8 Schumpeter in the twenty-first century

Creative destruction and the global green shift

John A. Mathews

Introduction

Amongst the many virtues of Schumpeter's *Capitalism, Socialism and Democracy* (1942, *CSD*) is its Chapter 7 on 'The process of creative destruction'. In this short six-page exposition Schumpeter lays out his famous analysis of capitalism as a restless social and economic order that never is, and never can be, a stationary system. He paints a picture of capitalism as driven by 'gales of creative destruction' whereby innovation allows new players to enter markets and create new directions, financed by capitalist credit creation that puts the innovators on an equal footing with incumbents. The Schumpeterian analysis focuses on the evolutionary dynamics of the industrial system as it shifts from one technological trajectory to another. In the 75 years since his book appeared there have been numerous studies of industrial evolution and creative destruction in such sectors as automobiles, electronics and IT. While valuable, these studies shed little light on the dominant trend of our time, which is the rise of China, followed by India, as emerging industrial giants. In this chapter the insights generated by Schumpeter in *CSD* are applied to the rise of new green industries in China, with a focus on their evolutionary dynamics and potential to disrupt established fossil-fuel industries in the West.

Indeed, Western industrialism has achieved miracles, promoting unprecedented levels of prosperity and raising hundreds of millions out of poverty. Industrial capitalism is now diffusing east, where Japan was the first, followed by the four Tigers (Korea, Taiwan, Singapore and Hong Kong) and now China, all of them incorporating themselves into the global industrial world. India, Brazil and many others are expecting to follow the same course, which is best described as a Great Convergence. But as China, India and other industrialising giants grow, they are confronted with an inconvenient truth: they cannot rely on the Western industrial development model with its fossil-fueled energy systems; resource throughput rather than circularity, and generic finance – for reasons to do with extreme spoliation of their own environment and energy security and resource security concerns as much as concerns over global warming.

By necessity, a new approach to development is already emerging in the East, with China leading the way in building green industry at scale. As

opposed to Western zero-growth advocates and free-market environmentalists, it can be argued that a more sustainable capitalism is being developed in China – as a counterpart to its all-too-obvious black developmental model based on coal, oil and gas. In the words of Hu Angang, this alternative is the 'inevitable choice for China' – and by extension, one might say for other developing countries as well (see Hu 2006a, 2006b). The tension between the green development pathway and the black pathway is a defining feature of the next Great Transformation.

The core elements of this emergent industrial model are threefold: 1) the enhancement of energy security through basing energy systems on manufactured energy devices – rather than extracting and drilling for fossil fuels in increasingly tense geopolitical locations; 2) the enhancement of resource security through restructuring the economy along circular lines (the closing of industrial loops) rather than the traditional linear economy; and 3) the greening of finance to drive the transition. This new 'green growth' model of development, being perfected first in China and now being emulated in India, Brazil, South Africa (the BICS countries) and eventually by industrialising countries elsewhere, as well as by advanced industrial countries such as Germany and Korea, looks set to become the new norm in the twenty-first century. It is a model grounded in manufacturing and the diminishing costs associated with the learning curve that accompanies manufacturing, as Hao Tan and I put it in our 2014 article in *Nature*, 'Build energy security through manufacturing renewables' (Mathews and Tan 2014).

A Schumpeterian evolutionary dynamics approach to analysing these trends, as opposed to neoclassical comparative static approaches that are obsessed with comparative cost-based instruments like carbon taxes, promises to generate distinctive insights. Earlier sociotechnical transitions, as identified by Perez, Freeman, Berry, Louça and others, have been characterised by an emergent pervasive technology that has falling costs and costs lower than incumbent technologies as well as applications across the economy. The case can be made that the characteristics of the current transition to renewable energy systems and circular economy constitutes a sixth such wave or surge of fresh development. Like its predecessors, it is already starting to wreak creative destruction in established industries – as is felt in the coal industry, gas and oil, electric-power generation and automobile industries as companies such as Tesla and BYD bring new technologies to the market and rewrite the rules of global competition.

While mainstream economists talk about the climate-change challenge framed in terms of costs and the role that carbon taxes could play in driving alternatives, the reality seems rather to be that the energy and resources transformation that is under way calls for major structural changes and state intervention, best described in Schumpeterian terms. China's renewable energy revolution and circular economy initiatives are driving cost reductions globally as well as in China and are creating business opportunities for new firms everywhere; this process may be viewed as the world's first case of a country

breaking free of carbon lock-in by building its own domestic renewable energy industries and circulation of resources through state entrepreneurship.[1] As China grows its market for renewables and resource circulation processes (such as urban mining of materials), so its firms become more receptive to licensing advanced technologies from companies in advanced countries. These developments create complementarity between advanced firms in the West and Chinese mass producers – with the proviso that Chinese firms themselves are fast approaching the innovation frontier as well.

The test of Schumpeterian insights lies in their ability to shed light on contemporary industrial evolutionary dynamics. The global green shift that is under way is a case where the process calls for Schumpeterian insights in order to explain it adequately; it is a test case for the continued relevance of Schumpeterian evolutionary analysis and in particular the role of creative destruction in moving one technoeconomic system to another – or removing the vestiges of one system to create space for the new. The existence of these successive waves or surges of development is an empirical reality; the real issue is the framing of a theoretically sound explanation for their rise and fall that encompasses technological as well as financial and institutional dynamics. In the current case of the global green shift the role of China in driving the process gives it added interest and relevance.

Long waves in the global economy

The study of long waves in economic life has many antecedents, amongst which the most celebrated are those of the Russian scholar Nicolai Kondratiev, who did his principal research during the 1920s. Indeed, his major work as known in the West was his long paper published in the German *Archiv für Sozialwissenschaft und Sozialpolitik* in 1926.[2] Because he made the 'politically incorrect' finding that capitalism could go through evolutionary waves (in place of the terminal crisis favoured by the theorists of the Communist International) he was shot by Stalin's secret police. Today we are allowed to study the long-wave phenomenon with rather more political freedom.

