorian founders as a sort of pleasure energy, rather like heat, but without the meaningful physical units (Edgeworth, 1881). This equation of utility and energy turned economics into a kind of mechanical optimisation problem – what Jevons called a 'mechanics of self-interest and utility' (Jevons, 1957, pp. xvii–xviii) – with prices serving as a relative measure of utility, and therefore value. Today, economic models work in terms of relative prices, but are understood to be optimising utility.

This assumption, that market prices and value are effectively the same thing, is equivalent to collapsing the two aspects of money to a single point. Money objects therefore have no special properties, they just happen to be convenient for exchange. But this Newtonian, mechanistic approach fails in economics in much the same way that it breaks down in physics. Particles are not just self-contained billiard-ball-like objects, and neither is money; both embody dual properties which need to be taken into account. And rather than being based on a deterministic map, the link between price and a meaningful measure of value – like perceived utility – is loose and unstable. This has implications for how we analyse economic uncertainty and make predictions.

3. Risk Analysis and Forecasting

A cherished goal of mainstream economics has long been to link microeconomics and macroeconomics, the individual and the economy as a whole, and include them in a single mechanistic model, thus allowing us to predict the economy the same way we predict a physical system. This reductionist approach also underlies risk analysis and forecasting models. The role of money has traditionally been excluded, because it is assumed that prices reflect rational calculations of utility. However, if prices are seen as emerging out of the complex, fluid interactions of the money system, the reductionist approach makes as much sense as an engineer trying to use atomic physics to compute the turbulent flow of water.

Consider, for example, the standard techniques used to assess risk in financial markets, such as Value at Risk (VaR). These methods were inspired by Eugene Fama's efficient market hypothesis, which assumed that 'in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value' (Fama, 1965, p. 4). While, 'in an uncertain world the intrinsic value of a security can never be determined exactly ... the actions of the many competing participants should cause the actual price of a security to wander randomly about its intrinsic value' (Fama, 1991). It was later noted, for example, that due to the 'joint-hypothesis problem' one can't actually test the intrinsic value without making further hypotheses about future returns, which are also affected by things like the discount rate (Cochrane, 2011), but these details didn't change the central message that the current price was the best estimate of intrinsic value.

In risk models price changes are, therefore, treated as random perturbations to this assumed steady state, and are modelled by statistical techniques, such as the normal distribution. The standard deviation of the price is found by setting it equal to the standard deviation of price changes over a certain recent period (typically a few months or years). The risk of the price changing by a certain amount is then easily computed. Unfortunately, the method is not very reliable. In 2007, as just one example, the CFO of Goldman Sachs complained that they were seeing what amounted to 25-standard-deviation moves, not once but several days in a row, which has a probability of approximately zero (Tett and Gangahar, 2007).

If we treat prices, not as an accurate measure of 'intrinsic value' or utility, but as an emergent phenomenon, which imperfectly reflects a societal idea of value, then it no longer makes sense to assume that prices are at equilibrium, or that price changes follow a normal distribution, or that future volatility can be reliably approximated from past volatility. If we treat money as a psychoactive quantity, it is not appropriate to treat the market as made up of rational investors whose collective actions somehow drive prices to their 'correct' level. And if we acknowledge the entangled nature of the credit system, it no longer makes sense to view investors as independent. Instead, the quantum uncertainty at the heart of money feeds directly into the economy. In place of a 'mechanics of self-interest and utility' we have something much more subtle, shifting and elusive.

An asset's price is affected by many things including investor psychology, or changes in credit availability, and sentiment, too, can change in an instant – regardless of past performance. The 'bounded rationality' described in behavioural economics doesn't quite capture the extreme swings in opinion which characterise financial crises. Taking this uncertainty into account shows that it is unsafe to assign near-zero probabilities to extreme events, or assume that risk can be hedged away based on mathematical modelling of different assets. (Traders of course know this better than most modellers, but financial incentives mean that they often prefer to use models that underestimate risk when there are profits to be made – see Wilmott and Orrell, 2017.) Model assumptions quickly become invalid, as everyone tries to exit their positions at the same time, and price movements become highly correlated.

