GRESHAM COLLEGE

7 FEBRUARY 2019

BUBBLES, MANIAS AND MARKET FAILURES

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Thank you all, it's a great honour to be here. This is actually my second time lecturing in this hall. I was first here about 5 years ago in 2013 when I was talking about something else entirely. I'm thrilled to be back, and I would like to thank Michael Mainelli, who is not here, for in fact convincing me to do this for a second time.

Tonight, I'll talk about bubbles, manias and market failures and particularly about the unintended consequences of regulatory responses to these events. And I think when you begin talking about the subject, it's almost imperative that you start with Tulipmania which is the paradigmatic early-modern financial crisis.

Some of you may recognise this wonderful print from 1637/38 by Peter Nolpe which shows a fool's cap in which people are playing a gambling game that was played in the inns near the flower markets. It was a kind of auction game, bit of a spread-betting game in which they bid up the price of tulips. And this print shows the devastation that Tulipmania was supposed to have caused to the morals and the economic welfare of the Dutch republic.

Now most of when we actually see copies of this print, don't see the copies from the 1636-37 but rather recycled copies from the 1720s in a much different context. We'll talk in a moment about that context. But the important thing is to realise that this was a speculative mania putatively in tulips. When you begin to look at it, you realise that it's actually in these exotic tulips, the Semper Augustus tulip, which is pictured on the side as an example. These exotic tulips were actually diseased. They had a kind of plant-lice that caused them to create these wonderful patterns. In order to replicate the patterns, you then had to clone the tulips, which is a feature of tulip biology. This meant the tulips became more fragile and more diseased in subsequent generations. Cultivating these tulips was quite a risky business. Not every tulip you put in the ground came out in six months. There was indeed in the 1630s a bit of a speculative bubble in these tulips. But the mythology of Tulipmania actually combined this speculative bubble in these tulips with the much more conventional garden variety bubble in common tulips that was occurring in these flower markets largely because many people were trapped in Dutch cities and towns because of the plague; the harbours were closed, the 30 years war was raging on, and over the winter and spring of 1636-37, all this speculative activity was occurring. It came to the attention of the Dutch authorities and they were quite keen to put a stop to it.

But in any case, the details of this Tulipmania have been mythologised in such a way that it's become a kind of ideal-type of the speculative bubble. Why is that important? Because many of these myths essentially exist to the present day. People think about tulips as 'fetish' objects. Every time you get a financial innovation, whether it's derivatives or the Bitcoin blockchain, someone in *The Economist* pens an editorial saying Bitcoin is like, "Tulipmania – there was this speculative bubble in the 1630s, the whole thing is going to end in tears. The government should do something." This notion of these tulips as fetish objects is something that has come into the conventional wisdom even though what happened at the time was quite a bit more complicated.

The other thing that is interesting is this notion of these irrational prices that were being paid; the idea of over £10,000 per bulb in 1637 money. That's clearly a lot of money because a middle-class family in London or Amsterdam could survive on £50-70 a year in the 1630s. So, these are outlandish prices that were purportedly paid, and they are quoted as gospel when thinking about this bubble. So there is this notion that the prices crashed

back to 3-5% of the high and that's the kind of thing that regulators want to discourage because [we are meant to agree] that's clearly bad for society if people are speculating in this way.

The resulting myth was that the entire society was involved in some way, that the poor were preyed upon, that people were committing suicide in the wake, that people were selling their houses, mortgaging their shares in the Dutch East Indian Company in order to speculate on this, and even by the time you got to the 20th century, in historical literature people were saying this was the cause or possibly symptom of Dutch decline, the end of the Dutch golden age was all because of this Tulipmania and as a consequence, it's very important that regulators do something to stop this. So you've got this myth that has come down to us over the ages that gets magnified in every retelling.

Perhaps the version that you are most familiar with is the kind that gets peddled in *The New York Times* or maybe *The Atlantic* of the 'return of the repressed', that society represses the last memory of the financial bubble and that it returns in another form, say Bitcoin or credit-default swaps, dot.com mania or that whatever the cartoonist is trying to satirise at the time.