Kondratiev's work was taken up by the doyen of business-cycle studies in the US, Wesley Mitchell, in 1929, and by Simon Kuznets at Harvard in his book on economic cycles, published in 1930. With these antecedents, it was Schumpeter who really championed Kondratiev, naming the wave that now bears his name in his 1939 masterwork, *Business Cycles*. So, it was Schumpeter who was really responsible for introducing K to the West – and thereby breathing life into the evolutionary-economics tradition.[3] And Schumpeter made an important addition to K's long-wave dynamics. K had delivered himself of the observation that each successive downturn saw a cluster of technological innovations being introduced (because the conditions favoured innovation). Schumpeter took this observation and turned it into a driving force behind why one wave succeeds another.

This observation (or hypothesis) has been elaborated on by modern scholars.[4] The central idea is that the economy is a dynamic, evolving system which moves through 50–60-year 'spurts', each driven by a new technoeconomic paradigm. It really is a scandal that so little work has been devoted to this central topic in economic analysis. The work itself seems to go through 'cycles', where there was an initial spurt triggered by Kondratiev himself and Schumpeter; then another cycle in the 1980s triggered by interest in an emerging fifth K-wave on the part of Perez and Freeman at SPRU and Ayres, Marchetti, Nakicenovic *et al*. at IIASA, plus others like Kleinknecht in The Netherlands, Berry in the US and Tylecote, Lloyd-Jones and Lewis in the UK. Now perhaps there will be a new spurt triggered by interest in a sixth wave emerging, based on greening trends, in the 2010s, together with an appreciation of the financial drivers of successive technological surges or waves.[5]

Schumpeter's greatest contribution perhaps was his inspired guess that the long cycles revealed in capitalism by Nicolai Kondratiev were triggered by clusters of technological innovations. This has resulted in informed scholars identifying the 'Kondratiev-Schumpeter' long-cycle evolutionary account of capitalism (e.g. Korotayev *et al*.) – or what the Danish scholar Andersen tellingly calls the 'engine of capitalism' after Schumpeter's own terminological innovation. Thompson (2014) looks to capture the same effect in the notion of technological clustering, which he suggests should be taken as the prime concept driving the evolutionary dynamics of the global business system. It is indeed a dynamic and disruptive account of evolution – not the incrementally progressive change assumed in mainstream neoclassical economics. As such it has great affinity with the punctuated-equilibrium perspective in biological evolution, introduced by Gould and Eldredge (1977), as an elaboration of the Darwinian approach, which now dominates the field. Let me call this the 'Kondratiev-Schumpeterian punctuated equilibrium' approach to evolutionary economics.

Five waves of industrial change

The industrial revolution ushered in a totally new period of economic evolution, one that is known as 'modern economic growth' (see Mokyr 2001, 2016). The pre-industrial agrarian economy, with its rises and falls in wealth and income governed by crops and the weather, plus pestilence and war, gave way to a quite different kind of economy, where systematic knowledge acquired by the scientific method became the basis of technologies and technological advance.[6]

Focusing on the technoeconomic drivers of change in our industrial system, we can draw from a Schumpeterian literature to identify five transitions in the period since the first transition, known as the Industrial Revolution – with a sixth putatively under way in the current period. The point is that each transition involves major social, technical, financial and business

upheavals that go well beyond mere economic substitutions effected by relative price movements. In my own work on this topic I have identified two streams of literature as making a major contribution. There is the stream that focuses on the actual K-waves as measured using sophisticated statistical techniques – as done by K himself and subsequently by Berry and most recently by the Russians Korotayev and Tsirel – in work validated by Devezas (2012).[7] There is a stream that focuses on the institutional details of each shift in technoeconomic paradigm, with a clear focus on the 'reverse salients' involved and the struggles between the emerging technologies and business interests and the vested interests defending the status quo. A third stream of scholarship focuses on the financial dynamics, as elaborated by Minsky, Kregel and others.[8]

The key point is that the waves involving upturns and downturns in economic categories – from prices to GDP to industrial sectors – are an empirical reality, obvious to all who are prepared to look at the evidence. But what accounts for these waves is anything but obvious – in fact to find an adequate explanation must count as one of the greatest problems of the social sciences. Schumpeter himself started an extremely fruitful line of advance with his hypothesis that the successive waves are driven by spurts of new technoeconomic clusters. But then there is the issue of what drives the clustering of technological innovations. Schumpeter took what is arguably a wrong turn in imposing a deterministic, cyclical process on the historical data in his *Business Cycles*, in place of allowing the evolution to proceed in an open-ended fashion.

Let us look at the data first, prior to framing hypotheses. The most widely accepted dates for the five waves of technoeconomic change since the industrial revolution are those provided by Korotayev and Tsirel, as given in Table 8.1. Each successive wave with a clear upswing and downswing can be dated more or less as follows.

Table 8.1 Upswings and downswings in industrial capitalism, 1760–2011

Long wave number	*Phase*	*Onset*	*Ending*
1st	A: upswing	1780s	1810–1817
	B: downswing	1810–1817	1844–1851
2nd	A: upswing	1844–1851	1870–1875
	B: downswing	1870–1875	1890–1896
3rd	A: upswing	1890–1896	1914–1920
	B: downswing	1914–1920	1939–1950
4th	A: upswing	1939–1950	1968–1974
	B: downswing	1968–1974	1984–1991
5th	A: upswing	1984–1991	2008–2012?
	B: downswing	2008–2012?	?

Source: based on Korotayev and Tsirel (2010), 2, Tables 1, 2.