The field of quantum finance also takes a quantum approach, in that it models assets such as stocks as having a value that is fundamentally indeterminate, and uses the quantum formalism to come up with its own versions of formulae, such as the Black-Scholes equation, for pricing options (Haven and Khrennikov, 2013). A key difference is that, while these models are usually based on those from mainstream economics – Baaquie (2000, p. 1) wrote, for example, that 'No attempt is made to apply quantum theory in re-working the fundamental principles of finance' – the aim of this paper is exactly to argue that those principles are not valid, because of the nature of money (which, as in other areas of economics, is not discussed much in finance). However, quantum money and quantum finance share the basic insight that prices are best seen as indeterminate, with their values only revealed during transactions, rather than simply as random variables.

4. Macroeconomic Models

As another example of the reductionist approach to economic modelling, policy makers continue to rely on so-called dynamic stochastic general equilibrium (DSGE) models in order to assess how a change in government policy, such as a trade agreement, will affect the economy. As the Bank of England's Andrew Haldane observes, these models typically incorporate an equilibrium which is 'unique, stationary and efficient,' a view of the economy which is 'ordered and rational,' and result in dynamics which are 'classically Newtonian, resembling the damped harmonic motion of Newton's pendulum' (Haldane, 2014, p. 3). Unfortunately, this elegance comes at the expense of realism. In particular, as William White (2013, p. 13) points out, 'An important practical aspect of [DSGE] models is that they make no reference to money or credit, and they have no financial sector'. The model used by the Bank of England to simulate the economy before the recent banking crisis, for example, had the singular disadvantage of not including banks. In fact, as White observes, 'such crises were literally ruled out in DSGE models by the assumption of self-stabilisation'. The result, according to Haldane (p. 4), is that DSGE models 'have failed to make sense of the sorts of extreme macro-economic events, such as crises, recessions and depressions, which matter most to society'.

Some DSGE models do make steps towards including a financial sector. An early attempt was the 'financial accelerator' of Bernanke, Gertler and Gilchrist (1996), which accounted for the fact that borrowing costs are inversely related to the borrower's net worth. However, while this addressed changes in credit *allocation*, it did not address the issue of credit *creation* by banks, i.e. the new money produced by making loans. A number of more recent models do include this aspect, but here the greatest challenge is that 'banks that create purchasing power can technically do so *instantaneously* and *discontinuously*, because the process does not involve physical goods, but rather the creation of money through the simultaneous expansion of both sides of banks' balance sheets' (Jakab and Kumhof, 2015, p. ii.). As discussed further below, this does not fit easily with the core idea of DSGE models, which is that economic variables are continuous and self-stabilising.

Clearly we cannot understand economic uncertainty unless we first acknowledge the role of money and the financial sector; but a deeper problem is the picture of the economy as a utility-maximising machine which, in turn, is based on ideas about money. If we remove the foundational assumption that monetary values measure (in a proportional sense) the energy-like quantity of utility, and see them instead as numbers that are subject to a variety of nonlinear and discontinuous forces, then these complicated attempts to optimise the economy come apart rather quickly.

These shortcomings of conventional models are particularly important in a world economy which is increasingly dominated by debt. According to mainstream economics, as summarised by Ben Bernanke (1995, p. 17), the debt cycle 'represent[s] no more than a redistribution from one group (debtors) to another (creditors)'. In this linear view of the economy, debts and credits cancel each other out in the aggregate, just as the two sides of money are assumed to merge into a neutral chip. However, this again ignores the pivotal role of private banks, who act as a kind of amplifier on the system, by accelerating money creation when times are good, and decelerating it when times are bad. It also ignores the entangling effects of money and debt. While debts may cancel out in a numerical sense, the power relationships they embody do not, and nor does their vulnerability to sudden and discontinuous change. These aspects were dramatically demonstrated during the crisis when some massive firms at the center of the financial network, such as AIG, had to be bailed out by the government. The nominal value of all derivatives in existence has been estimated at over a quadrillion dollars; it is unlikely that this will simply aggregate out in the next crisis (Wilmott and Orrell, 2017).