These narratives are in fact very historically contingent. They have many sources each with a different context. In the case of the initial print that you saw with the fool's cap, the version that we are familiar with is not actually from the 1630s; it's actually from the 1720s. There is a compendium of cartoons after the South Sea Bubble in the Mississippi Scheme that was printed in Amsterdam that collected all satirical literature that was satirising, parodying these various bubbles, and there was even a small bubble in Amsterdam 1720, but the satirists hadn't got to work on that yet. So instead what the author of this compendium did was go back to the 1630s and collected all the cartoons he could find that were still extant from the 1630s and published those in order to satirise the bubble in the 1720s in Amsterdam, which is probably the only reason why we know about Tulipmania, because these cartoons about the 1630s were so obscure that if they hadn't been discovered and given the second life as recycled, the episode would probably have disappeared from our memory.

Many of you knew, if you knew about Tulipmania before the recent financial crisis, probably had occasion to read at university Charles MacKay's famous book *Extraordinary Popular Delusions and the Madness of Crowds*. He was a Whig journalist from the 19th century who really disliked superstition. He disliked witchcraft. He disliked what he regarded as the barbarity of the Middle Ages. And he wanted to use Tulipmania as yet another example of the absurd things that people believed in the past and the absurd things that they did. This to him was an example of what The Enlightenment had swept away. That is how Tulipmania entered the consciousness of 19th century audiences. His account relied heavily on Johann Beckmann's account, *A History of Inventions, Discoveries and Origins (1797)*, where the narrative was actually slightly different. It was about those bad forms of innovation that can tempt people, that are socially deleterious, and that we need to understand their histories so that new innovations, new inventions don't have that horrible side-effect.

Where did this all this come from beyond these prints that they saw in the 1720s in the *Great Mirror of Folly*? The sources for the actual Tulipmania episode are largely these contemporary Dutch dialogues which the Dutch Calvinist authorities had commissioned in order to lampoon what they regarded as the bad behaviour of Anabaptist flower growers. These exotic tulips were principally grown by Anabaptists, who were a religious minority and were not very liked by the Dutch Calvinists, despite the fact that there was religious toleration in Amsterdam. So the authorities commissioned these dialogues to suggest that these evil flower growers had encouraged the social disease of speculating on tulips. All those prices that people find, and all these vignettes of suicides and terrible social contagion, actually come out of these dialogues. These dialogues were just religious polemics. They're not necessarily a particularly good reflection on what was going on in the 1630s.

All this was picked up again by Keynes because he was interested in this in terms of his notions of about how animal spirits work and what can eventually be done to smooth aggregate demand and how you think about what investor confidence is. That was serendipitous because there was a Dutch historian Posthumus who was investigating the origins of the Dutch Tulipmania in the late 1920s. He happened to publish his article on this a few months before the financial crash of 1929. The fact that he published this episode about Tulipmania a few months before the crash in 1929 meant everybody who experienced the stock market crash in 1929 found Tulipmania as a good, ready analogy, good explanation of what had happened.

So you've got these various different sources of this myth. What's at stake is more than just *Schadenfreude*, laughing at the misfortune and folly of others. Was there actually something about this that's important for our understanding of these crises and how we manage them?

These are changing narratives of financial crises. The way in which they change are quite important because it's always about regulation. In the earliest incarnations, to the extent that you can find references to these in the 17th century, including those two religious dialogues I've pointed out, this is about morality tales. This is about the religious authorities' needing to impose religious uniformity, needing to discourage greed, needing to discourage idolatry, needing to say that this horrible gambling game is against the sensibilities of Dutch Calvinists and their regulatory response was to punish it as gambling with the understanding of sending a message about what was acceptable in terms of the religious values of the day.

When you fast forward to the 19th century, this is about rationality and irrationality in The Enlightenment sense. In the 1820s you had the crash of 1825. In the 1840s, you had these railway manias. It's very convenient to suggest that financial panics are on par with superstitions of unenlightened eras, equivalent to witchcraft, alchemy, mesmerism. And that was a different context because it's convenient to the people who wanted to regulate these to think of them that way.

