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

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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 and economic forecasting 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.

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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 & 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 are the first things that come 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 transactions. 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 previous article in *Economic Thought*, 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, 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.

[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, 205-208.

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) or extrinsic (something assigned by the state). Bullionists for example argue that money needs to 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 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 in (Orrell, 2016; Orrell and Chlupatý, 2016), 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 attain a numerical value (in the money's units) as well, namely the price, by a kind of contagion. 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.

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 behavioral economists (and for that matter most humans) have long noted. The idea of rational economic man, central to the utility maximization assumed in orthodox models, falls apart rather quickly when money is involved, which is one reason money has been excluded from models.

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, xvii–xviii) – with prices serving as a measure of utility, and therefore value.

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. This is especially the case when it comes to analysing economic uncertainty and making 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 assumes that market prices accurately reflect the 'intrinsic value' of the underlying asset (Fama, 1965). Price changes are treated as random perturbations to this steady state, caused by the reaction of independent, rational, utility-optimising investors to events such as news or announcements. They can therefore be 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 things that were 25-standard-deviation moves, several days in a row' (Tett & Gangahar, 2007). A 25-standard-deviation event is something that is not expected to happen even once in the duration of the universe.

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. And if we treat money as a psychoactive quantity, it is not appropriate to treat the market as made up of rational, independent investors whose collective actions somehow drive prices to their 'correct' level. 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, and sentiment can turn on a dime – regardless of past performance. The 'bounded rationality' described in behavioural economics doesn't quite capture the extreme swings in sentiment 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 & Orrell, 2017.) Model assumptions quickly become invalid, as everyone tries to exit their positions at the same time, and price movements become highly correlated.

As another example, 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). Unfortunately, this elegance comes at the expense of realism. In particular, as former Deputy Governor of the Bank of Canada William White (2013) 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.'[2] 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, 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.'

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 the energy-like quantity of utility, then these complicated models 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), 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 ignores the pivotal money creation role of private banks, who act as a kind of amplifier on the system. It is therefore unsurprising that central banks were surprised by the crisis (it involved debt).

4. 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 economomy, prices are not precisely determined from fundamental properties, and 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.

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

[2] An exception is that used in Benes & Kumhof, 2013, which Steve Keen described as 'the first theoretical neoclassical paper to acknowledge the actual nature of banking, and to try to take this into account in a mathematical model.' Keen, 2012.

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 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 and network theory – developed for the study of complex organic systems, and incorporate lessons from other life sciences such as ecology and systems biology (Orrell & 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). 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, while providing realistic, empirically-based estimates of uncertainty. There is certainly also a role for more complicated approaches such as agent-based models (Bruno, Faggini & 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.[3] 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.[4] 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, & Stein, 2014). It may also be possible to modify the design of the financial system to reduce such

[3] As an example from a different context, see Orrell & Fernandez, 2010.
[4] 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.

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).[5]

5. 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.

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 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 preciesly calculated but can be estimated based on e.g. 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 forecasted 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 fail to take into account the fact that passengers electing 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 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 reevaluation of the relationship between price and value, and by implication the role of money.

[5] The same idea has been proposed by a number of economists including Henry Simons, Irving Fisher, Frank Knight, Milton Friedman, and Herman Daly.

6. 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. 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 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 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 & 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 prediction 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.

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