5. The Uncertainty Principle

In quantum physics the uncertainty principle states that, at a subatomic level, quantities such as position or momentum can be known only approximately; measuring one introduces uncertainty in the other. It arises because of the dual wave/particle nature of matter. A particle's position is described by a probabilistic wave function, and is undetermined until it 'chooses' a value during a measurement. Similarly, in the economy, prices are not precisely determined from fundamental properties, nor do they measure some quantity such as utility or labour. Instead they are assigned as an emergent property of the money system and are only indirectly related to the concept of value. Prices are measured through monetary transactions – i.e. exchanges of money objects – which themselves influence the price of the thing being purchased, just as measuring an electron's position by bouncing photons off it changes its momentum.

Economics, therefore, has its own version of an uncertainty principle, which is rooted in the fundamental incompatibility, inherent in money, between precise number and fuzzy value, but feeds through into the rest of the economy as well. In some ways the situation is even worse than in physics, since there is no Heisenberg to tell us a bound on the range of uncertainty. However, this does not mean that we should throw up our arms in despair. Indeed, the message is the opposite: by understanding money we can reduce the uncertainty in the economy.

Acknowledging the dynamic and inherently uncertain behaviour of money changes the way we see the economy, from a mechanical process to a living system, in which money plays the role of a biologically (or psychologically) active substance. This shift in perspective, in turn, affects the way we treat risk and make predictions. If we see price as an emergent feature of the economy, then we can look for general design principles which will help us to reduce risk in the first place. Instead of relying on reductionist models, it makes more sense to use a systems approach that exploits techniques such as complexity theory, network theory and nonlinear dynamics (developed for the study of complex organic systems) and incorporate lessons from other life sciences such as ecology and systems biology (Orrell and McSharry, 2009). And instead of trying to predict the exact timing of market crashes, or the precise economic effects of a trade agreement or a new technology, we should adopt an approach which emphasises humility; search for ways to improve robustness; and retain a flexibility and agility which acknowledges that the future is unlikely to resemble the past. Models are best seen as patches which capture some aspect of the complex system.

Viewed this way, the predictive uncertainty that we confront in economics is not so different from the uncertainty that is taken for granted in other fields where living things are involved, such as medicine. Perhaps the problem is that, because money is based on number, we have become used to the idea that the economy is a kind of predictable, mechanical system – rather than something with a life of its own. But as we've seen, numbers are only one side of the story.

For example, merely bolting a simulated financial sector onto existing DSGE models is unlikely to lead to more accurate predictions. A problem with reductionist models of any sort is that, as they are made more detailed, the number of unknown parameters, whose values cannot be accurately inferred from the data, tends to explode (sometimes called the identification problem, see Romer, 2016). This is one reason why, paradoxically, simple models often outperform complicated models at making predictions (Makridakis and Hibon, 2000). As Benes, Kumhof and Laxton note, DSGE models do not escape this problem when a financial sector is added:

> 'The existence of nonlinearities, and of evolving financial sector policies to guard against financial crises, poses some very difficult estimation issues. It is well known that the estimation of nonlinear models can require much larger sample sizes to identify functional forms and to detect the very existence of nonlinearities' (Benes, Kumhof and Laxton, 2014, p. 48).

The turbulent, unstable nature of the money system also means that the convenient assumptions of equilibrium, rationality and utility-optimisation – which form the basis of DSGE models – no longer apply. A better approach may be to use simpler (but nonlinear) models that capture the important dynamics (see, e.g., Keen, 2017), while providing realistic, empirically-based estimates of uncertainty. There is also, certainly, a role for more complicated approaches, such as agent-based models (Bruno, Faggini and Parziale, 2016), however these typically involve a large number of parameters and may be better suited to exploring the dynamics of a system than making specific predictions.[2] Statistical approaches, such as machine learning, are also useful for finding patterns in large quantities of data (but rely on the future resembling the past).

As another example, forecasters are frequently asked to spot economic bubbles and predict when they will burst.[3] However, since prices are only loosely tethered to the fuzzy concept of value, and their movements are subject to investor dynamics and psychology, it follows that asking forecasters to predict the exact timing of a crash is no more reasonable than asking a doctor to tell a patient the exact date of a future heart attack. A more realistic approach is to estimate the expected losses under extreme 'fire sale' conditions, and propose ways to protect against these losses (Wilmott, 2001, pp. 505-526).

