Neoliberalism and technology: Perpetual innovation or perpetual crisis?

Laurence Reynolds and Bronislaw Szerszynski

The final version of this paper was published as Chapter 1 of

Neoliberalism and Technoscience: Critical Assessments,

ed. Luigi Pellizzoni & Marja Ylönen, Farnham: Ashgate, 2012, pp. 27-46.

Please cite that version.

Introduction

The neoliberal era has often been imagined as a period of intense technological revolution. The goal of a high-tech 'knowledge based economy' (KBE) of perpetual innovation has been elevated into a key guiding principle and salvationary strategy for advanced capitalist economies. Innovation is held up as the solution to multiple problems that became apparent in the 1970s, including the crisis in capital accumulation, the globalization of competition and the rise of environmental degradation. Since that decade we have been dazzled by a seemingly escalating proliferation of innovations, from information technology and mobile telephony through to biotechnology and nanotechnology. Yet, at the same time, there is also a sense that the high-tech promise of the 1970s, of a 'space age' where robots would replace workers, or the later prediction of a 'biotech century', have somehow not been realized. 'Tomorrow's world' never quite came about.[1]

Sceptical commentators have questioned the idea of the technological fecundity of the neoliberal period, arguing instead that the last quarter of the twentieth century and after has been a 'great stagnation', where we have reached a 'technological plateau' (Cowen 2011). A popular trope, deployed by both Gordon (2000: 60) and Cowen (2011), has been to compare the dramatic changes in everyday life that resulted from technological transformations during the first half of the twentieth century with the much more modest changes experienced since then. Save for the Internet and mobile telephony, the basic technological infrastructure (based on cars, oil, etc.) has seen little radical transformation. In this trope, our contemporary

[1] *Tomorrow's World* was a futurological UK BBC television programme on the impact of new technology that was first aired in 1965, reached its heyday in the 1970s, and ran until 2003.

experience is indeed one that looks like a plateau when compared with the radical techno-social change that someone reaching old age in the 1960s would have experienced over the preceding half century.

We will explore this apparent paradox in this chapter, with our main focus not on the innovation of new consumer goods, but on what Marx called 'the forces of production'. It is useful here to introduce Marx's own distinction between goods produced for 'Department One' and those for 'Department Two', where the former denotes products that are means of production, and the latter consumer products. Our task therefore is to interrogate whether the period emerging from the crisis years of the early 1970s that has come to be called 'neoliberalism' saw the assemblage of a new set of productive forces. To what extent was the apparent success and renewed global expansion of capitalism in the neoliberal period based upon a new 'techno-economic paradigm' or 'third industrial revolution'?

As we shall see, for sceptical commentators such as Smil (2005) and Gordon (2000), what was heralded in the early 1990s as a 'new economy' based upon infotech and biotech is in no way comparable with the substantial development of the forces of production that was achieved in what has been dubbed the 'second industrial revolution', which began in the late nineteenth century and reached full fruition in the decades following the Second World War. Optimistic talk in the 1970s of a 'third technological revolution' is, in this view, misplaced.

We begin by locating the neoliberal period within an analysis of the different terms that scholars have used to describe the systemic shift in the structure of capitalism in the 1970s. We then go on to critically examine the claims that this shift was made possible by a 'third technological revolution'. In the 1990s, capitalism appeared to recover from its two decades of stagnation and went on to have two decades of growth, a revival which was purported to constitute a fifth Kondratieff wave made possible by a new suite of technologies. We bring sceptical commentators to bear on this account, examining the weak performance of the high-technology sector in terms of productivity. We also survey some of the factors that may lie behind this – and also behind the resumption of growth that occurred nevertheless. We then set the transformed relationship between science and capitalism in the neoliberal period in historical context, by examining their couplings in earlier techno-economic regimes. We conclude by using the story of an 'innovation plateau' to describe the two faces of the relationship between science and capitalism in the neoliberal period: on the one hand, an economy largely characterized by mundane technologies and globalization, and on the other a scientific commons continually appropriated and harvested by capital and caught up in political economies of promise.