In brief, the initial surge was driven by new developments in water technology, both in terms of power (water wheels) and transport (canals), involving the factory mode of production itself and new sources of power such as steam. The first steam engine (or 'atmospheric engine') was demonstrated by Newcomen in 1712; it was put to use in pumping water out of coal mines. The Boulton and Watt partnership was created in Birmingham in 1775 as a means of exploiting Watt's patent on the steam engine with a separate condenser; the firm became a driving force as it expanded in the nineteenth century. The shift to the downswing occurred during the Napoleonic wars. The principal industry utilising the new water power and steam power was textiles, particularly cotton – the first 'carrier industry'.

A new wave was initiated by the development of steam power applied with greater efficiency to factory work and to transport, in the form of a moving locomotive. The new surge was carried by vast investments in railroads, as tracks were laid across Europe and the US after being pioneered in Britain. The key factors in the second wave were thus steam and iron, which were able to overcome the incumbent water-based systems as their costs declined, provoking the 'canal panic' of 1837. The Great Western Railway, founded in 1833, received its enabling Act of Parliament in 1835 and operated its first trains in 1838 – marking a significant moment in the second Kondratiev. In the US the Union Pacific Railroad was founded with the Act of Congress 1862 during the Civil War. This second industrial surge was examined closely by Schumpeter himself in his 1939 work *Business Cycles* – in what Andersen (2002) has called Schumpeter's proto-case of 'railroadisation'.

Moving closer to the modern era, a third wave of investment and technological change plus creative destruction was launched by both steel and electric power in the 1890s, in a new upswing terminating the long depression that lasted from the 1870s to the 1890s. The new electric motors were pitched against the incumbency of steam power and triumphed in the early years of the twentieth century because of falling costs and because of greater efficiency; the electric motors were able to harness power to machines wherever they were used, rather than from the central 'prime mover' that characterised the steam-powered workshop. It was the Bessemer process that transformed the world of iron into a world of steel – and it was the founding of a new steel company in the US by Andrew Carnegie in 1872, based on the Bessemer process that launched a new era and resulted in the formation of US Steel. In the new world of electric power, the greatest innovations were by Westinghouse and Edison and Tesla, resulting in the formation of major K3 firms General Electric and Westinghouse. In Germany, which was also rising to industrial leadership, the major K3 firms founded at the time were Siemens and AEG, which became the core of Germany's subsequent technological supremacy.

The heavy engineering of the 3rd K-wave proved to be a major impediment to its diffusion, and it proved no match for a fourth K-wave, which was launched in the early twentieth century with the arrival of the internal

combustion engine (ICE) and the external combustion engine (diesel engine) as motive power for individual transport vehicles, based on the emergent oil industry as the source of fuel. This was the K-wave of oil, with the automobile as the lead industry and mass production as the lead organisational form. The origins of the K4 wave lay in the introduction of mass-production principles by Henry Ford in the automobile sector, perfected at the Highland Park (Michigan) plant in 1915, introduced during the downswing of the K3 wave. The introduction of this mass-produced car to the market was followed by unprecedented market expansion and cost reductions that flowered and diffused worldwide in the postwar boom (upswing of the K4 wave) – and that provide a glimpse of what is happening with green products such as renewable energy devices today.

The K4 wave is generally reckoned to have come to an end during the 1980s as financial crashes triggered new speculative booms – this time focused not on hardware like cars and white goods but on computers and information technology and the software that drove these new 'intelligent' devices. Early innovations were the transistor created as the first solid-state device in the 1960s and then the first 'chip' created by Intel in 1970, followed by the microprocessor in 1971. New fortunes in IT and software were created by completely new firms like Microsoft, Apple, Symantec and Oracle. The early investments were made in the downswing of the K4 period, only to bloom and flourish in the upswing of the K5 wave, in the late 1980s to the early 2000s.

This timing of successive waves dates our present period as the emerging downswing of the 5th K-wave, when investments in IT and knowledge industries continue to be made at scale but cannot be expected to carry the global economy to new levels of prosperity. Instead, investments in a new key factor are needed to do the job – and the best candidate for this new role is greening.[9]

Technoeconomic paradigms and their shifts

There are several sources that feed into this present exposition of a sixth wave transforming the global economy and shaping cities in a new urban geography. The first is Schumpeter himself and his fundamental conception of the evolutionary character of the capitalist system, or what he liked to call the evolution of the capitalist engine (a phrase picked up and utilised to great effect by his expositor, Esben Sloth Andersen, in his (2009) masterwork). The central concept in this stream of work is the notion of creative destruction and the long waves initiated by innovation (or clusters of innovative products and technologies). It is perhaps not widely appreciated that it was Schumpeter who really 'imported' Kondratiev and his long waves into Western economics – and gave the K-waves a conceptual underpinning in the form of technological innovation that they had not had in Kondratiev's own work.

Then there is the stream of work that elaborates on long waves and structural crises of adjustment, in which the work of Freeman and Perez (1988) is fundamental, with its central notion of the sociotechnical paradigm and the series of shifts in such paradigms culminating in the emergence of a fifth such shift in the 1970s and 1980s. This fundamental work introduced its taxonomy of innovations, as encompassing (1) incremental innovations (the most common); (2) radical innovations; (3) changes of technology system – where both radical and incremental technical innovations combine with organisational innovations; and (4) changes in 'techno-economic paradigm' – the most fundamental and far-reaching of all. It is viewed as having pervasive effects throughout the economy.

As elaborated by Perez in successive papers (Perez 1983; 1985) and by Freeman and Perez (1988) each successive TEP is characterised by a key factor or dominant cluster of technologies that have the characteristics that they feature:

1 clearly perceived low and rapidly falling costs;
2 almost unlimited supply over long periods; and
3 clear potential for incorporation of the key factor in products and processes throughout the economic system.