We can also search for indicators – similar to the biomarkers used in medicine – which warn of the probability of a crash. As Hyman Minsky (1972) showed, one of the main nonlinear feedback loops affecting the price of assets, from stocks to houses, is the credit cycle. The money supply is dominated by bank lending, particularly mortgages, which occurs at a heightened level when economic conditions are good. The easy access to credit drives further price growth in a positive feedback. The process therefore tends to run out of control until reaching a crisis point. Although again the system is not easy to predict – the nonlinear feedback loops make it that way – excessive credit growth can be monitored and used as a warning signal (Eidenberger, Neudorfer, Sigmund and Stein, 2014). It may also be possible to modify the design of the financial system to reduce such feedback loops in the first place. A radical, if often-proposed, step would be to move towards full reserve banking, which takes private banks out of the money creation process altogether (Soddy, 1926).[4]

6. Frame Shift

The uncertainty introduced by the fluid, unstable relationship between price and value affects areas of modelling that may seem far removed from the dynamics of money. The problem is that decision makers have, in many cases, been sold a lie: mechanistic models based on economic principles promise to reduce any problem to abstract calculations of utility, and any shortcoming can be repaired by adding more detail. Ideas about money are, of course, not the only reason for this approach, but they act as a kind of lynch pin which justifies its use.

[2] As an example from a different context, see Orrell and Fernandez (2010).
[3] Not everyone admits that bubbles exist. As Eugene Fama told the *New Yorker* magazine, 'I don't even know what a bubble means' (Cassidy, 2010).
[4] The same idea has been proposed by a number of economists including Henry Simons, Irving Fisher, Frank Knight, Milton Friedman and Herman Daly.

Consider, as a basis for tackling complex modelling issues, the following two belief sets:

(1) The economy is essentially a machine for optimising utility through barter, and utility can be inferred from prices. Any problem can be approached by breaking it down into parts (e.g. investors, companies), expressing the interactions between the parts in terms of general 'laws', and solving. Model inaccuracies can be addressed by adding more detail. Uncertainty can be computed by taking into account stochastic variations around an equilibrium, rather than through comparisons of the model's performance with reality.

(2) Prices are an emergent feature of market interactions, and are only loosely tethered to the fuzzy social concept of value. Rather than break a complex problem down into parts, it makes more sense to choose the appropriate level of analysis. The preference is for simple models that can be accurately parameterised from existing data. Uncertainty cannot be precisely calculated, but can be estimated based on, for example, a model's track record. Model predictions are compared with actual results, and are updated using a Bayesian approach.

An example of an area where approach (1) is the default, is that of transport forecasting (Forster, 2015). A 2006 study led by economic geographer Bent Flyvbjerg showed that for rail projects, passenger numbers were overestimated in 90 percent of cases, with an average overestimation of 106 percent (Flyvbjerg, et al., 2006). Forecasts were more accurate for road projects, but half had a difference between actual and forecast traffic of more than +/-20 percent, and in a quarter of cases the difference was more than +/-40 percent. Forecast accuracy showed no signs of improving with time, or with more advanced models or computer power. As with VaR or DSGE models, such models reflect an essentially static model of the economy; and they fail to take into account the fact that passengers elect to use, say, a train over their car, is not just the mechanical result of utility optimisation, but involves the same kind of complex, context-dependent interplay between price and value that is at the heart of money (for example, money spent on a car may be experienced very differently from money spent on public transport).

As Flyvbjerg et al. (pp. 13-14) note, the lack of progress in predictive accuracy in recent decades suggests that 'the most effective means for improving forecasting accuracy is probably not improved models but instead more realistic assumptions and systematic use of empirically based assessment of uncertainty and risk'. Model simulations can also be coupled with scenario forecasting techniques to sketch out a range of alternative futures (Zmud et al., 2014). But this change in perspective, and a shift from approach (1) to approach (2), ultimately requires a re-evaluation of the relationship between price and value and, by implication, the role of money.

