6 High-Tech: Power and Unpredictability at the Technological Frontier and in Bitcoin

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In scientific inquiry and technological change the presence of uncertainty, linked to power, is explicitly acknowledged and actively explored. Innovation and improvisation define and constitute manifestations of protean power that are related closely to more familiar control power. The resulting technological and knowledge shifts have important consequences, as actors cope with questions and solutions that arise in the face of risk and uncertainty.

This chapter focuses on these dynamics. They unfold in especially interesting ways when the most relevant actors *agree* that uncertainty is pervasive and unavoidable. Two empirical illustrations, knowledge frontiers and bitcoin technology, explore the different manifestations of protean power in detail. The first example traces improvisation, learning, and advances in science and technology fields, taking us well beyond the narrow bounds of the "controlled" experiments on which they rest. The innovation fueling scientific discovery and start-up industries occurs in contexts so complex that the outcomes and underlying processes remain in the realm of unknown unknowns. The second example explores the bitcoin revolution that combines radical and operational uncertainty, the responses they elicit, and the co-evolution between control and protean power.

Knowledge Frontiers

The drive to improve the human condition unites innovators of all stripes. With each discovery or novel solution, new hurdles arise. Some obstacles can be the direct result, anticipated or not, of changes initially labeled as progress. A common theme across scientific disciplines and fields of innovation is the continuous debate about the adequacy of questions

[1] LS would like to thank David J. Chen, Isaac Kriley, Winnie Lo, and Eric Tran for illuminating conversations about uncertainty in medical science. PK would like to thank Benjamin Cohen, Eric Helleiner, and Jonathan Kirshner for critical comments on the second half of an earlier draft of this chapter.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

asked and the reliability of answers offered. When a scientist sets out to conduct a series of experiments, she or he cannot know whether she or he will get a publication or the Nobel Prize. When an entrepreneur presents the plans for a new start-up, the viability, profitability, and overall impact of his or her endeavor is unknown. What drives these actors is not a predetermined risk calculation. Instead, curiosity, intuition, understanding of particular conditions, and the ability to spot opportunities as they arise fill the air in science laboratories and start-up incubators. The levels of eventual payoff, if any, are unrelated to actor expectations. The pursuit of solutions and improvements may bring about transformative change that falls well beyond the intended reach. The uncertainty surrounding such projects allows no guarantees; even highly promising projects can disappoint or turn into sources of danger.[2]

This section draws on examples from the outer bounds of science and technology that illustrate the varying degree to which actors seek or relinquish control power. The question is particularly resonant in these areas. Innovators understand better than most that whatever projects they launch, deep-seated uncertainty is their constant companion. They do, however, opt for different approaches in their daily confrontations with unknown or unknowable unknowns. And this produces different types of relations between control and protean power in a context marked by different constellations of risk and uncertainty. The following episodes span the range from attempts at carving out as much control power as possible; to instances where its advantages are exploited with its limits fully recognized, and, finally, to situations where no control is sought in the first place.

DNA Editing

In the form of precision, reproducibility, and efficacy, control goes a long way in scientific experiments. It is therefore not surprising that CRISPR, a gene editing technique that meets all these requirements, swept through the world of molecular biology at unprecedented rates upon its initial publication in 2012. This reaction across many disciplines, led to an innovative and fundamentally agile implementation of the novel method and so endowed its creators with protean power. It altered how scientists handle both operational and radical uncertainty associated with studying living organisms. Without needing years of training or expensive equipment, scientists around the world can now use CRISPR to modify the DNA of any cell in an expedient and deliberate way.[3] Not long ago, such

[2] Baumann 2016. [3] Ledford 2015b.

technology was a matter of far-flung ambitions or science fiction. Today, the ability to modify genes at will affects virtually all bio-engineering and medical fields, from disease resistance in crops to studying human cancer mutations. Mistakes in editing the genome have been reduced to a minimum. The enthusiasm for CRISPR might suggest full control as all uncertainty has been eliminated.

Yet, despite the impressiveness of this new technique, many scientists have issued stark warning calls to "think carefully about how we are going to use that power."[4] One set of challenges falls into the category of unintended consequences. The "democratization" of gene editing resulting from this new-found accessibility of DNA modification threatens to put the technique into inexperienced hands, with consequences no one can foresee. Similarly, even if proper precautions are taken, there is still the possibility of CRISPR cutting the DNA in places other than those intended by researchers, threatening irreversible changes. Critics of widespread and unregulated CRISPR application refer also to the much discussed issue of matching the break-neck pace of CRISPR applications with ethical and safety standards.[5] Modifying the genetic code of malaria-carrying mosquitos to eliminate their ability to spread the disease or wiping out invasive species in delicate ecosystems has clear advantages.[6] At the same time, the conversation about unanticipated effects relates directly to actor experience of uncertainty, especially in uncertain contexts of inadequate regulation. Altering the germline of an organism is an inherently complex matter, necessitating separate oversight efforts for each species – fruit flies differ considerably from mosquitos. However, the everyday uncertainty of translating scientific insights and expertise is quickly overshadowed by considerations of the uncertainty that disrupted ecosystems would produce.