The crisis of the Seventies and the end of the 'Golden Age'

'Neoliberalism' is one way of naming a set of strategic responses by states, corporations and other actors to the crisis decade of the 1970s (Harvey 2005). The term usually denotes the eventual new direction taken after the crisis and collapse of the Keynesianism or organized capitalism during the global political turbulence opened by the insurgent year of 1968, the collapse of the Bretton Woods international order and the OPEC 'Oil Shock'. The year 1973 is frequently taken as marking a key turning point (e.g. Harvey 1989, Jameson 1992), dividing the second half of the twentieth century into two periods. The first, described variously as 'the long boom' or the 'Golden Age' of capitalist expansion, roughly falls between the end of the Second World War and the 1970s, (Marglin and Schor 1992, Brenner 2002a). The second period, from around 1973 to the present moment, has been characterized as one dominated by 'neoliberalism', a period of economic and political restructuring, privatization, deregulation and globalization in response to the 1970s crisis.

However the question of precisely how to characterize these two periods has brought forth a range of theorizations and terminologies. Some of these focus on state–economy relations, others highlight the techno-economic, others finance, politics or culture. For Lash and Urry (1987), the post-war 'Golden Age' period marked the zenith of 'organized capitalism', a term derived from Hilferding ([1910] 1981) and Bukharin ([1918] 1972) to describe the tendency from the turn of the twentieth century onwards towards the concentration of capital, leading to the fusion of industrial, banking and commercial capital with the state. Here, competition between firms becomes transformed into imperialist competition between states, and the state increasingly steps in to organize the economy and society, creating scientific and bureaucratic hierarchies to manage industrial production and social reproduction. This organization of capitalism, while initially performed by the state and managerial elites, is progressively also taken up by organized labour and civil society.

In a similar vein, for Ruggie (1982) and Harvey (2005) the pre-1970s 'Golden Age' can be described as one of 'embedded liberalism'. Ruggie uses this term to describe the international order established in response to the mid-twentieth-century catastrophes of global depression and war, leading to a new post-war order that was neither a disembedded market liberalism nor a protectionist and autarkic state-led monopoly capitalism. Other descriptions name this as a Keynesian or Welfare State period, while others still describe the importance of this *dirigiste*, state-led economic form in developing countries between 1945 and 1970 (Kennedy 2006). According to all of these theorizations, however, by the 1970s a period of change had set in.

Similarly, the naming of the period since the 1970s as 'neoliberalism' is only one attempt at description amongst many others. Thus it has been proposed that the period also marks the beginning of a 'post-industrial society' or an 'information age' (Drucker 1969, Toffler 1970, Bell 1973, Castells 2000), 'postmodernity' (Lyotard 1984, Baudrillard 1984, Jencks 1986, Harvey 1989, Jameson 1992) or 'post-Fordism' (Piore and Sabel 1984, Aglietta 1979, Lipietz 1982, Lash and Urry 1987, Jessop 1992). More recently, many of these theories have been combined in the policy discourse of a 'knowledge-based economy' (OECD 1996), a concept which bears an uncanny resemblance to autonomist Marxist accounts of a new period of capitalism based upon the exploitation of a 'general intellect' (Hardt and Negri 2000, Tronti 1966, Virno 2001) or 'cognitive capitalism' (Moulier-Boutang 2012, see also Gandini this volume). Theorists of social change have often been primed by a cultural expectation that we should be living through a period of 'epochal' changes, where these expectations are combined with the explanation of them. These works therefore inevitably move between descriptive and performative dimensions, being inescapably bound up with the changes themselves and becoming crucial in the self-understanding of the actors involved in these transformations. Hardt and Negri declare this period marks a 'qualitative passage in modern history' from the standpoint of historical materialism, adding that:

> When we are incapable of expressing adequately the enormous importance of this passage, we sometimes quite poorly define what is happening as the entry into postmodernity. We recognize the poverty of this description, but we sometimes prefer it to others because at least postmodernity indicates the epochal shift in contemporary history. (Hardt and Negri 2000: 237)

Later, they add that 'postmodernization' is synonymous with 'the informationalization of production' (Hardt and Negri 2000: 280). For us this raises the question of the relationship between science, technology and this alleged epochal shift into a new phase of capitalism that began around the crisis decade of the 1970s.