Today, we often talk about bubbles as irrational in a psychological sense, whether it's the Freudian psychological sense of the cartoon that I showed you, which is echoed at UCL by one of my colleagues David Tuckett who talks about emotional finance, or whether it's the more conventional behavioural finance explanations of Prospect Theory, Hyperbolic Discounting, Endowment Effects – all of these are cognitive biases that make up behavioural finance. However you try to encapsulate it, this is about this notion of irrationality in a psychological sense and we have modern theories for explaining it, which give us different regulatory recommendations, whether it's having a 'market nanny' who's meant to stop speculation if it occurs, or whether it's finding some kind of a 'nudge' that encourages traders to behave more responsibly. These modern psychological theories underpin the modern regulatory response.

What we find is that things like these cartoons are actually encapsulating a modern employment of these financial crises that fits very well with the dominant theories of how regulators should respond to them, particularly this notion of 'irrational exuberance' or 'euphoria', the kind of Alan Greenspan response. It's very convenient for the regulators to point to these crises and to hive them off and explain them that way.

This is not a particularly helpful way of thinking about it. The reality behind financial crises is that we narrate them because we're trying to make sense of market failure. When markets are operating normally, success explains itself. There's no reason to try to narrate that. But once you have a market snap, whether it's a panic, or a mania or a conventional market failure, you need to find a way of explaining what has happened. All of these mythological stories are essentially nonsense but it's actually history of that nonsense that we need to understand. We need to understand why it became so important to people in the 17th century to think about it one way, the 18th century and 19th century to think about it in another way, and why the 20th century is obsessed with thinking it about it in yet a different way. You begin to see how financial crises and the regulatory responses to follow them end-up sowing the seeds, effectively, for the next crisis.

I want to pause for a moment and reflect by what we mean by unintended consequences because that's something thrown around quite often. It's a convenient trope of *The Times* or *The Economist* or *Financial Times* as centre-right and centre-left press like to talk about the unintended consequences of policies. Policymakers are not as omniscient as they think they are. And as a consequence, they can't anticipate what's going to go wrong when they take a particular course of action. That comes in the first instance from Edmund Burke who today is now often suggested to be the father of conservatism, although he would have very much rejected that because there were few people he despised in the 18th century more than Tories. He was an old Whig. He believed in the American Revolution. He didn't like the French Revolution, but he didn't like Tories either. He would absolutely refuse the label of the Father of modern conservativism.

But he did believe in two things. The first of which is also actually echoed in Adam Smith, who essentially cribs that line and gives it a different gloss. And that is that, "No man, who is not inflamed by vain-glory into enthusiasm,

can flatter himself that his single, unsupported, desultory, unsystematic endeavours, are of power to defeat the subtle designs and united cabals of ambitious citizens. When bad men combine, the good must associate; else they will fall, one by one, an unpitied sacrifice in a contemptible struggle." What he recognised was what Smith recognises, which is that when capitalists combine to restrain trade, their very success in doing so and that when regulators try to think about responses to financial bubbles, they're presented with lobbying on the part of market participants and financial capitalists who are trying to influence policy direction or the other. So Edmund Burke understood that. He was in no sense naïve about the extent to which lobbying of one description or another is something that occurs and that what we today call 'regulatory capture' is a feature of this and an important phenomenon to consider.

But Burke also understood that, "That which in the first instance is prejudicial may be excellent in its remoter operation and its excellence may arise even from the ill effects it produces in the beginning. The reverse also happens; and very plausible schemes, with very pleasing commencements, have often shameful and lamentable conclusions." Indeed, many of the well-meaning responses to regulators to financial bubbles have had shameful and lamentable conclusions. Pausing to reflect on Burke is worth doing because he was quite foresighted in recognising both of these features.