The desire to control something so fickle and expansive is strong. It is interesting to observe the various attempts at control clashing in the arena newly opened up by CRISPR. At first, scientists wanted better control over their laboratory tasks. Subsequently, the need to regulate both the process and outcomes of such activity brought another element of control to the forefront. And all along, the shocking novelty and broad applicability of CRISPR technology has fueled a fierce battle over patent ownership.[7] This is no minor matter. It affects the particular paths that subsequent developments take, as well as the point of contact at which scientific and regulatory control attempts meet.[8] The result: disregard for key unknowns and

[4] Ibid. [5] Ledford 2015a. [6] Khatodia et al. 2016. [7] Ledford 2016.
[8] For a related account about innovation in the context of power over information flows, see Marlin-Bennet 2017.

creation of space for newly creative solutions that may bypass this particular manifestation of protean power and replace it with new ones.

The quest for intellectual property rights is a matter of reaping large financial benefits from commercializing the technology at hand. In the language of power, that means gaining competitiveness in pharmaceutical markets and, importantly, financing additional research and innovation. The self-perpetuating model of research investments seems like it might be capable of bypassing the underlying uncertainty. In practice, however, the picture is not nearly so simple. First, once inventions are streamlined and scaled up to generate profit, the focus shifts away from agile creativity in finding resourceful answers to pressing questions toward generating protean power that is converted into control through the identification of material benefits. Exchange represents one move in the reversible relationship between the two power types. Movement in the opposite direction is fueled by the fact that initial impact of an invention in no way guarantees continued or future success. In the case of CRISPR, the interaction is further marked by regulatory uncertainty stemming from battles over patents and the particular policy stance that governments take on the technology.[9] It introduces pressures from researchers working on still newer methods to match or outperform CRISPR capabilities.

Paradoxically, then, the quest for control has produced additional uncertainty. Fighting for intellectual property rights has underscored the desirability of CRISPR technology and at the same time increased the incentive for others to come up with alternatives. Patent battles will likely result in the development of still newer methods that will bypass this avenue of progress altogether. All obstacles surrounding the adoption of CRISPR gene modification highlight the pervasiveness of uncertainty despite actors' desire to control what limited aspects of it they can, either through patent adjudication or ethics and safety regulations. In this example, control power and protean power are deeply entangled in competitive relations. The shifts from one power type to the other have typically been shaped by actor experiences of their context and fleeting openings for intervention.

Ambitious Journeys

In frontier science, the fundamental interference with probability calculations arises from the very nature of the questions considered.[10] Scientists

[9] Falk, Decherney, and Kahn 2016; Jones 2015.

[10] As if the complexity of the questions considered was not enough, researchers face the uncertainty of continued existence of their laboratories. First, there exists a lag between the demonstrability of scientific principle and its commercialization, testing the patience

"control" what they can, but readily admit that an unknown set of unknowns may drive the ultimate success or failure of their work. As a result, many innovators make no pretenses about seeking control beyond a very limited point.[11] In fact, they deliberately open up the playing field for others, realizing that ideas and innovations cannot be forced but, if nudged along a specific path, may follow a semblance of the initial creators' vision. Studies harnessing the immune system to fight cancer at the National Institutes of Health (NIH) are a case in point. Contrary to the common practice of making research information available only following formal publication, Dr. Steven Rosenberg of the National Cancer Institute, himself a pioneer of immunotherapy for more than three decades, has advocated the sharing of unpublished data to expedite progress.[12] Given the complexity and fluidity of both cancer and human immunity, there is too much to be learned from early discoveries. The job is simply too big for any one research team to tackle alone. Aware of the urgency of the endeavor and committed to scientific progress over personal profit, Dr. Rosenberg's leadership acknowledges uncertainty and stops short of seeking to rein it in.[13]

The race to produce human insulin in the late 1970s documents the unanticipated effects that uncertainty can have on the specific pathways scientific discovery takes. The task that would-be innovators faced at the time was to produce human insulin in the laboratory, as opposed to harvesting it from limited livestock pancreases. Several competing companies sought to reap the commercial rewards of reaching the goalpost first, but probabilities of success were incalculable. Scientists had to create a molecule of the insulin protein and find a way to produce it in vast quantities – both extremely high bars to clear. Overwhelming uncertainty and fluidity of actor interrelations shaped the eventual outcome: the race was won neither by major university laboratories nor industrial Goliaths wielding an abundance of conventional resources. Rather, the prize was claimed by Genentech, a start-up David who embraced the unknowns with agility and creative experimentation.[14] The scientists in this small company set up a laboratory in a converted warehouse. They did not work against dominant actors in the industry as they tried to solve a scientific puzzle, and ended up participating in the birth of bioengineering as a field. In what later proved to be a key move, they did not try to clone the insulin molecule from human DNA but instead assembled it

of funding sources. Second, as the CRISPR episode illustrated, regulatory obstacles can have an impact on the survival of research programs themselves.

[11] In the context of medical science such an attitude is particularly closely linked to clinical trials of new treatments and techniques. Chadi 2017.

[12] Rosenberg and Barry 1992: 151–52. [13] Ibid. [14] Watson 2003.

"from scratch." This decision put them in a position to bypass the exploding regulations requiring high-security laboratories for work combining human DNA with other (bacterial) organisms.[15] As for conventional resources, Genentech had relatively few and ended up generating protean power by not following predictable paths to either scientific or commercial success.