The crux of their paper was the demonstration that these characteristics at the time held most persuasively for IT and IT-related products, i.e. products of miniaturisation, electronics and digitalisation. Moving backward in time they argued that these characteristics held for the key factor of the 4W (oil) and (by extension) for mass production and the automobile. Further back the key factor of the 3W they argued to be low-cost steel (rather than electric power); and in the 2W low-cost steam-powered transport. Perez herself in her 1983 and 1985 papers referred to 'technological styles' as something that encompassed more than 'just' an innovation. By the 1988 paper she was happy to adopt the terminology 'technoeconomic paradigm' (TEP) and this remains the term of choice.[10]

In a manner closely similar to Freeman and Perez (1988), I wish to argue that in our own time an emergent paradigm shift is based on the key factor input of renewable energies and circular economic system (CERES) packaged together in eco-cities (or smart cities), where we see (1) drastically declining costs (and where the argument is that their costs are declining for fundamental reasons related to the fact that they are products of manufacturing); (2) unlimited supply of renewable energy sources (and recirculation of material inputs, potentially endlessly); and (3) demonstrated potential for incorporation in power systems, food production, water regeneration and in manufacturing and transport generally, i.e. right across the economy. In addition to key factors satisfying conditions of having low and descending relative costs, plus virtually unlimited supply and potential all-pervasiveness, Perez specifies that a new key factor should also demonstrate the potential to reduce

costs of capital and other inputs into productive activities – which is clearly the case with the green-shift products and processes (see Perez 1983, 4).

If we include this fourth element as well, we see that it too fits the introduction of renewable energies and recursive materials systems since these elements have the demonstrated capacity to reduce costs for all other factor inputs (e.g. as water costs increase, due to scarcity, so water regenerated in renewable energy powered desalination systems becomes relatively much more cost effective).

The TEP based on fossil fuels is being superseded by RE-based power systems not because of perceived differences between 'green' and brown electric power (appealing to moral and ethical choices) but because the RE-based power is falling in cost relative to fossil-fuel-based power, and the RE-based power is finding wider and wider applications, e.g. in urban food production and urban water regeneration. If it is agreed that the mode of diffusion of a new TEP occurs through applications across multiple sectors, then we see a new green surge occurring driven by renewables and the circular economy, we find multiple applications of renewables across multiple sectors – including in food production and water regeneration, where urban-based innovations are emerging based on the capacity to supply virtually unlimited energy from solar and wind sources. This complex of IT-enabled renewable energy technologies constitutes a 'key factor' that enjoys steadily reducing costs (and prices) based on the fact that all the activities involved depend on the production of manufactured devices. Because of these falling costs associated with manufacturing experience curves, the 6W key factor may be seen as having widespread effects, bringing renewable electric power to ever-widening circles of users and enhancing their energy and resource security.

The 6W motive branches are those that are involved in the manufacture of renewable-energy devices (e.g. wind turbines and solar PV cells), energy-storage devices (e.g. lithium-ion batteries) and electric-grid devices (e.g. inverters, energy centres). The prosperity of these motive branches rises as the adoption of the 6W energy systems diffuses. Correspondingly the 6W carrier branches are the power-generation systems as well as electric-vehicle systems that utilise the key factor of renewable electric power. These, too, are products of manufacturing and reduce in cost (and then in price) as a result of the experience curve.[11]

Thus, we can identify 'induced branches' as those that are related to the diffusion of the carrier branches, such as the manufacture of EV-charging stations, battery-replacement stations for EVs and other such sectors that have no role in the fossil-fuel economy but constitute essential infrastructure in the 6W economy. We see then that *manufacturing* is the activity that is common to the key factor itself (renewable electric energy) and to the motive branches, the carrier branches and most of the induced branches (Mathews and Reinert 2014). What we need to demonstrate is that a surge exists in manufacturing activities related to renewable-energy and energy-storage devices that make the generation of renewable energy cost-competitive with traditional fossil-fueled

sources and ultimately more cost-effective than incumbent thermal sources. It is relative costs that account for the rise of a new surge and its supersession of an existing TEP – without having to posit an over-determined cyclical phenomenon. The missing element is the role played by finance, particularly state entrepreneurial finance – and here we see China playing a leading role in greening its financial system and giving full rein to development banks like the China Development Bank in driving investments towards green projects.[12]

The green shift of the twenty-first century as the 6th K-wave: the rise of China

Now there is a powerful argument linking the global green shift as a dominant technoeconomic development to the geopolitical shift that sees the rise of China as an industrial giant. Let us then review the evidence supporting the claimed shifts that are the dominant trends today – the shift in manufacturing east, and the green shift away from fossil fuels. They are in fact linked, at a profound level, because it is China that is driving the shift of manufacturing east, and as it does so, it finds that it has to drive the green shift, as well(Figure 8.1)[13].

Our starting point is the green shift that is currently under way in the industrial economies – including (and especially so) in the rising industrial giants, China and (to some extent) India. As China and eventually India build their vast manufacturing engines, so they discover the need to power them with energy sources – of which fossil fuels are the obvious and initially favoured candidates – just as has been the choice made by all previous rising industrial powers.

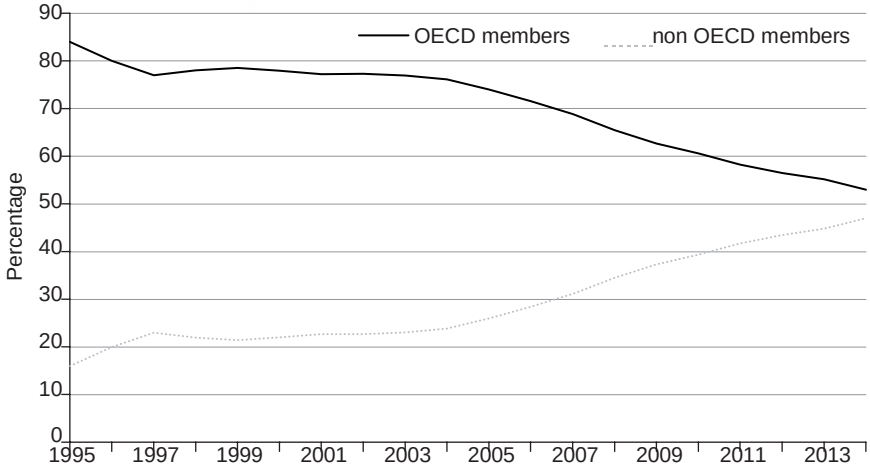

Figure 8.1 Manufacturing moving east.
Source: OECD Development Centre.