These features are part of our modern theories of regulation which fall into two categories. There is the well-known public interest hypothesis which is the ideal-normal type of regulation. You want regulation to ensure prices are affordable to consumers, and that the risks associated with financial assets is reasonably priced and transparent. You want regulation to improve and sustain service levels, particularly in financial markets, but also elsewhere. You want regulation to address market failures and externalities, especially the social impacts of whatever it is that you are trying to regulate. That's your ideal kind of type. That's what you want regulation to do. But there's also the private interest hypothesis that says, in reality regulation is a response to lobbying by producers and market participants and that regulatory capture is commonplace. And I think that probably the best way to summarise this is another cartoon, and I'm by no means targeting Goldman Sachs, this is the cartoon that has them identified but there are many bulge bracket banks that behave this way. You might just argue that Goldman Sachs is somewhat more successful than the others, but not different in character. Here you've got a journalist who's saying, "You didn't learn the lessons of the crash, did you? You're right back to the same high-risk game!" And he's saying, "That's not true!" "What's changed?" "Fewer competitors!" And indeed, the fall-out of the crash but also the regulatory response raised the barriers to entry, forced out competitors and has created an environment which is perhaps at least as risky as the one that the we faced at the beginning of the last financial crash.

That idea of regulatory capture and the unintended consequences of financial crises is something that's been baked into it for as long as we've been aware of these financial crises in markets. In order to illustrate that point, I want to look specifically at the South Sea Bubble which is the ground zero moment in the UK for thinking about crises in the financial markets. Here is a famous print of the South Sea Bubble. Most of you probably know it in rough outline. You've heard of the idea that there's the South Sea Company, that its stock runs up in value and it crashes, lots of people lose money, everybody from Locke to the Duke of Newcastle to the Duke of Portland and others were involved in this and that it was something very traumatic in early 18th century Britain, but also in France and elsewhere.

But to think about it more precisely, we need to recognise this was a crisis that always involved the government. The South Sea Company was a parastatal. It was not a fully private firm in a sense that we think of them today. In 1720, the British government debt stood at £50 million. To put that in context, the average middle-class family in 18th century London could live on £50-70 a year, so that's an awful lot of money. Debt service is eating up the revenue from the excise. So the government is cash-strapped in the 1710s and 1720s. You also have the War of Spanish Succession, which was very costly. And you have this situation where you have very large government debt. Some of it is held by three companies, all of which are familiar to you, which are effectively holding that debt on behalf of the government. The Bank of England has a fairly small share, as does the East India Company. The South Sea Company by 1720 had £11.7 million of government debt. At the same time, there were these redeemable bonds in private hands that were about £16.5 million, another £15 million in unredeemable annuities. That's how the government debt is proportioned. This is a serious crisis for the government of Britain just as the regent had a similar problem in France in 1720.

This is about state-finances as much as it is about private speculation, and to illustrate this, what you can see is that in the late 1710s, by 1715, British government debts services is eating up 60% of the revenue. This is a crisis for the government which has to decide what to do. You've got the South Sea Company which was established in 1711 by some Tories who wanted to take advantage of first of all the election in 1710 which puts them in power, and secondly the fact that it's fairly clear that the War of Spanish Succession is going to end, and that you're going to have the Commercial Treaty of Utrecht which gives an *asiento,* that is which gives the right to conduct slaving in the south seas, and the Spanish end up granting that to the British. So they wanted to take advantage of this commercial treaty. But, by 1720, its main revenue was in its finance operations on behalf of the government. In March of 1720, it won the right to acquire that last £30 million in government debt and to exchange that for shares in the company. So this is actually a government debt deal: a debt-for-equity swap. That debt-for-equity swap along with the subscription shares which allowed people to buy shares in the South Sea Company on instalment were financial innovations, so what you could do is just as you could in the '70s or '80s to buy white goods, you could buy on instalment and pay it off over time, you could buy South Sea Company shares on instalments in the 1720s, and that was part of the enticement of getting so-called retail customers into the game.

The other thing that is quite important in this context is that in 1720-21, there's this massive mega bubble in equities in London, Paris and Amsterdam. Everybody becomes interested in South American trade and wants a piece of the action so that's what makes the South Sea Company so enticing to investors in London. The Mississippi Company is likewise enticing in France. And in Amsterdam, companies that are getting into the game with South American trade were also doing very well. In Britain, that includes marine insurance companies that have invested and who have already a lot of marine insurance and as a consequence have corporate treasuries that are investing as well in share companies that are trying to get in on the trade. What happened in 1720-21 that pushed the price up very quickly is that all the major assurance companies, writing both marine and fire insurance, the London and the Royal Exchange, their corporate treasuries were investing in South Sea Company stock. That was combining to run-up the price, along with these debt-for-equity swaps, and along with instalment-shares where retail customers could buy shares over periods of time on instalment. This drove up the shares quite considerably. As you can see from this chart, you've got a period of unrelenting upward march of share prices, rather like perhaps London property in the last five or six years.