There is one final but important layer in the recombinant insulin story that quite possibly may characterize all potentially transformative scientific discoveries. In the 1970s, the scientific community deemed the uncertainty surrounding the impact of genetic engineering to be extremely high. It convened a conference of experts in 1975 to set out guidelines and limitations based on past laboratory practices and existing risk perceptions. Recombinant DNA work, however, was so fundamentally different that previous knowledge was not particularly useful for setting expectations. The Asilomar conference, along with a panicked public response, ended up temporarily tying the hands of many scientists.[16] Effectively, it choked the usefulness of conventional resources and benefited agile actors who did not have them in the first place. Although the rules were later relaxed, the unique mix of unknowns with which actors had to contend marks the late 1970s in both bioengineering and protean power history.

The products of innovation in early laboratory experiments are not driven by control power. It is only once relatively less complex elements of the initial scientific discovery become recognizable and manageable that they attract resources. Innovations in both science and industry have to be clearly visible if they are to be comprehensible to control power and the financial backing accompanying it. This entangles the relations between protean and control power against a background of deepening uncertainty about future success. Ultimately, this uncertainty is relieved only temporarily by impressions of predictability as solitary breakthroughs make news.[17]

Start-ups

At first glance, there is a clear difference between how scientists and start-up developers approach the uncertain context in which they operate. Unlike the deliberately open, bottom-up, and unstructured attitudes surrounding the birth of new companies, strict methodological approaches like experimental design in natural sciences are meant to reduce most unknowns and offer some semblance of control over the

[15] Ibid.: 115. [16] Johnson 1983; Watson 2003. [17] Rosenberg and Barry 1992: 233.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

world under study. However, scientists are the first to admit that what is observed in a petri dish does not readily translate into living organisms, and what is true in mice need not be true in humans. Conversely, unconventional office layouts and novel management strategies provide a surprisingly well-grounded approach to stimulating creativity and represent much less of a free-for-all world than we might assume. The key quality that these seemingly distinct fields share is the recognition that scientists and entrepreneurs both operate in a world that combines risk with uncertainty. It therefore pays to cover the bases of what is known to work. Yet by nature of the questions asked and objectives pursued, agility and openness to new discoveries, hunches, and even surprises, are needed to overcome constraints imposed by risk calculations.

In their driving quest, start-ups seek to identify opportunities in the realm of the unknown and unknowable. Their greatest hurdles lie in the incalculability of risk in a wide range of products and services that have great potential in national and global markets. All firms operate within the same environment. Working together in close proximity, as in Silicon Valley, these firms can generate important agglomeration externalities that serve the industry extremely well. Individually, however, start-ups seek to respond to some aspect of the uncertainty that their existing competitors and potential customers also experience. Although these ventures vie for market power, none have the illusion, at the outset, of controlling or dramatically transforming national or global markets, although some, like Google, Facebook, Airbnb, Uber, Tesla, or Chobani, eventually do. Neither the innovators nor their investors know whether any pay-offs will follow. Successful start-ups uncover needs that their prospective clients may not even realize exist. Located at the margins of technological innovation, countries like Peru also develop novel digital practices and global connections. These can yield alternative development trajectories that are truly innovative and do not merely replicate technological futures imagined as universal in Silicon Valley and other global centers of innovation.[18] When tracing the competition of control and protean power among start-ups on a global scale, we do not speak of filling gaps but of creating spaces for riding out the next wave of uncertainty, instead of being swept away by it.

Not attempting even limited control, a number of prominent start-ups deliberately abandon what would otherwise be valued capacities for a partial steering of relevant market segments. When Tesla offered its electric car technology patents for no-fee fair use by those interested in adopting the technology, it did so with the hope (but no guarantee) that

[18] Chan 2013.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

everyone would eventually adopt the Tesla platform. The creation of a network of recharging and battery replacement stations is the only viable avenue Tesla has toward reaching big-company status. By giving up control, it effectively expanded the ranks of those working to make gasoline-powered transportation irrelevant. The source of Tesla's power comes from the knowledge that it will continue to evolve together with other innovators who will participate in this spontaneously emerging network. If successful, the process could have a transformative impact on the operation of the car industry as a whole. Similarly, in the late 1980s Intel chose to put its resources behind building a platform for the chip and personal computer industries rather than pursuing a highly promising new product. Promoting a new standard and thus increasing demand provided Intel with a powerful run throughout the 1990s.[19]

Similar tactics have been pursued by other start-ups. Responding to uncertainty by actively encouraging innovation, regardless of who reaps the direct benefits from new ideas, is at odds with traditional approaches to building market power by carefully guarding copyrights and patents. In other examples, "Apple, Google and Amazon are all racing to build computers we can talk to, that'll understand us … but they face competition from a surprising place – small entrepreneurs using software they're getting for free."[20] Thousands of individual programmers, on nights and weekends, work together on mastering the transfer of human language to computer applications using Wit.Ai software. There is no single actor that possesses control over how the innovative process unfolds. Yet the work being done is something "that could end up ruling the technology universe."[21]

Recognizing the prevalence of everyday and radical uncertainty in global markets, start-ups cannot afford to ignore it, nor can they settle for merely chancing upon solutions that a continually stimulating environment may produce as it challenges established power configurations. Rather, as these examples illustrate, start-ups deliberately give up that control to fully embrace the uncertainty they know they cannot and do not wish to avoid. As Taylor Owen argues, the power that distinguishes high-tech and the digital world is formless, unstable, and collaborative.[22] We call it protean.