The green transition that is currently under way is the single most important feature of the current world, along with the rise of China as the world's premier manufacturing power. Indeed, the two features or processes are tightly linked, because China's rise is based on the building of a huge energy system to power the manufacturing system. China has discovered the limits to trying to build this energy system on the basis of fossil fuels alone. The limits are not so much commodity-supply limits of the kind investigated and popularised by the Club of Rome study of 1972 on *Limits to Growth*, but rather geopolitical limits as China finds that its quest for resources and especially fossil fuels around the world runs into problems involving economic blockades, trade wars, civil wars, revolutions and terrorism. Compelled by these factors, along with the terrible immediate environmental problems created by China's headlong rush to industrial maturity, China is finding that conventional energy and resource strategies ('business as usual') no longer work, and it is instead engaging in an alternative 'green growth' strategy that is proving to be very successful. This alternative is driven by reducing costs, market expansion and manufacturing innovation as China becomes a principal global player in installing renewable energy systems (such as wind power and solar photovoltaic cells) and in manufacturing the devices needed to capture the renewable energy sources.[14] China's green and black strategy is easily discerned when we look at longitudinal data on electric power generation (Figure 8.2).

The effect of this rapid expansion of fossil fuels input in China is well known – it is unbreathable air and undrinkable water, combined with rising

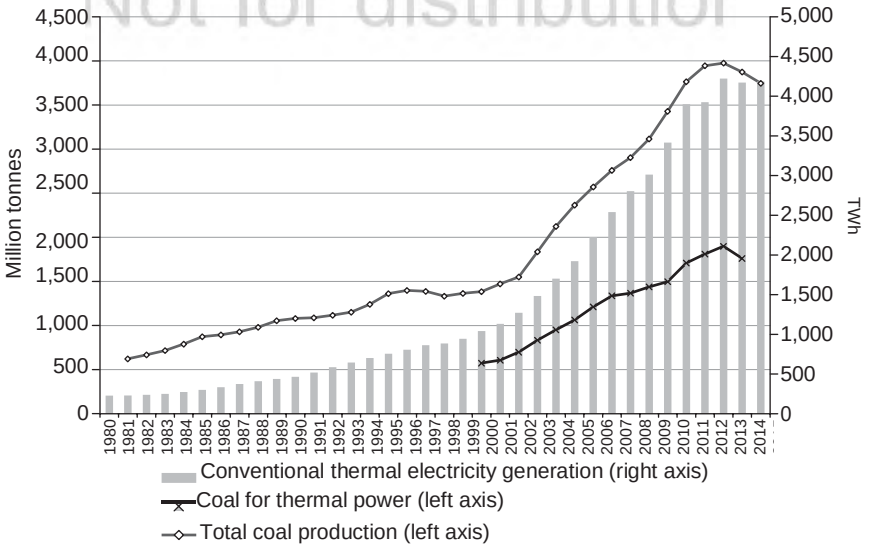

Figure 8.2 China's 'green and black' energy system, 1980–2015.
Source: Mathews (2016).

geopolitical tensions as China (and now India) scour the planet for fuels and resources. But China has stumbled on an effective remedy for these problems – renewable energies and urban mining or recirculation and regeneration of resources. The evidence demonstrating this shift is again clear and unequivocal. Consider Figure 8.3, which shows the rapid increase in proportion of electric power generated from water, wind and sun – rising from a low of 20% a decade ago to reach 34% in 2016 – a 14% shift in capacity in a decade. (The corresponding shift in electricity generated from WWS sources is also shown, rising from 15% to 25% over the same period.) This is an astonishing rate of change for such a huge system with its vast fossil-fuel infrastructure.

The conventional economic account of this green shift is to focus on switching from one energy system to another as a matter of substitution, where the price of one commodity/product versus another is determined in some equilibrium framework. Policy initiatives can be taken in such a framework by cost-moderating instruments like green taxes or market-mediated caps on emissions. Apart from the fact that such interventions have proven to be very weak when put into practice and stand little chance against the raft of subsidies that have historically supported the fossil-fuel system (oil and gas industry, coal industry, power-generation industry), these equilibrium-based instruments offer precious little insight into the workings of energy-industrial dynamics. But Schumpeter's approach, as exemplified in his major books (the

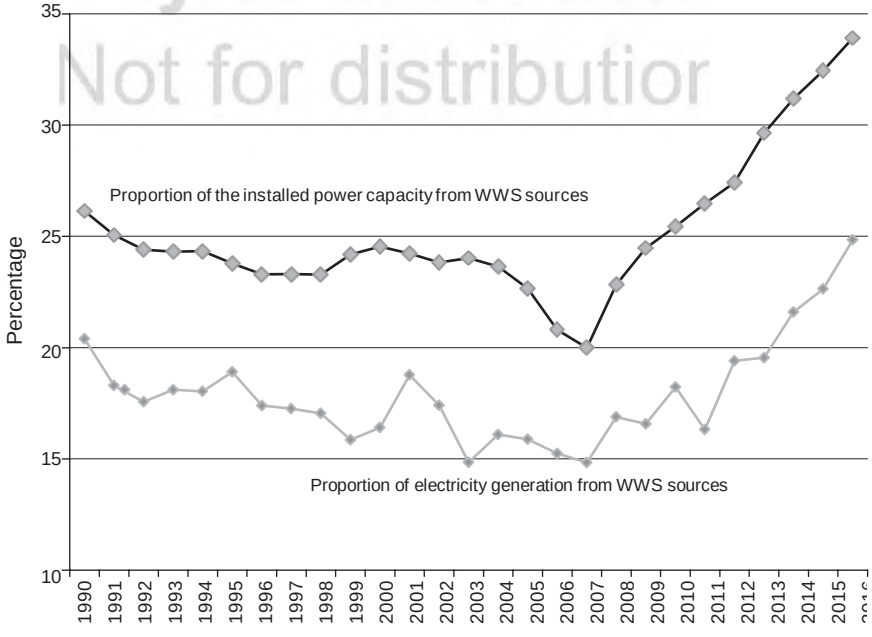

Figure 8.3 Greening of China's electric power system, 1990–2016.
Source: Globalgreenshift.

youthful *Theory of Economic Development* (1934) and the more mature *Business Cycles* (1939)) and briefly in his *CSD*, is far richer and promises to generate far more fruitful insights than the conventional approach.