The point is, the directors become very worried that the other firms that are involved in South American trade, some of which are quite dodgy like salvage companies that are going to raise Spanish shipwrecks or new colonies or other mad schemes, are distracting investors and making them less interested in South Sea Company shares. So they lobby Parliament to introduce the Bubble Act. The Bubble Act is going to ban all of these bubble companies other than the South Sea Company, and these two London assurance companies that are important to the South Sea bubble. That ends up sending a message to the market that there's something wrong: Parliament needs to step in and ban the other types of investment. That signals that something is a bit fishy. And the bubble begins to unwind and collapses.

But the Bubble Act is passed anyway. It incorporates the Royal Exchange and the London Assurance Company which you know from most of the rest of the 18th century in terms of writing fire insurance, not marine insurance, which is what the other companies and then Lloyd's market do. All new joint stock companies have to have a royal charter which then also creates opportunities for rent-seeking and government lobbying and the subscription shares which are so popular are banned until the 1840s. Contrary to popular belief, the South Sea Company did not bankrupt the company which continued merrily along until the 1850s when it was wrapped up along with the East India Company after the Sepoy Rebellion.

Towards the end of the bubble, shares are back down to where they were before the beginning of the bubble. You have a regulatory intervention, the Bubble Act, which casts a long shadow for about a hundred years over British financial markets. What does it end up doing?

First of all, here's a share from the late 1720s, to suggest that the South Sea Company is going strong in this period. People have to invest in something. This is one of the few joint stock companies with a royal charter. But there is a long shadow that is cast over British financial markets.

We begin to see this with the Canal Mania of 1790-1815. Because you have this long period where only a handful of companies have royal charters, and as a consequence are able to trade on Exchange Alley and are essentially the blue chip stocks of the 18th century, when you start having a need to raise finance for these canals, you end up having canal companies which are very closely held in regional areas. And you have competition to build canals often right next to each other. As a consequence, the bubbles that you get from Canal Mania tend to be localised and reflect the idea that these markets are not deep enough to raise the finance necessary. What then happens is that these canal companies start flooding Parliament with private members' bills trying to get themselves royal charters. There's an enormous amount of corruption and Parliament responds in 1825 by abolishing the Bubble Act.

That creates Steamship Mania, which is the biggest stock market mania in British financial history and probably the one you've heard least about. The Steamship Mania is taking advantage of the fact that Canal Mania, despite the large amount of money that changes hands, has resulted in building in-land canals in Britain and there is also the coastal business as well. These steamships lead to an enormous financial bubble. In 1824/5 in anticipation of the repeal of the Bubble Act, and after it, which is a pent-up demand for joint stock company shares and an enthusiasm about the potential of steamships, 624 companies try to raise £372 million through the issuance of 6 million shares. If you do a simple NPV calculation, that's £40 trillion in today's money. So this is an absolutely enormous financial bubble. I would imagine you have never heard of it.

This also occurs in the 1820s during another problem in financial markets which is around the sovereign bond boom where, following Rothschilds and Barings, a lot of London bankers are handling sovereign bond issues for newly liberated Latin American countries. You get that kind of boom and crash where you have some sovereign bonds that correspond to countries that don't even exist. Perhaps you've heard of that. But at the same time, you have this Steamship Mania, and of the 70 steamship companies that are promoted, who get enough money to begin operations, only three are in existence in 1827. So you get massive fall-out in a sense that 624 companies become 70 become 3. Yet in that same period from 1824 to 1827, you get the birth of modern steamships because the number of steamships doubles and then doubles again and the tonnage increases dramatically. Despite being the biggest bubble and the one you haven't heard of, the Steamship Mania results in a lot of steamship lines being established, they go bankrupt, they're bought by other steamship companies, so the social effects are perhaps less toxic than some of the other bubbles you've heard about.