In other readings, this decade of crisis takes on significance as a moment of transition between two 'long waves' of economic development. Long wave theory originates with Nikolai Kondratieff (1925), who noted decades-long cycles in prices, interest rates, trade and production. With an average length of around 50–60 years, each 'Kondratieff wave', or K-Wave, is seen as made up of two main phases, an 'upswing' or 'expansionary' phase, and a 'downswing' or 'depressive' phase (Mandel 1995: 20–21). For some long-wave theorists, such as Joseph Schumpeter (1934), Christopher Freeman (Freeman and Louçã 2001) and Carlotta Perez (2002), these cycles are driven by technological innovation. In this view, each upswing phase of a K-Wave requires a new industrial revolution, one in which a 'lead industry' (Rostow 1978) or 'general-purpose technology' (Bresnahan and Trajtenberg 1995) generalizes a whole new set of technological productive forces across the economy. Technologies that have been claimed to have performed that kind of catalytic role, such as steam power, railways and electric motors, are, according to most commentators, essential for an industrial revolution.[2]

Such understandings of Kondratieff waves are highly relevant to our understanding of the neoliberal period. According to proponents of K-Waves, in the 25 or so years after the Second World War the economy was undergoing the expansionary upswing of the fourth K-wave, based on oil, mass production and petrochemicals, and the crisis of the 1970s represents the start of its depressive downswing. But, for neo-Schumpetarians such as Freeman and Perez, this crisis decade also marks the start of a fifth wave, one based around a new suite of technologies such as information and communication technologies and biotechnology. It is this kind of claim that we are interrogating here. Are there any signs of new lead industries or general-purpose technologies which might carry a new long wave of economic expansion? Or will economic growth and increased productivity have to come from within the existing techno-economic paradigm? To fully answer – or even articulate – such questions we have to attend to the difficult question of *why* expansive waves start and end.

[2] Other commentators, however, are sceptical about such 'innovation-centric' accounts, arguing that if a purported 'general purpose technology' had not been available, in most cases its function could have been filled by an alternative, existing one (Fogel 1964, Fishlow 1965, Edgerton 2006).

For Mandel (1995), expansive periods enter periods of crisis and a downswing because of endogenous factors generated by the internal contradictions of capitalist development, such as the tendency of the rate of profit to fall. However, the transition to a new expansive phase is the outcome of a cluster of historically contingent or exogenous factors. These include wars, revolutions, and crises where capital is destroyed and/or the costs of labour are massively reduced. Other factors behind the start of a new K-wave can include the innovation of a new assemblage of productive forces or techno-economic relations. Mandel's analysis helps us hone our question. If capitalist development went into an era of crisis in the 1970s (due to the exhaustion of the previous long wave), then what accounts for the much heralded period of expansion in the 1990s and after? In particular, was there a new assemblage of techno-economic relations sufficient to restore the rate of profit?

A third industrial revolution?

The moment of crisis and transition in the 1970s was understood by many participants and commentators at the time as a new technological revolution. A cluster of new technologies around the microprocessor opened the prospect of a fundamental reordering of economic and social relationships that was billed as the coming of an 'information society' (Bell 1973). In this vision, 'smart production' would see workers replaced by robots, while the informationalization of the forces of production would make them both more resource-efficient and flexible. Following from the 1960s rhetoric of an economy re-forged in the 'white heat' of technological revolution, nuclear power and the space age, expectations were high. In time, the nascent sectors of biotechnology and nanotechnology would be placed within this growing pantheon of promised high-tech futures, a pantheon that seemed to offer salvation not only from the economic quagmire but from the environmental crisis, recognition of which began to proliferate at this time. For some, this heralded a coming 'third industrial revolution', as significant as the second industrial revolution that began 100 years earlier in the 1870s and had profoundly shaped the twentieth century. Was the period of neoliberal globalization and economic growth after the 1970s based upon this promised high-tech 'third industrial revolution' – or were some other factors at play? In this section we discuss this question, focusing on the cases of ICT and biotechnology. Did either of these have the potential to become a 'lead industry' or ‘general-purpose technology’, in the way that has been claimed about steam power or the electric motor in earlier periods of strong economic growth?

The claims of ICT to be a general-purpose technology has had to contend with what Robert Solow (1987) called the ‘productivity paradox’. Solow pointed out that the time of proliferation of computers in the 1970s and 1980s was also a time of slowing productivity in the USA and more widely. Solow’s paradox has been much debated since. David (1990) countered by arguing that general-purpose technologies always have a delay before their productivity benefits are realized, citing the low productivity growth in the United States between 1900 and 1920 despite the existence of electric dynamos and motors. The productivity gains from IT did seem to start to be realized in the mid-1990s, when the USA experienced a productivity surge that some analysts claimed was entirely due to the application of IT (Rhode and Toniolo 2006: 10–11). Yet others argue that the productivity gains associated with computers have been confined to the IT sector itself and to computer-intensive parts of the economy (Gordon 2000, Field 2006). Overall, multi-factoral productivity (MFP) growth in the 1990s was in fact lower than that in the 1930s; and in the 88% of the economy that lies outside durable manufacturing, MFP growth *decelerated*, despite investment in computers (Gordon 2000: 72).