If we start with the concept of creative destruction, we see that Schumpeter's approach in *CSD* would imply that the rise of a new cluster of renewable energy industries would be accompanied by the decline and fall of traditional industries, namely those based on fossil fuels. This is an evolutionary perspective, one that views the energy sectors as being in perpetual disequilibrium and shaken by waves of firms deploying new energy technologies taking over from those that cling to the prevailing technologies. The mode of supersession of one industrial cluster by another was always the focus of Schumpeter's analysis – as it needs to be in the case of the twenty-first-century shift in energy and resource systems.

Schumpeter himself took the trouble to exemplify his evolutionary analytical perspective by utilising the case of 'railroadisation' in the nineteenth century. This is what the current Danish Schumpeterian scholar Esben Sloth Andersen has called Schumpeter's principal case and reference point in describing the evolutionary dynamics of capitalism. Now we can take a similarly important case, around 100 years after Schumpeter's major scholarly interventions, in the form of the global greening shift that is having widespread creative destructive effects worldwide.[15]

Essentially, greening is a process of creative destruction – a destruction of the entire fossil-fuel industrial order and its supersession by an alternative energy and resources order based on renewable inputs. This is not the mere substitution of one or two products by different products – as in electric power produced from coal substituted by electric power produced by wind and sun. Rather it is a whole system transition or shift from one system based on fossil fuels to another system powered ultimately by renewables. A technoeconomic system transition implies taking cognisance not just of prices (as in the equilibrium-based mainstream economics perspective) but of other key factors including technologies (e.g. wind and solar power devices and their use to generate power, or EVs and batteries); infrastructure (electric power smart grid; EV charging stations); government policies (e.g. feed-in tariffs; public auctions of renewable energy concessions); finance in all its forms; and institutions and business models.

Correspondingly a Schumpeterian perspective on creative destruction focuses attention on the means of resistance waged by the incumbent firms and the technologies they support, as they strive to delay or block the supersession that is under way. It is an open-ended struggle whose outcome is anything but determined.

All these features can be seen in the current green shift that is diffusing worldwide. And just as there was a lead country with its lead firms driving previous technoeconomic shifts, so is there a lead country in the twenty-first century driving the shift to a green economy. In the nineteenth century there was the shift from mail coaches and canals to railroads, when the lead country

was initially Britain, later followed by Germany and the USA. In the late nineteenth and early twentieth centuries there was the new wave sparked by electrification, where the lead country was the USA and to some extent Germany. In the twentieth century, as the fourth Kondratieff unfolded, based on oil, automobiles and mass production, the lead country was definitely the USA, and leading 4K firms like Exxon-Mobil, GE, GM and Ford were American. In the late twentieth-century, fifth Kondratieff based on IT/ICT, there has been a multipolar expansion with the lead shared at different times by US, EU and Japanese firms. Now in the twenty-first century we see the emergent sixth wave driven by applications of IT to energy and electric power, to food and water production and regeneration, and to the shaping of cities themselves as the envelopes of further technoeconomic advance.[16] China is emerging as the lead player as it moves rapidly from imitation to innovation.

China's greening of finance

As in other aspects of the greening of the economy, China is emerging as a leader in the financial aspects of the process. Take the role of the China Development Bank, which has extended lines of credit to Chinese solar photovoltaic (PV) companies like LDK and Yingli Solar, and to wind power companies like Goldwind, thus propelling them to leadership in the China market and subsequently to global dominance. Yingli, for example, enjoyed a $5.78 billion line of credit as of June 2011; LDK Solar received $9.1 billion; Suntech Power $7.6 billion, and Trina Solar $4.6 billion; while Sinovel Wind received a credit line worth $6.5 billion. All up, by 2010 Chinese firms had invested over $50 billion in clean energy, far surpassing the levels of any other country – largely financed by the China Development Bank and other 'policy banks' that provided the financial muscle behind the Chinese entrepreneurial state's green surge.[17]

While these preferential loans provided an initial impetus, China's green finance initiatives have since broadened and deepened.[18] Chaired by Dr Ma Jun of the People's Bank of China, the Green Finance Task Force issued its long-awaited report *Establishing China's Green Financial System* in April 2015 – making China the first country in the world to issue specific guidelines on the crafting of green securities.[19]

China is adopting a realist and pragmatic perspective on sources of green finance, viewing this as the driver of a technological transition. The 2015 report states that no more than 15% of all green investment can be expected to come from fiscal sources (i.e. tax-based investment). This means that the bulk of the financing – or 85% – is expected to come from the private sector, through various green finance channels (bank loans, green bonds, investment funds).

Ma Jun lists six core principles of greening of finance in his foreword to the report. These are what China's green financial system should move towards:

1 Building new channels for green investment, and not just restricting polluting investment;
2 Opening up new channels through new specialised green lending and investment institutions (such as a green bank), and not just relying on existing banking channels;
3 Steering private capital to the greening of industry, reducing reliance on administrative orders;
4 Ushering in a range of new green instruments such as green bonds, green stocks, green funds and green insurance, and not just providing green loans;
5 Changing the behaviour of financial institutions through financial and legal measures, with public funds aiming to leverage private funds up to tenfold; and
6 Providing necessary financial infrastructure that will enable green investments to thrive (such as green credit ratings, environmental impact data) rather than just offering administrative support for green investment.