Bitcoin: Spinning Gold out of Straw?[23]

Famously, the Grimm Brothers told the story of Rumpelstiltskin, an imp who helped a peasant girl spin straw into gold and could disappear into

[19] Yoffie and Cusumano 2015: 90–130. [20] Henn 2014. [21] Ibid.
[22] Owen 2015: 37–47.
[23] The distinction between Bitcoin the technology, and bitcoin the currency, is sometimes marked in text by capitalizing the former, not the latter. For reasons of convenience and

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

thin air. Updating this story for the twenty-first century requires only slight adjustments. Straw then is numbers now, crunched by tens of thousands of computers whirring 24/7 in electricity-rich, Icelandic-cold caves all over the world, but increasingly in China. The imp then disappearing into thin air when the girl guesses his name correctly, now is bitcoin's anonymous Japanese-named creator, Satoshi Nakamoto, who published a paper detailing the bitcoin protocol in November 2008, developed the necessary software in 2009, and took her or his farewell in 2011.[24]

Bitcoin is a cryptocurrency invented to bypass the political and financial centers of power. A prime example of protean power, it came on the scene in 2008–9 at the height of financial uncertainty and with the hope of undermining the state's and financial sector's control over currency. In the words of a former advisor on innovation to Secretary of State Hillary Clinton, Alex Ross, bitcoin illustrates a "wider trend towards networked and globalized power structures that tend to undermine the nation-state-based systems to which we have grown accustomed."[25] Not so. What we have grown accustomed to is overlooking the protean power potentials that are lodged in the controls that the nation-state-based system has always harbored within itself. This case illustrates the close connections between protean and control power that run like a red thread through all the other cases reported in this book.

The resourceful initiatives of a broad assemblage of innovative actors – nerds, libertarians, and cyber-cosmopolitans – seeking to circumvent the control of financial institutions and financial actors undercuts the notion of the unchallenged control by any one sector or group of actors. Admittedly, the new currency may not have lived up fully to some of the more optimistic, initial expectations of revolutionizing the world of finance. Bitcoin's underlying blockchain technology, however, has great potential for the creation of distributed, fully transparent ledgers that could revolutionize many practices of those exercising control in the fields of finance, government, and law. Ironically, banks and financial institutions, the primary targets of bitcoin's mysterious inventor Satoshi Nakamoto and his or her libertarian allies, are beginning to exploit a new technology originally designed to undermine them. The story of bitcoin is one of multi-cornered political struggles, unanticipated effects, and the lack of control.[26]

consistency, and because the context makes the difference between the two normally clear, we will refer to bitcoin in lowercase throughout

[24] Nakamoto 2008; Popper 2015b. [25] Owen 2015: 71.

[26] McKeen-Edwards and Porter 2013: 24–26.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

Bitcoin undercuts notions of money as an instrument of control developed, for example, by Talcott Parsons.[27] His consensus theory of power built on an analogy between the circulation of money in the economy and power in the polity. Interested in the nature of power more than its effects, Parsons downplayed conflict and imposed on an inchoate political reality a self-perpetuating practice of affirmation in the political legitimacy of established centers of authority. This perspective catches part of money's power dynamics, but it overlooks both refusal and innovation that mark protean power's disruption of financial and technological routines.

Instead of Parsons, many early users of bitcoin reflect the views of other theorists. Friedrich Hayek, for example, argued that government should not have a monopoly over the issuance of money.[28] Instead, there should be a competitive market in which currencies would be traded at variable exchange rates among both public and private actors. And currencies could be of different kinds: traditional gold- or silver-based, novel commodity-based, foreign, or virtual currencies like bitcoin. Currencies able to guarantee stable purchasing power, Hayek argued, would drive inflation-prone currencies out of business. Anticipating bitcoin by decades, Milton Friedman looked not to markets regulated by the Federal Reserve, but to a computer program as the preferred mechanism for increasing the money supply at a constant and well-publicized rate.[29]

Understood as both currency and technology, bitcoin points to the interaction between protean and control power, as Hayek and Parsons argued. And that interaction is reflected in processes and practices of innovation and refusal as well as affirmation. In a world "where innovation expands and complicates choice . . . local forces are in constant motion."[30] The bitcoin world provides a graphic illustration of local forces in motion – with the local here understood to be part of the virtual rather than the geographical world. A twenty-four-year-old bitcoin entrepreneur charged with money laundering and other crimes, Charlie Shrem, has likened Nakamoto to a second Columbus who "gave us the new world."[31] One enthusiastic characterization argues that bitcoin is "about freeing people from the tyranny of centralized

[27] Parsons 1963. See also Barnes 1988, 12–20; Giddens 1977: 333–49; Kindleberger 1970: 3–16.

[28] Cohen 2001; Hayek 1976; Rogojanu and Badea 2014: 104–5.

[29] In contrast to Friedman's proposal, bitcoin has a fixed supply of 21 million coins. In an era struggling with deflation rather than inflation, bitcoin's deflationary bias is even more severe than the gold standard and may eventually become an insurmountable problem. Needless to say, bitcoin or other electronic currencies will have to find a way to circumvent this deflationary bias in some form without losing the transparency that the blockchain offers.

[30] Shubik 2014: 11. [31] Sidel 2014.

trust. It speaks to the tantalizing prospect that we can take power away from the center – away from banks, governments, lawyers . . . and transfer it to the periphery, to We, the People."[32] In the words of a young Argentinian woman trading bitcoins, "It feels good, doing things that you are not supposed to, saying to the structures of power they don't have power over you."[33] In the summer of 2014 there existed reportedly 434 bitcoin meet-up groups with close to 50,000 members in 309 cities and 68 countries.[34]

What is Bitcoin?