But this a direct response to the repeal of the Bubble Act and ends up then setting the stage for the railway manias and subsequent financial crashes. One thing I could do is take you through that argument as it applies to the Railway <anias, perhaps as it applies to the sovereign bonds in the latter half of the 19th century, take you through that argument as it applies to automobiles, and aeroplanes and even the 1929 crash, but I want to do instead is to simply point out that these financial crises which regulators respond to in a particular way are also tied to the real economy and are tied to what we call in economic history, *Kondratieff*-waves, which are waves of innovation, focused around general purpose technologies that are in fact involve infrastructure in their origins. So, you have through five industrial revolutions, six of these waves that begin with steam engines and textiles and then steamship mania which I described, you then get railway manias, but at the same time you get the advent of railway and steam. You get electricity, chemicals, engineering, you get automobiles and petrochemicals, information technology with the dot com manias of the 1990s and early 2000s.

And the question is looking ahead, what is going to be the next big financial crisis. I have an argument here that I want to make to you about something specific that I think is actually going to be the focus of this and, why the regulatory response is so important and why the unintended consequences are perhaps so dangerous. How will next time be different? How will we conform to this pattern on the other hand? How will it differ from this pattern? And why should we be so concerned about that?

To begin with, I want to draw your attention to the IPCC report on holding global warning to 1.5 degrees centigrade, which I think most of you probably are aware of. It's been published recently. It gives you the targets for how far you have to decarbonise energy, transport, and the food supply. It also talks about how the effects of not decarbonising quickly enough. How you try to maintain 1.5 degrees centigrade, 2°C, 3°C, 4°C – those different scenarios. But embedded in that report is also the idea that if this cannot be achieved by decarbonising infrastructure and changing behaviour with respect to the food supply that we're going to have to have some kind

of negative emissions technologies and perhaps geoengineering, that will in some way serve to either sequester carbon or minimise global warning through interfering with the effects of the sun.

I'm not necessarily suggesting that these technologies are in themselves desirable or not. That's for you to decide. What I'm going to suggest is that that will be the focus of the next mega bubble because embedded within the IPCC documents is this notion that there will be some kind of carbon dioxide removal necessary to achieve the temperature targets that have been set.

Whether that takes the form of solar radiation management, trying to put up space mirrors, seeding clouds, or whether it takes the form of some kind of direct air capture, it's already baked into these international agreements. It simply becomes a question of how these are deployed and by whom, and how state actors approach that problem.

I want to reflect on the idea that too often, we think about this as an interaction between the state and the market. We're conditioned to do so because of the Cold War. The idea was that you've got the Marxists that it's all about the state, and the state controls the market, and you've got a planned economy. And this is all about a top-down approach. Whereas the notions in Western society is that it's all about the market. The market is about market efficiency, allocative efficiency. Market capitalism is better than a state-planned economy. It's a bottom-up approach.

What I think is true is that it's not a two-player game between the state and the market. It's actually a three-player game where you've got financial capital that's orthogonal to both the interests of the state and the interests of the market. And this idea is actually that I owe to Bill Janeway who as a vice chairman of Warburg Pincus and somebody who made Warburg Pincus a lot of money in the 1990s on BEA systems and in the software Veritas that handles online payments. But the point is that his observation – and here he significantly advanced Braudel's thesis (he was reading Braudel's history of the Mediterranean when he arrived at the idea) – is that this is not a two-player game, this is a three-player game. You've got financial capitalists who fund innovation. You have equities markets and have the state and what you have are three players who are trying to achieve their own agenda here. Capitalists and the market are not the same thing. Their interests are just as orthogonal to each other as they are to the state. I think this is useful insight in terms of understanding how the next bubble might unfold.

Because of the scale of climate change, which is a global phenomenon, you have on the one hand the technology – the carbon dioxide removal technology, both the type of technology that is going to sequester carbon permanently and the type that's going to sequester over a shorter time horizon – but you also have the beginnings of a market design of what this might look like, because the World Bank has already rolled out a pilot auction facility in tradable put options to allow developing countries to sell the carbon capture potential of reforestation in reducing global warming as a way of raising money to do these forest projects.