Rather as Fogel and Fishlow argued about the role of railways in the nineteenth century, Field suggests that much of the productivity gains in the wider economy could well have happened without computers; many of those productivity gains are being driven not by technological change itself but by changes in unit size such as big-box retailing (Field 2006: 109). Gordon (2000) provocatively suggests that that the steadily declining cost of computing power, far from indicating the strength of computers as a factor of production, in fact point to its weakness. The great inventions of the second industrial revolution did not experience the same continuous price decline, because the significant productivity gains provided by their adoption meant that demand kept up with supply. Gordon uses an analysis of the relationship between supply and demand in computing from 1963 to 1999 to argue that the main productivity gains offered by computers were realized early on their diffusion. For example, the productivity gain from developments in word processing technologies flattens out quickly after the development of automatic reformatting and cut-and-paste. As he argues, ‘[t]he fixed supply of time to any individual creates a fundamental limitation on the ability of exponential growth in computer speed and memory to create commensurate increases in output and productivity' (Gordon 2000: 62).

Biotechnology offers a similar story of widespread excitement and hype but little real impact on productivity. The turn of the twentieth century saw popular commentaries proclaiming *The Biotech Century* (Rifkin 1998) or *The Biotech Age* (Oliver 2003) – the former reacting with horror and the latter with hope to the prospect. In the early years of the present century, the discourse of the 'knowledge-based bioeconomy' (KBBE) was adopted by transnational policy organizations and the biotechnology industry. As the European bio-industry association puts it:

> In the 18th and 19th Centuries, European society was transformed by the Industrial Revolution and the steam engine. This was the Age of Engineering. In the 20th Century, the developed world reaped the benefits of chemistry, which provided the materials, productive agriculture and medicines which make our lives so comfortable and safe. The whole world is now in transition from the Age of Chemistry to the Age of Biotechnology. (EuropaBio 2005)

The discourse of the knowledge-based bioeconomy was embraced by the OECD, who defined the bioeconomy as 'the aggregate set of economic operations in a society that use the latent value incumbent in biological products and processes to capture new growth and welfare benefits for citizens and nations' (OECD 2005: 3), and by the European Union, who insisted that the KBBE would 'lead to the creation of new and innovative goods and services that will enhance Europe's competitiveness and meet the needs of its citizens' (DG Research 2005a: 3).

Yet despite massive investment of public and private money, the biotechnology revolution has not resulted in increased productivity or profitable commodity production. Wallace (2010) reports that only two medical biotech companies (Amgen and Genentech) and one agricultural biotech company (Monsanto) have made significant profits from selling commodities. Apart from the biggest biotech firm, Amgen, the medical biotech industry has made steady losses throughout its history. Although the 'biotech revolution' has accelerated drug discovery, this has not followed through into drug development and clinical practice, so has failed to reverse the decline in productivity of the pharmaceutical sector (Nightingale and Martin 2004). Despite heavy investment, profitability in the industry has been flat for over thirty years. As far as agricultural biotech is concerned, the industry has produced only two widely used traits – herbicide tolerance and insect resistance – and the evidence of increased agricultural productivity thanks to GM crops engineered to have these traits is ambiguous at best (Wallace 2010: 115, 119–21).

Thus, despite the proliferation of consumer electronics, the contemporary new knowledge economy has so far not produced anything equivalent to the paradigm-shifting technologies of earlier industrial revolutions. It is still possible that new, paradigm-shifting innovations will emerge in the next few decades from research in areas such as materials science and energy. But as mentioned above, in many ways, contemporary life in general and economic activity in particular is still fundamentally shaped by the cluster of hugely significant inventions that emerged in the second industrial revolution of the late nineteenth and early twentieth century: electrical power and motors, organic chemistry and synthetics, and the internal combustion engine (Landes 2003). The years between 1864 and 1917 constituted an 'age of synergy' in which the technological foundations for the twentieth century were laid (Smil 2005, 2006), making possible the 'long boom' from the 1940s to the 1970s, with its massive improvements in productivity, health, and standard of living. Yet while we are still living fundamentally within this same world, the capacity for it to continue to produce a stream of significant innovations seems to be becoming exhausted.