This view of economic uncertainty in some ways resembles the one promoted by Keynes in his *General Theory of Employment Interest and Money*, the title of which was apparently inspired by Einstein's *General Theory of Relativity* (Galbraith, 1994). According to Keynes, money can be viewed as a type of asset, and the demand for it depends on a number of factors. For example, if investors believe that bonds are overpriced, they may prefer to keep funds in cash; if they are confident in a particular enterprise, they may decide to borrow to invest; or if conditions are highly uncertain, they may decide to hoard savings in the form of cash. Such decisions inevitably rely on views about the future, which are highly uncertain:

> 'If we speak frankly, we have to admit that our basis of knowledge for estimating the yield ten years hence of a railway, a copper mine, a textile factory, the goodwill of a patent medicine, an Atlantic liner, a building in the City of London amounts to little and sometimes to nothing; or even five years hence' (Keynes, 1936, pp. 149-150).

One of the roles of the money system as an institution is to meet these fluctuating requirements. A difference is that in the quantum approach, uncertainty is viewed, not just as the result of future unknown fluctuations in the economy, but as an inherent feature of the financial system arising directly from the nature of money.

7. Conclusion

The traditional test of scientific models has long been to make empirically validated predictions. By this standard, economic models have failed spectacularly. But a greater concern is that when misused they actually help to create risk and instability. By modelling the economy as an inherently stable system, they give a false sense of security. One of the main causes of the 2008 crash was exactly the risk models and DSGE models which ignored the effects of money. These models encouraged risk taking by assuring us that risk can be calculated – and even removed using hedging strategies. Modellers therefore have an ethical requirement to address these issues (DeMartino and McCloskey, 2016), and a first step is to acknowledge the active role of money, and the unstable link it forges between price and value.

Money is not a neutral medium of exchange, but a remarkably complex substance which has profound effects both on the human mind, and the economy as a whole. Its power lies on its unique combination of the properties of number, with those of an owned thing. Searle, for example, compares ownership of money with possession of a queen in the game of chess. The latter,

> 'is not a matter of my having my hands on a physical object, it is rather a matter of my having certain powers of movement within a formal system … relative to other pieces. Similarly, my having a thousand dollars is not a matter of my having a wad of bills in my hand but my having certain deontic powers. I now have the right, i.e. the power, to buy things, which I would not have if I did not have the money' (Searle, 2005, p. 16).

However money is a special kind of institution, and has a special kind of power, because of its association with number. This is why currencies used in games can, quite often, cross over and be used as a form of money to buy things in the real world (Castronova, 2014), but chess pieces can't.

Acknowledging that market prices are an emergent phenomenon of the money system changes our ontological framework for economic modelling and helps us to make decisions under uncertainty in two ways. The first is that it shifts our mental perspective from seeing the economy as an essentially stable, optimal, mechanical system to seeing it as a dynamic, organic system; and from treating it as a highly-tuned machine that occasionally breaks for no apparent reason, to a lively system where change is the norm. This, in turn, means that probabilistic risk models based on assumptions of stability and efficiency, and traditional hedging instruments which attempt to remove that risk, should be replaced by models which acknowledge that the risk is not something that can be precisely calculated or simply engineered away. Complicated models based on detailed calculations of utility should be replaced by simpler and more transparent models based on more realistic assumptions. And models used to forecast the economy should account for money, debt and the financial sector.

Secondly, an appreciation of the fluid and connected nature of money points towards ways of making the economy more stable. Only by seeing risk can we do something about it. For example, we can learn from properties, such as redundancy and modularity, which lend stability to natural systems such as ecosystems (May, Levin and Sugihara, 2008).

Finally, and on a less serious note, forecasters have long tended to favour theories which give them an excuse for prediction error. According to efficient market theory, markets are unpredictable because they are so perfect that all changes are completely random and no one can beat the market. According to the butterfly effect, even tiny changes to a chaotic system – be it the weather or the economy – can lead unpredictably to large effects down the road. However, the problem with markets from a quantum perspective is not that they are completely random or chaotic but that, like quantum matter, they have uncertainty built in. While this may seem like bad news for forecasters, it does at least offer the perfect excuse when predictions go wrong: forecasting the economy is more difficult than quantum physics.

Acknowledgements

The author would like to thank the editors and two reviewers, Menno Rol and James Culham, for their insightful comments which prompted a number of improvements and clarifications in the text.