In broader historical perspective bitcoin is less radical than it may appear at first glance. Territorial money issued and guaranteed by states has been around for only a couple of centuries. Local and now electronic currencies have been central to financial systems for much longer. "Cross-border circulation of currencies was not only accepted but widespread, monetary policy as such did not exist, and private monies were commonplace."[35] Even today, for monies and near-monies, the state is "primus inter pares and not the supreme ruler."[36]

Bitcoin is the most important of hundreds of electronic currencies.[37] It is an open-source, copyright-free, decentralized, online financial network that is easy to use for sending and receiving payments.[38] Three significant differences set bitcoin apart from more familiar financial networks such as VISA or PayPal that are owned by profit-seeking corporations. First, bitcoin is neither owned nor managed by anybody. It is a peer-to-peer network of computers that processes bitcoin transactions. Second, in contrast to existing financial networks, bitcoin is completely open. If an actor wishes to create new bitcoin-based financial services, no one's permission or assistance is required. Finally, in contrast to existing financial networks that rely on conventional currencies such as dollars, this one comes with its own currency. While the value of bitcoin is uncorrelated with the value of the world's major currencies, thus illustrating the unknowability of outcomes,[39] the denomination of its value in terms of dollars illustrates the close connection between protean and control power.

32 Vigna and Casey 2015: 8. 33 Popper 2015d: 53. 34 Cofnas 2014.
35 Cohen 2001: 207. See also Helleiner 2003: 42–79; Middlebrook and Hughes 2015.
36 Shubik 2014: 3.
37 Deal B%K 2014; Böhme et al. 2015; Castronova 2014; Champagne 2014; Cohen 2001; Dowd 2014; Kelly 2015; Popper 2015a; Tapscott 2016; Turpin 2014; Vigna and Casey 2015.
38 Lee 2013. 39 Wu and Pandey 2014: 48.

Bitcoins are electronic tokens created by miners. Collectively, miners keep a decentralized ledger called the blockchain. It is controlled by no one and creates bitcoins. Miners are rewarded for the cost of their computational labor in bitcoins. In the words of Benjamin Cohen "money can be made by making money."[40] What started as individuals operating a few personal computers in their homes has evolved quickly into very large networks of computers, running into the tens of thousands that operate in different locations all over the world. In this manner dispersed, protean power very quickly has mutated into centralized, control power over a vital part of a functioning bitcoin payment system. Expensive chips powering large computer networks are necessary to solve the increasingly difficult mathematical problems that are rewarded by an ever-decreasing number of bitcoins.

Today huge amounts of computing power are needed to mine bitcoins. To receive 25 bitcoins valued at about 6,250 dollars in October 2015, miners must calculate roughly 10 quadrillion (one thousand million million) mathematical equations per second.[41] The computational and energy-intensive underpinnings of the bitcoin currency exist in tens of thousands of computers stretching from environmentally polluting Mongolia to environmentally green Sweden.[42] As early as 2013, the computational power behind bitcoin exceeded by a factor of 100 the combined performance of the world's largest 500 supercomputers.[43] According to one estimate, by mid-century the computer capacities for solving the mathematical problems that would lead to the issuing of additional bitcoins will approach the size of the universe, operating at the speed of light.[44] One of the trickiest challenges in the evolution of bitcoin is to structure the incentives for large-scale miners so that they can make adequate profits and thus continue mining. With the dramatic expansion in the scale of mining operations, the dynamics of protean and control power have shifted. By 2016, four Chinese mining pools accounted for over 70 percent of transactions on the bitcoin network, with the vast proportion controlled by only two companies. China had "effectively assumed majority control of the Bitcoin network."[45] With the price of bitcoin about doubling in 2016 and quadrupling in 2017, topping $4,000 in August 2017, in the second half of

[40] Cohen 2001: 201.
[41] Kelly 2015: 84. Kelly 2015: 16 reports a figure of 50 quadrillion per second.
[42] *The Economist* 2015a.
[43] *The Economist* 2013. In the first five years of its existence, the computing power behind bitcoin reportedly consumed 150,000 megawatt-hours of electricity, enough to keep the Eiffel Tower lit for two and a half centuries (Clenfield and Alpeyev 2014).
[44] Castronova 2014: 162–63. [45] Popper 2016b.

2016 Renminbi transactions accounted for 98 percent of total global bitcoin trading.[46]

Undergirding bitcoin, the currency, is the bitcoin technology. The bitcoin payment system is a protocol, a series of rules governing the exchange of information among interlinked computers. The protocol is a mathematical construct that cannot be forged. The computer code for the calculations that create bitcoins is open source and gradually evolving. Because any kind of application can be built on top of that protocol, this technology is important, even if bitcoin, the currency, were to fail altogether.[47]

Like alternating currents travelling over the electrical grid, bitcoin's blockchain is a foundational technological infrastructure. Without a roughly simultaneously emerging demand for its use, infrastructure technologies cannot develop. For the bitcoin payment system to evolve, a large and vigorous market for bitcoin currency is a necessity. The light bulb needed to be invented for the electric grid to become a worthwhile investment. Bitcoin currency in the twenty-first century plays the role of Edison's light bulb in the nineteenth century. It makes possible the development of a payment system that bypasses billing processors, credit card associations, banks, and clearing-house networks managed by regional Federal Reserve banks. Thus, it may drastically reduce the need for and power of such intermediaries and the fees they charge, putting at risk billions of dollars of sunk costs and tens of thousands of jobs in existing payment systems.[48]