This national strategy – the first of its kind to be explicitly drafted as such – underlines how seriously China is taking its role in greening its economy. The report proposes three major institutional innovations including the creation of green banks; the creation of green funds (i.e. green industry funds and public-private partnership arrangements); and a process of greening the existing development banks (such as the China Development Bank allocating part of its lending portfolio to targeted green investments). The report goes on to specify how China needs to develop specific green financial instruments, including 'discounted green loans' (i.e. offering bank loans at differential interest rates depending on whether projects meet green targets); permitting Chinese banks to issue green bonds, thus tapping into the debt securities market (and helping to grow it in China); and green IPOs, i.e. improving the mechanism through which firms' environmental performance is communicated and recognised in equity markets.

China's banks have since moved rapidly to issue a series of green bonds in pursuance of these goals. In October 2015, the Agricultural Bank of China (another development bank) issued a first green bond worth $1 billion. Then in January 2016 the Shanghai Pudong Development Bank issued a green bond worth 20 billion yuan (US$4.3 billion), designated for climate-related investments; then the Bank of China issued a green bond in July 2016 worth $3.03 billion. Chinese banks issued green bonds worth $36 billion in the year 2016 (compared with a global total of $81 billion), all targeted at institutional investors such as sovereign wealth funds, pension funds and insurance funds. Encouraged by these successes, individual companies are now starting to issue their own green corporate bonds.[20]

Thus, we have the situation where China is clearly paying as much attention to the financial as to the technological aspects of the current green surge, for the clear reason that it sees this surge as the means for bringing its

industrialisation aspirations to a strong conclusion. This green surge is a product of China's state entrepreneurship crafted as a means of driving creative destruction of the incumbent fossil-fuel industry – but in a socially responsible manner, since the Chinese government sees its political future as tied to its being able to meet the rising economic aspirations of the Chinese people. This is a world away from the narrow concerns of neoclassical equilibrium-based analysis, as much as from any tightly deterministic notion of economic cycles succeeding each other in clockwork fashion.[21]

Schumpeterian analysis superior to that of neoclassical economics

My purpose in this chapter is to draw out the contrast between a neoclassical economics perspective and the Schumpeterian perspective on the global green shift. The neoclassical perspective, which for some incomprehensible reason still manages to maintain its dominance in academia, is based on micro-economic static reasoning, i.e. micro reasoning at a single point in time rather than macro dynamic analysis. Based on the prevailing equilibrium assumption, the insights offered are that as the price of some factor of production changes so its utilisation in the production function will shift. In the case of energy inputs, the neoclassical framework contrasts fossil-fuel-energy inputs with renewable-energy inputs in terms of their current prices. Based on an externally induced crisis (namely climate change) it generates a policy proposal to decarbonise energy inputs, through the medium of raising the prices of fossil-fuel inputs. The most straightforward way to do so is through a carbon tax – although there are other means of making fossil fuel inputs less attractive, such as cap and trade schemes, whereby producers are allocated a 'cap' on their allowable carbon emissions and are enabled to trade these allowances in a carbon market.

These schemes of one kind of 'environmental taxation' or another are discussed in a setting where an external threat is perceived and a moral duty to act to avoid the threat is posed. The problem is that the political resistance to such environmental taxes by vested interests is profound and determined, so much so that there has been precious little progress achieved globally in reducing carbon emissions over the 20-plus years of operation of the UN-sponsored Kyoto Protocol. And sometimes the moral imperative is posed with breathtaking arrogance – as when a political party in the advanced countries ignores the moral imperative incumbent on themselves and calls down divine punishment on governments in developing countries where fossil-fuel usage is rising, as a result of their implementing a strategy of industrialisation. India and China are the two countries that are receiving most of this opprobrium.

This neoclassical economics framework is entirely contingent, and frames the shift that is observable as a price-mediated substitution of one input by another, without any sense of where the system might be headed, or why.

The story told is simplicity itself. In the past there was an effective shift to fossil-fuelled energy inputs, powering a wave of wealth-enhancing industrialisation. Today the environmental costs of these are discovered and so economists advocate a carbon tax to induce price-guided substitution of energy inputs. The fact that they have been advocating the same policy for some 20-plus years with very little to show for their efforts is not – apparently – seen as a negative. It is put down to the fact that major substitutions are politically complex and difficult to achieve.

By contrast a Schumpeterian perspective puts the green shift in a plausible industrial and historical setting and frames realistic proposals as to how it may be achieved or accelerated. First, the green shift is viewed not as a unique occurrence but as the latest in a series of technoeconomic shifts – each one driven by the same kind of concatenation of events. The economy is viewed not as a series of static adjustments but as an evolving system. The driver of change is the technoeconomic character of the economy at a point in time, where long-term waves of development are observed empirically, and theory is developed to seek to account for these wave-like shifts. An existing technoeconomic paradigm (TEP) is ousted by a successor, whose existence can be validated by reference to the parallel shifts that have occurred in the past, together with the role of finance and state entrepreneurship in driving change from one TEP to another (as in China). The driver of change is investment (rather than relative prices), facilitated by state development banks in the first instance followed by a multitude of private firms flocking to the rising industries.[22]

From this perspective, the current green shift may be viewed as the sixth such transformation since the industrial revolution, where each period is characterised by a dominant technoeconomic paradigm that rises according to well-recognised dynamics and is in turn ousted by a successor. This historical perspective draws attention to the dynamics of the shift, looking to identify the motive forces (key factors) that are generated as well as their carrier industrial branches and their induced branches. The role of finance is underscored by the greening of finance, which is now a global phenomenon, driven by the emergence of a green financial sector in China.