Technological innovation has been held up as the solution to economic crisis. In past such crises we have seen the emergence of new suites of technologies, which have had the capacity to restart faltering productivity growth and restore profit rates. However, as we have seen above, it is by no means clear that the neoliberal era managed to find such technologies after the crisis of organized capitalism in the 1970s. There have been a number of candidates for such technologies, but in each case there is as yet little sign of them making a real contribution to increased productivity. Nevertheless, capitalism did experience a new period of expansion globally after its crisis of the 1970s. How did this happen?

There are many factors underlying the apparent expansive period of capitalist development that followed the crisis of the 1970s. In this period, capital was unable to confidently invest in the development of the productive forces in the old industrial centres of the West, given the already high organic composition of capital (the ratio of non-labour costs to labour costs). Instead, capital sought other ways of reproducing itself, beyond investing in new cycles of commodity production within new techno-social labour processes. One of these strategies did indeed involve world-transforming technologies – however, these were not the high-technology productive forces imagined by 1970s futurologists. Instead, they were far more mundane technologies, whose roots lay in far earlier ages of technological innovation. Levinson (2006) draws our attention to shipping containerization, the distribution system based upon the standardized and ubiquitous rectangular metal box that could fit on lorries, ships and trains, thus facilitating a massive acceleration of the global flows or mobilities of matter and commodities. Likewise Smil (2010) directs our gaze to the diesel engines and gas turbines that propelled the container ships and air traffic as the 'prime movers of globalization'. These technologies allowed the global respatialization of the existing productive forces associated with the Fordist era, creating a new, respatialized, globalized Fordism. Thus instead of the 1970s visions of 'tomorrow's world' with fully automated production or bio-factories, the more prosaic reality was one where low paid workers in China and other parts of South East Asia worked with old, second-industrial-revolution productive forces and labour processes, made more productive via a global respatialization. This move, as part of a new 'spatio-temporal fix' (Jessop 2006, see also Harvey 1982) could alter the organic composition of capital by massively reducing labour costs, and facilitate the expansion of the world economy from the 1990s onwards. Of course, this global respatialization of 'second industrial revolution' techno-economic processes that gathered pace from the 1980s onwards was partly enabled by information technology. The material global flows of shipping containers, each unit travelling from one specialized location to another, required logistical governance that was made more feasible through information technology – but not impossible without it. Our claim here is that fundamental to the period of renewed capitalist growth around the closing decade of the twentieth century was a relatively 'low-tech' ensemble of cranes, diesel engines, containers, ships and logistical information technologies, not the spawn of the 'high-tech' R&D labs of the 'knowledge based economy'.

The post-1970s period also saw the phenomenon of 'financialization', where greater returns on capital could be found through global financial innovations such as futures and derivatives than in the production and exchange of material commodities. Brenner (2002a) argues that from the 1990s the continuation of capital accumulation on a world scale was dependant on a historic wave of speculation and a succession of asset price bubbles, first around the stock market, then housing and credit, noting the role of the US Federal Reserve and various state agencies in nurturing those bubbles. In this form of accumulation, instead of money (M) being invested in the production of commodities (C) to produce profits (M') according to Marx's formula of M-C-M', money was used to generate a profit directly, through interest or financial speculation

(M-M'). Technoscience – and the dreams, hopes, promises and expectations that revolve around it – were also caught up in these waves of speculative bubbles, most famously with the launch of Nasdaq and the dot.com bubble, but also the 'genomics bubble' that followed the sequencing of the human genome (Gisler, Sornette and Woodard 2010).

Thus, despite its failure to develop radical new productive forces, technoscience nevertheless has offered a number of mechanisms whereby profit rates could be restored, even if only temporarily. As well as the speculative bubbles discussed above, technological innovation has also created opportunities for higher-than-average returns on investment through corporate concentration, intellectual property and 'technological rents', but these have generally operated by capturing value from elsewhere in the global economy rather than creating new surplus value. But why has capitalism seemed unable to develop a new suite of technologies capable of recreating the strong economic growth of the post-war decades? There is not space in the current chapter to explore this in any depth, but there are clearly a number of interacting factors – some of which are internal to the logic of capital accumulation or technological innovation, while others are external, contingent factors.