In contrast to traditional payment systems run by private financial institutions or states, bitcoin technology has evolved with great speed. For one, the advantages of bitcoin are hard to deny. Final financial settlement time approaches near-real-time (an hour or less compared with 2–3 days) and at a fraction of current cost, 1 percent or less compared with 2–4 percent or more; international money transfer costs are even higher, varying between 5 and 11 percent.[49] As an optional form of payment bitcoin is now accepted by firms like IBM, Microsoft, Amazon, Expedia, iTunes, Dell, Bloomberg.com and many start-ups, including Bitpay and Coinbase. The number of American companies accepting bitcoin numbered about 140,000 by the end of 2015.[50] In the United

[46] Wildau 2017. Although it is by no means clear that the high correlation between the surge in the value of bitcoin and the weakening of the Chinese currency and capital outflows are causally linked, China's two largest bitcoin exchanges stopped withdrawals of the electronic currency in February 2017, after a warning by the central bank about the necessity of enforcing rules on foreign exchange transactions and money laundering.

[47] Hochstein 2014: 20. [48] Maney 2014.

[49] Hochstein 2014: 20; Kalmadi and Dang 2015; Shubik 2014: 10.

[50] Kalmadi and Dang 2015; Lee 2013; Maney 2014; Vigna and Casey 2015: 103.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

States currently there exist an estimated 500,000–1 million digital currency accounts.[51] In 2014, bitcoins were used in daily transactions worth about $50 million (up from $1 million in June 2011), compared with PayPal's $492 million and VISA's $19 billion.[52] ATM machines offering conversion of bitcoins to dollars have started springing up in several North American cities, including a new bitcoin center near Wall Street.

Bitcoin and the Dynamics of Protean and Control Power

An example of protean power and the most pervasive of a large number of private, electronic forms of currencies, bitcoin was introduced in January 2009, followed by about 700 other cryptocurrencies. As in Wagner's *Rheingold*, below the world of majestic daily global currency flows, measured in the trillions of dollars, many dwarfs were hammering away to create alternative currencies. Bitcoin saw the light of day when confidence in banking systems and central banks hit a nadir in 2008–9.[53] The financial crisis offered Nakamoto a fleeting opportunity for action that did not require having any special foreknowledge or concrete plans. At the height of that crisis, the control power of governments, banks, and large corporations over the economy had evaporated. Bitcoin became "a perfect object for the anxieties and enthusiasms of those frightened by the threats of inflation and currency debasement, concerned about state power and the surveillance state, and fascinated with the possibilities created by distributed, decentralized systems."[54]

Bitcoin was surrounded by plenty of uncertainty itself – about its feasibility, stability, and transparency. Supporters of bitcoin experienced first-hand that "there is no calculus of risk independent of an individual's affective self-reliance to uncertainty."[55] However, bitcoin was attractive apart from the escape it seemed to offer from an all-pervasive disregard of uncertainty. Individuals chose this new technological "infostructure" also because of the hope of reaping the benefits of a relatively egalitarian and open network and of immunity from hierarchical control by state and corporate elites.[56] What bitcoin supporters were seeking was perfect transparency. Thus, they adhered to a contradictory stance: total distrust in political and economic institutions, specifically governments and

[51] Cofnas 2014.
[52] Bitcoin can process only seven transactions per second, compared with tens of thousands for VISA. The average bitcoin transaction is about $500 compared with $80 for VISA. See Böhme et al. 2015: 214; Velde 2013.
[53] Weber 2016. [54] Surowiecki 2011: 106. [55] Massumi 2015: 4.
[56] Cohen 2001: 205; Hochstein 2014: 21.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

banks; total trust in social institutions, specifically networks mediated and facilitated by technology.

Actors such as Goldman Sachs, JP Morgan Chase, and NASDAQ who enjoy enormous control power in the world of finance are less interested in bitcoin the currency than in the blockchain technology on which it rests. UBS, Deutsche Bank, Santander, and BNY Mellon, for example, have teamed up to develop a form of digital cash to clear and settle financial trades.[57] This technology has the potential to replace middlemen and to make redundant all forms of verification in the transfer and recording of financial assets such as stocks, contracts, crowd-funding, property titles, and patents.[58] In addition, computational law may emerge as self-executing computer programs that largely reduce, even eliminate, the need for many ordinary legal services as counterparty risks disappear.[59] A recent report estimates the savings of distributed ledger technology to soon run to between $15 and $20 billion for cross-border payments, securities trading, and regulatory compliance.[60] About 20 percent of the users of a recent start-up, Chain, are developing non-financial blockchain applications, compared with less than 10 percent a year ago. And growing sums of venture capital are flowing into this market. It remains to be seen whether and how blockchain applications will affect or eliminate trusted intermediaries or entire legal, economic, and social structures that currently guarantee property rights. Apple Pay, a digital wallet, signals that bitcoin technology is beginning to reach mainstream consumers.[61] And as it does, the recalibration of protean and control power will proceed apace. Venture capitalists investing in this technology try to convert the uncertainty attending their investment decisions into risk by creating self-fulfilling prophecies. Giving speeches, convening workshops, and stressing emergent network effects are deliberate attempts at shaping beliefs about the blockchain technology that undergirds the bitcoin currency.[62]