Many developing countries, particularly in Africa and in South America have problems with deforestation. They're trying to do wholesale reforestation. Wholesale reforestation has the effect of taking carbon dioxide out of the atmosphere because of the carbon cycle. How do they finance these reforestation projects? One thing they can do is sell put options for the carbon dioxide removal potential of these projects and raise finance in order to get these projects off the ground. This is a potential market design for carbon dioxide removal writ very large. If you're going to do it in line with the way the IPCC imagines, it might happen.

But at the same time, you have players like sovereign wealth funds, you have venture capitalists, you have the inventors. Some of these technologies are unproven, some of which are in blueprint stage. And you have states that are going to start procuring this technology very quickly. If you don't believe me, there's a lot of activity on the part of the Chinese, trying to get direct air capture off the ground. You have various other projects that have seen venture finance in the US and Europe. For ocean fertilisation and other things to try to get natural carbon sinks, there's a lot of activity in this space amongst inventors, and many different ways of trying to finance it.

What I'm talking about here is climate engineering that's going to counteract global warming. It's a whole different range of technologies. That's important. The fact that it's a heterogenous set of technologies that makes it such an interesting problem. On the one hand, you have the solar radiation management, the idea of putting aerosols

in the stratosphere that are going to aim to affect global warming by reducing the amount of direct sunlight. You have iron fertilisation of the sea, which is supposed to increase its carbon potential. You have space mirrors. You have cloud seeding. You have the greening of deserts using genetically engineered crops that are supposed to absorb more carbon. Things that you might find a bit scary, for instance, there's some sense that massive volcanic eruptions in the past have effectively been a form of solar radiation management because they throw off so much ash that it cools the globe for centuries.

These things are being designed. People are trying to experiment with them. They are trying to estimate the effects of termination shock of one of these systems going on stream and then for whatever reason, coming off-line within abruptly rather than in a phased way.

All this activity is going on and it's going to be something that's going to be with us for the next 50 years if we're going to try to meet these temperature targets. So again, what are these different schemes? They fall roughly into two categories. They fall into the category of solar radiation management (SRM), which is trying to stop global warming, but doesn't really have that much potential for capturing carbon. And then you also have the carbon dioxide removal (CDR), which is not trying to directly influence global warming, but is trying to take away the carbon out of the atmosphere, in order to reduce its future global warming potential.

Why is this going to end up causing a financial bubble? First, you've got these technological challenges potentially around these termination shocks. What happens if you put up space mirrors, you cool the globe and then suddenly you shoot the space mirrors down, and you have a very quick shock to the system. Or what happens if you have a forest that absorbs a lot of carbon and then it catches some disease and all the trees die and that carbon is released very quickly? [You probably saw the article in the paper yesterday about the Spanish genocide in Latin America causing the Little Ice Age.] Termination shocks associated with this are quite serious.

There's something called an SRM bridge which potentially would solve this, but it's still something that's theoretical. The question is then who will finance and who will deploy these technologies, and how do you manage that without causing both physical and financial risk to everyone, not just residents of a particular national economy. The other thing is that if the way in which this is conceived is that individuals are supposed to change their behaviour, which means maybe eating less meat, travelling by plane less often, using less carbon-intensive forms of transport, less carbon-intensive forms of energy, the idea they can either change their behaviour, or they can buy some kind of off-set to off-set their carbon footprint. Which is what many will do.

This is already something that exists. You can buy a carbon off-set if you fly, it tells you how much carbon the flight produces, which allows you to buy that off-set. You've got voluntary carbon off-sets, you have these markets now for about 10-15 years, both in Europe and in the United States. And the idea is that if individuals are meant to buy these to off-set their carbon footprints, until we manage to decarbonise energy transport and the food supply, then how should these products be structured?