For example, Tyler Cowen (2011) argues that by the 1970s developed economies such as the USA had already picked all the 'low-hanging fruit' of economic growth – available land, scientific and technological breakthroughs, and universal education – and that it was all but inevitable that growth would falter. Brenner (2002b: 9–10) uses studies by Zvi Griliches and others to argue there was no decline in the pace of scientific invention after 1973, just a decline in the innovation and diffusion of new technologies. He suggests that persistent over-capacity in global manufacturing industries had led to low profits, and thus to low levels of investment and the stalling of processes of technological change (Brenner 2002a). Webber and Rigby (1996: 492–3) argue that the 1970s was a victim of Marx's 'law of the tendency of the rate of profit to fall' (Marx 1981), which describes how investment in new technologies, while increasing output per worker, has the effect of increasing the organic composition of capital, putting a downward pressure on surplus value and thus profit rates. They argue that the fall in profit rates in advanced economies from the 1970s onwards was because 'increases in the amount of plant, equipment and raw materials per worker were not offset by improvements in efficiency', thus starving industry of investment in new technologies. Arthur (1994) invokes more general laws of technological development, identifying the way that scale economies, learning effects, adaptive expectations and network effects all work to decrease the incentives for individual economic actors to adopt new technologies, and thus to 'lock in' incumbent technologies.

In reality, it is likely that all of these factors, and the interactions between them, have played a role in the production of the late twentieth-century technological plateau in terms of productive forces. But it is also important to attend in more detail to the changing relations between science and capitalism in the neoliberal period, which process interacted in complex ways with the dynamics that have just been described – sometimes clearly a response to the failure of science to produce new 'general-purpose technologies' for the economy, and sometimes perhaps contributing to that failure. In the next section we thus turn to these questions, and try to put these changing relations in a longer historical context.

Science and neoliberalism

As we suggested in the previous section, in the period since the 1970s science, too, became embroiled in processes of financialization, being drawn into new 'political economies of promise'. This involved attracting venture capital, corporate and public funds for speculative new technoscientific developments. Rather than science being part of M-C-M', as a source of new processes and products, it became more caught up in M-M', as an object of speculation. Thus instead of being simply involved in new rounds of general accumulation via the innovation, production and sale of new commodities, science also became more deeply embroiled in new rounds of speculative appropriation. In the neoliberal 'knowledge based economy', as well as being a means of production generating new products and processes, science becomes a product – and a commodity – in itself.

But for something as intangible and collective as scientific knowledge to become a product or commodity, it must be enclosed, stabilized and held in place by a legal infrastructure of patents, intellectual property laws and other institutional arrangements (see also Pellizzoni and Ylönen this volume). Starting in the 1980s, scientific research, especially in universities and other public institutions began a process of reorganization to fit it ever more closely to the needs of industry and tropes of global competitiveness (Etzkowitz, Webster and Healey 1998, Kenney 1986, Kleinman and Vallas 2001, Kleinman 2003, Slaughter and Rhoades 2004). Thus the landmark Supreme Court decision of *Diamond v. Chakrabarty* in 1980 enabled the patenting of life, and was part of a massive extension of the appropriation of science as intellectual property, while in the same year universities were made to become owners of intellectual property with the 1980 Bayh-Dole Act. A 'university-industrial complex' (Kenney 1986) was consolidated, involving novel couplings and combinations of 'public' and 'private'. The scientific spaces of universities became increasingly like those of corporations – and vice versa – in a process of 'asymmetrical convergence' (Kleinman and Vallas 2001, Vallas and Kleinman 2008). Not only are there more linkages between public and private, between universities and corporations; there are also more linkages or networks between private bodies, such as small scale research 'start-ups' and corporations. All this is to facilitate the flow of knowledge between diverse public and private scientific spaces, between the spaces of its collective and social generation and the spaces of its private appropriation and enclosure.