Most major banks and some large corporations and central banks, including the Federal Reserve and the Bank of England, have in-house teams that are exploring bitcoin's underlying technology for their operations.[63] An association of big banks called the Clearing House is trying to develop a network among the big banks that would permit instantaneous transfers between all accounts of all network members, thus eliminating the risk and uncertainties of having billions of dollars

[57] Arnold 2016. [58] *The Economist* 2015a. [59] Hochstein 2014: 23.
[60] Stafford 2015. [61] Castranova and Fairfield 2014.
[62] With one-third of their investments failing, these rhetorical strategies are only partly successful. Susan Athey interview, April 14, 2015, Ithaca, NY.
[63] Popper 2016c; 2017; Popper and Lohr 2017.

in limbo for days while transactions are settled. In contrast to early bitcoin enthusiasts, these banks are interested in very large payments which account for most of the money moving around the world each day.[64] Harnessing the blockchain for managing transactions in foreign currency markets, for example, with their daily turnover of more than $5 trillion, would increase directly the control power of the financial sector and indirectly that of the state. Innovative applications of the bitcoin protocol to non-financial transactions are potentially far-reaching in fields as different as accounting, music, and law. But for the most part they remain today highly unpredictable.

Bitcoin is thus driven by the interaction of protean and control power as both speculators and investors alike must cope with calculable risk and incalculable uncertainty.[65] Bitcoin supporters thought they had discovered a sweet technological escape from the doomsday scenarios of a world riddled by uncertainties.[66] Yet increasingly bitcoin's underlying technology is driven by the influx of venture capital seeking profitable commercial applications of the blockchain. For now, entrepreneurs can intuit only dimly different applications of the blockchain technology that extend well beyond electronic currencies and payment schemes, such as those for products and services. Despite that unavoidable impediment, in nominal dollars, blockchain technology attracted more than $1 billion in venture capital in 2014 and 2015, dwarfing the funds attracted by the internet at its dawn in 1995, when *Newsweek* ran an article titled "Why the Internet will Fail."[67]

Uncertainty and risk incite some actors to circumvent the reach of the state while at the same time inviting regulatory activities by the state. Bitcoin makes it difficult for governments to "follow the money." It offers avenues for conducting undetectable transfers of funds, possibly for a variety of nefarious purposes.[68] Entrepreneurs like Pascal Reid, Michael Abner, and Charlie Shrem, for example, have been arrested on charges of facilitating money laundering. Bitcoin enthusiast Andreas Antonopoulas has an optimistic take on government efforts to control bitcoin: "first they ignore you, then they laugh at you, then they fight you, and then you win."[69] At the same time, seeking to exercise control, governments are beginning to regulate bitcoin and other electronic currencies in an uncoordinated fashion.[70] For example, the US Internal Revenue Service (IRS) has classified bitcoin as property and thus assumed some regulatory control. The Chair of the Federal Reserve Board, Janet Yellen, in

[64] Popper, 2015c; 2015d. [65] Whitehouse 2014. [66] Griffin 2014: 33.
[67] Smith 2014; Tapscott 2016: 9. [68] Chafkin 2014. [69] Thomas 2014.
[70] Raymaekers 2015: 36.

https://doi.org/10.1017/9781108597456.007 Published online by Cambridge University Press

contrast, has declared that bitcoin is beyond the regulatory reach of the Federal Reserve since it has no ties to any bank. Congressional reactions to bitcoin have been similarly mixed.[71] Foreign governments have also reacted in different fashions. The German Finance Ministry, for example, has recognized bitcoin as a unit of account. In contrast, in 2013 China's Central Bank prohibited the processing of transactions in cryptocurrencies and suspended trading on several bitcoin exchanges, thus causing a collapse in the price of bitcoin and shifting Chinese entrepreneurs, unexpectedly, to become the most important miners of bitcoins worldwide. Hong Kong meanwhile is trying to position itself as Asia's center for bitcoin. Russia has followed the lead of the Chinese government without enjoying a Hong-Kong-style fallback option.[72]

Conclusion

"Money is not some separate force, easily divided from other, more human, concerns. Money is changing now, very fast, but only because we are, too," writes Adam Davidson.[73] Like language, bitcoin is a social technology that is spontaneously and rapidly evolving, and delivers outcomes through competition, imitation, and emulation that no one can anticipate. It undercuts the conventional presumption that only state-issued money is "real." Alternatives to national currencies, typically minuscule, are often local: Ithaca hours and the Berkshare in the United States; Simecs in Italy; Auroracoins in Iceland; QQ in China; M-PESA in Kenya; Tem and Sano in Greece; Peaches, Bees, Wheels, Measures, and Soil in different parts of France; and similar varieties of currencies in Spain are different examples of local currencies that have sprung up, diminished in importance, vanished altogether, or lasted for decades.[74] In many rich countries alternative currencies, such as airline miles, have become durable complements to national currencies. Under-served by banks, poor markets in Africa have seen the emergence of "mobile-minutes" as alternatives to official currencies. In addition, there exist also supranational, regional currencies such as the Euro. Private electronic currencies such as bitcoin offer a global complement to state-issued currencies.