When we combine geopolitical insights with those from industrial dynamics we get even closer to the present realities. In the case of the global green shift we have the simultaneous occurrence of a shift in manufacturing east (specifically to China in the first instance) plus the shift in terms of industrial dynamics to a post-fossil-fuel world. And these two trends are in fact deeply connected. As China industrialises (which it is pursuing in the name of enhancing wealth and income) so it finds it necessary to build a vast energy system to power its growth in manufacturing. It starts, of course, with fossil fuels – like all previous industrial powers. As it does so it comes across not just immediate environmental limits to expanding the scale of fossil-fuel usage (unbreathable air and soiled water) but geopolitical limits in the form of threats of war, revolution and terror as China penetrates regions of the earth

that are less and less stable in search of fossil fuels (and resources) that are less and less accessible.[23] And so China looks actively for an alternative to fossil fuels in order to enhance its energy security – and an alternative to linear resource flows through recirculation as a means to enhance resource security. And as China makes the discovery that renewable devices and closing industrial loops are products of manufacturing, and as such generate increasing returns and can be performed anywhere, so its commitment to driving the emergent green surge both technologically and financially is deepened.

We have then an argument that starts with empirical realities, namely the observable green shift that is under way together with the shift eastwards in manufacturing and the energy choices (and resource choices) that are imposed on China to drive this industrial engine with some degree of energy security (and resource security). And we have a theoretical explanation for these shifts in terms of a clustering of green energy technologies that are becoming available (as the grip of fossil fuels is loosened) and are driven primarily by China as the optimal candidates for powering China's industrialisation. This is a powerful application of Schumpeter's conceptual apparatus applied in a new, twenty-first-century setting.

Notes

1 On carbon lock-in, see Unruh 2000; Unruh and del Rio 2012.

2 See Kondratiev 1926. This article was translated into English by W.F. Stolper and appeared in the *Review of Economic Statistics* in 1935. By that time Kondratiev was in prison in the Soviet Union, a victim of Stalin's purges. He was executed by firing squad probably in 1938. For a brief biographical treatment, see Grinin, Devezas and Koratayev 2012.

3 At the same time it has to be said that Schumpeter forced the Kondratiev swings into a tight cyclical framework that has done lasting damage to the study of long-range economic and industrial phenomena. For a critical treatment, see Burlamaqui's chapter in this collection.

4 Those scholars of note include Ayres, Berry, Devezas, Freeman, Gruebler, Lloyd-Jones, Lewis, Louça, Marchetti, Nakicenovic, Perez, Tylecote and others, as well as Russians Grinin, Korotayev and Tsirel, while Modelski has traced the long-wave concept back through 20 such waves occurring over the past 1000 years of globalisation. As a sampling of the work reported, see Allianz 2010; Andersen 2002, 2009; Ayres 1990a, 1990b; Freeman 1983, 1997; Perez 1983, 1985, 2002, 2010, 2015; Freeman and Perez 1988; Freeman and Louça 2001; Kleinknecht 1986; Korotayev and Tsirel 2010; Nefiodow 2006; Tylecote 1992; Lloyd-Jones and Lewis 1998; Berry, Kim and Kim 1993; and Gruebler and Nakicenovic 1991.

5 A business case for a new cleantech era is provided by Milunovich and Rosco 2008, while Wilenius and Casti 2015 continue the argument using the notion of 'X-events'.

6 It is fitting to describe the agrarian economy as Malthusian, since it was best described by Thomas Malthus at the very moment that it was disappearing in the early nineteenth century.

7 Devezas 2012 reports on a spectral analysis of the unfolding of global GDP growth rates, where cycles of periods 7.5 years, 15 years, 32 years (weak) and 52 years (strong) are clearly identified.

8 For expositions, see Burlamaqui 2015, Keidel and Burlamaqui 2016 or Burlamaqui and Kattel 2016.

9 Others, such as Nefiodow 2006 and the insurance firm Allianz 2010, have opted for biotech and personalised medicine, which I agree is a world-changing technological innovation but in my view is likely to see its flourishing in the next K-wave, after the conditions favourable to it are created by the emerging sixth wave.

10 For a general history of Perez' evolving concept of the TEP, see the chapters in the collection edited by Drechsler, Kattel and Reinert 2009.

11 See the argument spelt out in Mathews and Reinert 2014)

12 See the studies by Sanderson and Forsythe 2013, Keidel and Burlamaqui 2016 or Burlamaqui and Kattel 2016.

13 For my successive contributions on these themes, see Mathews 2011, 2012, 2013, 2015 as well as Mathews and Tan 2011, 2014, 2015, 2016).

14 On the falling costs of renewables, and in particular the falling costs of solar PV cells, see, for example, Bazilian *et al*. 2012.

15 See Andersen 2002 for his excellent contribution to Schumpeterian scholarship.

16 On cities as shapers of technological and financial trends, see, for example, Batty 2016 or earlier work by Bettencourt and West 2010.

17 See Sanderson and Forsythe 2013, 147–151. These scholars take the investment story up to 2012. There has been continuity of support since then. For example, Yingli Solar received a loan from CDB in June 2013 worth another $165 million; see the story at https://qz.com/77347/china-development-bank-makes-bet-on-yingli-as-a-solar-survivor/.

18 The following paragraphs are based on the chapter 'Greening of Finance' in Mathews 2017.

19 See the report at: www.cbd.int/financial/privatesector/china-Green percent-20Task percent20Force percent20Report.pdf.

20 On these trends, see the Climate Bonds Initiative, *Bonds and Climate Change: State of the Market 2016*, at www.climatebonds.net/resources/publications/bonds-climate-change-2016.

21 On the narrow concerns of equilibrium-based analysis, see for example Chen (2008); on a critique of deterministic economic cycles, see for example Burlamaqui (this volume).

22 From this perspective, the judgement of Nathan Rosenberg 1994 made a quarter-century ago that Schumpeter must be counted as a profoundly 'radical' economist, is surely justified.

23 See, for example, the discussion of China's efforts to fashion novel 'loans for oil' deals with such countries as Ecuador (Gholz, Awan and Ronn 2017).

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