Should they simply be able to buy carbon dioxide removal future, where they're saying, "I'm producing this much carbon now, but I'm betting that in 20 years, there's going to be some technologies that takes that carbon out," then how should we regulate those products, because that's enticing to people. There's a moral hazard there. If you're convinced that in 20 years there is going to be some nifty direct air capture technology that pulls carbon out of the atmosphere, and you still want to fly to Bali on a holiday, then you can go online potentially if these markets are designed that way and buy your carbon dioxide future that off-sets your carbon now, but by betting on some technology in the future, that's attractive to people. And there are firms that are already imagining that they can offer that. They are already thinking how they can market these futures that allow you to behave in a high carbon way now, with the promise of technologically off-setting it later.

So the question is, should we allow these things, and if we do allow these things, how should we design them? Should they be futures? Should they be more like the World Bank's tradable put options, but perhaps more safely designed? Should they be managed by the blockchain? If they are managed by the blockchain, what version of the blockchain, because there are some versions of the blockchain that cause a huge carbon footprint themselves, because of the way in which Bitcoin is mined. States, venture capitalists and the inventors of these technologies are thinking about how they're going to work.

There is this potential for an SRM bridge. There's an interaction between these technologies because you can have a situation where you might decide that you need space mirrors for a while in order to reduce global warning. But then you want the carbon dioxide removal technology to kick-in 20 or 30 years later that reduce. So these things work together. You might even structure contracts that somehow handoff between an SRM solution now and a CDR solution later. Professor John Shepherd of Southampton has got a nice 'Napkin Diagram' of how this bridge might work.

The point is that the people who are designing these technologies are already thinking about that. They might structure these hybrid products and take advantage of one technology now, one technology later. While this is going on, you need to think about it in terms of the markets; you need to think of the state, and how other nation states or how some kind of global governance might organise these markets; you need to think about the inventors of this technology; and you also need to think about financial capital and all its forms, whether it's sovereign wealth funds, or more traditional sources of institutional capital and how these things will work together.

At UCL, we have started a research programme to do this. We've published studies of potential market designs in *Environmental Research Letters*. We've also published on the moral hazard component in the *Environmental Law Review*. And we've published on the blockchain as a potential way to design these markets in *Frontiers in Engineering Management*. We're not the only ones.

This is the next big bubble because it is already baked into the international agreements for fighting climate change. It's baked into the IPCC's framework because they're saying it's impossible to meet the 1.5 or 2°C targets with behavioural change alone because the scale of the transition is so great that it requires that. What does that mean? What that means is that we need to think through these regulatory issues.

Unlike these previous financial bubbles, this is unlikely to be something as simple as a share bubble. It's possible there will be share bubbles. It's possible that there will be all sorts of companies that are trying to raise conventional equity finance to start firms that produce direct air capture technology. But, that's going to be a small part of this. Because so many of these solutions – whether it's reforesting an area or finding a lot of pumice and chucking it in the ocean, or trying to alternative the nature of the oceans' carbon sink – these are not conventional companies that are producing a product that you can invest in. These are schemes that people are doing to alter the carbon balance of things that are natural geographic features.

What's going to be the focus speculation is the ability to write these derivative contracts that say that you've got a particular type of carbon dioxide removal technology that's going to remove x tons of carbon from the atmosphere at some future date. Someone who's required to off-set the carbon that they're producing now is going to buy that – that's the kind of thing that's going to lead to a financial bubble. This is based on technological innovation because people are betting that future technological innovation is going to solve a problem that they are contributing to today with their own behaviour. The safety issues go way beyond investors losing money by investing in a share that ends up being worth nothing or being worth at the end of the bubble approximately what people paid at the beginning of the bubble as we saw with South Sea Company.

This is going to potentially affect society as a whole because of the scale of the externalities associated with allowing people to go ahead, and to continue to emit carbon with the hopes of being able to off-set it down the line by technology that doesn't presently exist. So I think that the potential for this being catastrophic is something we need to think about now.

The problem is that the regulations for the last financial bubble were designed to regulate bank leverage are not fit for purpose to regulate what's going to come next. Because this is not going to be about bank finance. This is going to be about individual households trying to buy these products in order to off-set their own behaviours. Other firms will do so as well. This bubble is not going to be about financial economy, it's going to be about the real economy, and trying to deal with climate change. That's something that we need to begin to think about again. That we become so obsessed with financialisation that what we missed here is that the next financial bubble is going to be about something else entirely.

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