The collapse and utter failure of bitcoin the currency is possible.[75] The fact that its inventor, Nakamoto, remains anonymous should make

[71] *The Economist* 2013; Griffin 2014: 33.
[72] The IMF seems ill-equipped to regulate electronic currencies like bitcoin. See Plassaras 2013.
[73] Davidson 2015b: 46.
[74] Cohen 2001: 210; Rogojanu and Badea 2014: 105–7; Shubik 2014: 3–4.
[75] Dowd and Hutchinson 2015; Yermack 2013.

anybody wary of possible insider trading and private information that could mark bitcoin as a gigantic Ponzi scheme that will at some time, somehow, and somewhere explode – unpredictably. Wild gyrations in the dollar value of bitcoin have shown that it is as vulnerable to speculative bubbles, as are other currencies or assets. And these gyrations have been reinforced by serious concerns about repeated incidences of large-scale fraud.[76] Investors on Wall Street and in Silicon Valley are guessing and betting that under risky and uncertain conditions bitcoin will somehow outgrow its current phase as a speculative investment object, while providing enough demand for further development of the underlying infrastructure technology for related and unrelated purposes. Even if bitcoin the currency were to fail altogether, bitcoin the technology, embodied in its central idea, the blockchain, will persist. Hopes for a dawn of democracy brought about by bitcoin the currency after 2008 have been disappointed. And so are the hopes of advocates of blockchain technology as a force for empowerment of the disempowered.[77] The empirical record suggests otherwise. For example, sharp disagreements among influential members of the bitcoin network about the currency's technical protocol, specifically the size of a given block, illustrate the tension between "populists," who are intent on broadening bitcoin's commercial potential, and "elitists," who are committed to posing a radical challenge to existing currencies. And this tension is acquiring an international dimension as it pits American against Chinese firms.[78] Disappointment and disillusionment hang in the air as hacking and even death threats are dividing what a few years earlier had been a tight community.[79] In short, the fight over the future of the blockchain technology illustrates how the co-evolution of currency and technology is shaped by the variable relation between protean and control power.

At the end of the Grimm Brothers' tale, in a fit of total fury, the imp splits himself in half while the peasant-girl-turned-queen and her king live happily ever after. One recent, unconventional application of the blockchain was in fact made in the marriage market. Diamonds, it turns out, are not forever – blockchains are. At least that is what David Mondrus and Joyce Bayo decided when they became the first couple to use a bitcoin automated teller machine to record their written vows in front of fifty guests.[80] In the future, on the way to the altar, taxis may be both self-driving and self-owned – by bitcoin blockchains. Traditional wedding planners, and for that matter, all planners, take note!

[76] Kaminska 2016; McLannahan 2015; Soble 2015; Trautman 2014.
[77] Tapscott 2016: 22–25, 86, 227. [78] Popper 2016b. [79] Farrell 2016; Popper 2016a.
[80] Ember 2015.

Conclusion

The blending of control and protean power produces interesting outcomes in areas characterized by a consensus about procedures needed to minimize risk, while the majority of actors recognize that uncertainty, and therefore the futility of risk calculations, remains the overwhelming norm. The *Cancer Moonshot* and the efforts to pull off a "Mars-shot" illustrate a different blending of the control power tools that scientists wield and the agility and improvisation that they need. The research teams behind the CRISPR gene-editing technique resorted to extracting what limited control patent ownership might provide. Cancer and space-flight scientists use probability-based calculations sparingly and open their minds to fundamental unknowns. And start-ups do not set out to control the surrounding context at all. The knowledge frontier thus illustrates a range of responses that contradict the notion of effective control power. Seeking to challenge established patterns of (control) power, innovators are agile as they seek to harness potentialities that might help them to take the next step.

Rather than showing that control power has limitations, the bitcoin story is one of fighting fire with fire. The emergence of bitcoin, following the financial crisis of 2007–8, leveraged profound uncertainty about the future of global finance, further complicated by the intricate architecture of interdependent financial systems. Support of the blockchain technology came first from individuals seeking to bypass an irremediably crisis- and inflation-prone financial system and later from corporate actors who instead sought to increase its efficiency. Thus, the creation of an alternative and highly volatile currency was intended to undermine failing financial structures and practices, illustrating the limits to a world of exclusive risk calculations. At the same time, central banks and financial institutions quickly realized the potential of the underlying blockchain technology for future growth and profits.

This study of power in areas that, more than most, hinge on improvisation and innovation reveals that uncertainty affects power dynamics both by the nature of the questions asked and the degree to which actors appear satisfied with the answers they receive. The experience of uncertainty is associated with unexpected threats as much as the promise of novelty and improvement. Both stir human creativity. Accidental discovery, for example, unites the possibilities of a disciplined approach to science while allowing the possibility of interpretation and creative connections that determine its ultimate success. From a different angle, the bitcoin case shows creativity in two important ways. The mathematics undergirding bitcoin the currency was genuinely innovative. It was sprung on the world at a moment of great uncertainty at the height of a global financial crisis. Furthermore, the creativity shown by venture capitalists and bankers seeking to exploit and adapt bitcoin technology was impressively improvisational. It is impossible to know at the outset where such disruptive but generative efforts end up, yet acknowledging uncertainty throughout the process of invention alters the range of the actualization of power potentialities in important ways. We may still be far from finding a cure for cancer, a landing on Mars, or finding a reliable buffer against financial crises, but we can be sure that seeking opportunities in uncertainty mixes elements of protean and control power.

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