References

Ahir, H. and Loungani, P. (2014) *Can economists forecast recessions? Some evidence from the Great Recession.* Discussed in Harford, T. (2014) 'An astonishing record – of complete failure.' *Financial Times,* May 30.

Arrow, K. J. and Debreu, G. (1954) 'Existence of a competitive equilibrium for a competitive economy.' *Econometrica,* 22, pp. 65–90.

Baaquie, B. E. (2007) *Quantum Finance: Path Integrals and Hamiltonians for Options and Interest Rates.* Cambridge: Cambridge University Press.

Benes, J., Kumhof, M. and Laxton, D. (2014) 'Financial crises in DSGE models: a prototype model.' *IMF Working Papers,* 14 (57).

Bernanke, B. (1995) 'The macroeconomics of the Great Depression: a comparative approach.' *Journal of Money, Credit, and Banking,* 27 (1), pp. 1–28.

Bernanke, B. (2009) Commencement address at the Boston College School of Law. Newton, MA, 22 May.

Bernanke, B., Gertler, M. and Gilchrist, S. (1999) 'The financial accelerator in a quantitative business cycle framework.' In J. Taylor, and M. Woodford (Eds.) *Handbook of Macroeconomics*, Vol. 1, pp. 1341-1393). Amsterdam: Elsevier.

Bruno, B., Faggini, M. and Parziale, A. (2016) 'Complexity modelling in economics: the state of the art.' *Economic Thought* 5, (2), pp. 29-43 http://et.worldeconomicsassociation.org/files/WEA-ET-5-2-Bruno-et-al.pdf

Castronova, E. (2014) *Wildcat Currency: How the Virtual Money Revolution Is Transforming the Economy Hardcover.* New Haven, CT: Yale University Press.

Cochrane, J. H. (2011) 'Presidential address: discount rates.' *The Journal of Finance,* 66 (4), pp. 1047-1108.

DeMartino G. and McCloskey D. (Eds.) (2016) *The Oxford Handbook of Professional Economic Ethics*. Oxford: Oxford University Press.

Edgeworth, F.Y. (1881) *Mathematical psychics: An essay on the application of mathematics to the moral sciences.* London: C.K. Paul.

Eidenberger, J., Neudorfer, B., Sigmund, M. and Stein, I. (2014) 'What Predicts Financial (In)Stability? A Bayesian Approach'*.* Deutsche Bundesbank Discussion Paper 36/2014.

Fama, E. F. (1965) *Random walks in stock-market prices.* Chicago: Graduate School of Business, University of Chicago.

Fama, E. F. (1991) 'Efficient capital markets II.' *The Journal of Finance,* 46 (5), pp. 1575-1617.

Forster, A. (2015) 'Can anyone save us from the misuses of transport modelling?' *Local Transport Today*, 13 November.

Flyvbjerg, B., Holm, M. S., and Buhl, S. L. (2006) 'Inaccuracy in traffic forecasts.' *Transport Reviews,* 26 (1), pp. 1-24.

Galbraith, J. (1994) 'Keynes, Einstein, and scientific revolution.' *The American Prospect*, 5 (Winter), pp. 62-7.

Haldane, A. (2014) 'The Revolution In Economics' in *Economics, Education and Unlearning: Economics Education at the University of Manchester*, pp. 3-6. Manchester: Post-Crash Economics Society.

Haven, E. E. and Khrennikov, A. (2013) *Quantum Social Science.* Cambridge: Cambridge University Press.

Jakab, Z. and Kumhof, M. (2015) 'Banks are not intermediaries of loanable funds – and why this matters.' *Bank of England working papers* 529.

Jevons, W. S. (1875) *Money and the Mechanism of Exchange.* New York: D. Appleton & Co.

Keen, S. (2015) *Will We Crash Again? FT/Alphaville Talk.* Available at: https://www.youtube.com/watch?t=130andv=JKy6_yy3C3U

Keen, S. (2012) *The IMF Gets Radical?* Retrieved from Business Spectator: November 5. Available at: http://www.businessspectator.com.au/article/2012/11/5/business-spectator/imf-gets-radical

Keynes, J. M. (1936) *The General Theory of Employment, Interest and Money.* New York: Harcourt, Brace.

Kiyotaki, N. and Wright, R. (1989) 'On money as a medium of exchange.' *The Journal of Political Economy,* 97 (4), pp. 927-954.

Knapp, G. (1924) *The State Theory of Money.* London and New York: Macmillan.

Lucas, R. (2009) 'In defence of the dismal science.' *The Economist,* August 6.

Makridakis, S. and Hibon, M. (2000) 'The M3-Competition: results, conclusions and implications.' *International Journal of Forecasting,* 16, pp. 451–76.

May, R.M., Levin, S.A. and Sugihara, G. (2008) 'Ecology for bankers.' *Nature*, 451, pp. 891–93.

Minsky, H. P. (1972) 'Financial instability revisited: the economics of disaster.' In: *Reappraisal of the Federal Reserve Discount Mechanism*, pp. 95–136. Washington, DC: Board of Governors of the Federal Reserve System.

Ormerod, P. (2000) *Butterfly Economics: A New General Theory Of Social And Economic Behavior.* New York: Basic Books.

Orrell, D. (2012) *Truth or Beauty: Science and the Quest for Order.* New Haven, CT: Yale University Press.

Orrell, D. (2016). 'A Quantum Theory of Money and Value.' *Economic Thought*, 5.2, pp. 19-28 http://et.worldeconomicsassociation.org/files/WEA-ET-5-2-Orrell.pdf

Orrell, D. (2017) *Economyths: 11 Ways That Economics Gets it Wrong.* London: Icon Books.

Orrell, D. and Chlupatý, R. (2016) *The Evolution of Money*. New York: Columbia University Press.

Orrell, D. and Fernandez, E. (2010) 'Using predictive mathematical models to optimise the scheduling of anti-cancer drugs.' *Innovations in Pharmaceutical Technology,* 33, pp. 58–62.

Orrell, D. and McSharry, P. (2009) 'System economics: Overcoming the pitfalls of forecasting models via a multidisciplinary approach.' *International Journal of Forecasting,* 25, pp. 734–743.

Romer, P. (Forthcoming) 'The Trouble With Macroeconomics.' *The American Economist*. Available at: https://paulromer.net/the-trouble-with-macro/

Samuelson, P. A. and Nordhaus, W. D. (2001) *Economics,* (17th ed.). Boston, MA: McGraw-Hill.

Searle, J. R. (2005) 'What is an institution?' *Journal of Institutional Economics,* 1 (1), pp. 1-22.

Soddy, F. (1926) *Wealth, virtual wealth and debt. The solution of the economic paradox.* New York: Dutton.

Tett, G. and Gangahar, A. (2007) 'Limitations of computer models.' *Financial Times,* 14 August.

Turner, A. (2014) 'Printing money to fund deficit is the fastest way to raise rates.' *Financial Times*, 10 November. Available at: http://www.ft.com/intl/cms/s/0/8e3ec518-68cf-11e4-9eeb-00144feabdc0.html/

White, W. R. (2013) 'Is monetary policy a science? The interaction of theory and practice over the last 50 years.' In: M. Balling, and E. Gnan (Eds.), *50 Years of Money and Finance – Lessons and Challenges.* Vienna: SUERF.

Wilmott, P. (2001) *Paul Wilmott Introduces Quantitative Finance*. Chichester: John Wiley.

Wilmott, P. and Orrell, D. (2017) *The Money Formula: Dodgy Finance, Pseudo Science, and How Mathematicians Took Over the Markets*. Chichester: Wiley.

Zmud, J. P., Barabba, V. P., Bradley, M., Kuzmyak, J. R., Zmud, M. and Orrell, D. (2014) *Strategic Issues Facing Transportation, Volume 6: The Effects of Socio-Demographics on Future Travel Demand.* NCHRP Report.

SUGGESTED CITATION:

Orrell, D. (2017) 'A Quantum Theory of Money and Value, Part 2: The Uncertainty Principle.' *Economic Thought*, 6.2, pp. 14-26. http://www.worldeconomicsassociation.org/files/journals/economicthought/WEA-ET-6-2-Orrell.pdf