This transformation of knowledge generation in the neoliberal period may be described as the privatization of science. However, this is a contradictory process, with limits. Knowledge generation is the accumulated effect of networks of cooperation, collective effort and public institutions. It grows through public flows, being a 'non-rival good' whereby multiple users do not consume it but actually generate more knowledge. Merton (1973) recognized the essentially collective and social character of the production of scientific knowledge when he described the norm of 'communalism' in the 'ownership' of scientific discoveries. This leads Jessop (2000) to argue that if in the 'knowledge based economy' knowledge is a productive force, then it exhibits a tendency (noted by Marx in his time) for capitalism to rely upon increasingly collective and interlinked productive forces. Furthermore, in this Marxian schema these ever more collaborative productive forces stand in ever greater contradiction to their private appropriation. This is a contradiction at the heart of the knowledge based economy that must be managed. As Jessop notes:

> Knowledge is a collectively generated resource and, even where specific forms and types of intellectual property are produced in capitalist conditions for profit, this depends on a far wider intellectual commons. (Jessop 2002: 129)

This 'wider intellectual commons' is the central resource upon which the appropriation and capital-accumulation strategies of the businesses of the new knowledge economy depend. In their analysis of the role of public science in the creation of biotechnology, McMillan, Narin and Deeds (2000) found that of scientific papers cited in biotechnology patents only 16.5% originated in the private sector, but more than 70% were still the product of scientists working in solely public scientific institutions such as universities.

This crucial role of public institutions in generating the knowledge base that private appropriation depends upon underlines the continuing role of the state and public funding. Indeed, the moves mentioned above, such as the reorganization of university-commercial relationships and the legal frameworks supporting intellectual property, formed part of a new state strategy in the neoliberal era. It has often been noted that the neoliberal era did not simply see de-regulation and the 'retreat of the state' but rather complex forms of re-regulation and the reorganization of the public sphere to be optimized for global competition – a form of state intervention named by Cerny (1990) as a 'competition state'. In the field of innovation and science policy, this change has been described as the rise of a 'Schumpeterian Competition State' by Jessop (2002: 96) 'because of its concern with technological change, innovation and enterprise'. In this form, the state attempts to manage the contradictions of the KBE – including those around the commodification of the knowledge commons:

> The state has roles in both regards: it must promote the commodification of knowledge through its formal transformation from a collective resource (intellectual commons) into intellectual property (for example in the form of patents, copyright and licences) as a basis for revenue generation; but it must also protect the intellectual commons as a basis for competitive advantage for the economy as a whole. (2002: 129)

Here the 'intellectual commons' – including science – have to be maintained in part as a commons. If the act of appropriating or enclosing encroaches too far into the scientific commons, then they cease to be productive for capital. This can be seen in the problem of 'patent thickets', defined by Carl Shapiro as 'a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology' (Shapiro 2001: 120).

Thus, in the neoliberal era, there are limits to the full subsumption of science under the logic of capital and its private appropriation as a commodity. This construction of science as a 'commons' points to a kinship between its neoliberal appropriation and what Marx described as 'primitive accumulation' or Harvey (2003) calls 'accumulation by dispossession'. For Marx, this form of accumulation preceded full capitalist accumulation (the extraction of surplus value from labour and the production of commodities described under the algebra of M-C-M'). Instead, primitive accumulation draws value into the capitalist system from 'outside', from pre-and extra-capitalist social forms. Subsequent Marxists have seen this as an ongoing process (De Angelis 2007). Here, instead of fresh sources of accumulation being sucked into the system from an ‘external’ frontier, the existing capitalist infrastructure (science, education, welfare, etc.) become privatized, reorganized and cannibalized. To describe this, Huws (2012) develops a category of ‘secondary primitive accumulation’ in contrast to the more traditional forms of ‘primary’ primitive accumulation. Whereas in primary primitive accumulation value is extracted from natural resources or activities carried out outside the money economy, secondary primitive accumulation, by contrast, involves public services such as education and healthcare. These were developed for their use value in the form of services, arising as non-commodified spaces but still within the capitalist economy. Neoliberal strategies involve the privatization of these services, and their transformation from use value to exchange value. Like public services, science developed as an institution within capitalist society. Both of these kinds of institutions serve the logic of capital accumulation but are never totally subsumed or reducible into it. Science remained as a ‘commons’, yet unlike with ‘primary primitive accumulation’ this ‘scientific commons’ did not pre-exist capitalism but is produced within it. Thus any strategy to enclose aspects of this scientific commons represents a secondary primitive accumulation, in a mode similar to the attempts to exploit public services. Yet as we saw, this commons can never be totally enclosed, or the production of scientific knowledge would be stifled. Rather, the commons must be partly maintained as such – in order to be ‘harvested’ by the private appropriation strategies of business.

Such theorizations of the ‘scientific commons’ and ‘secondary primitive accumulation’ can help us understand not only the neoliberal transformation of science, but also help put these into a much longer historical perspective of the shifting relations between science and capitalism. As the Marxist historian E.P. Thompson once quipped: ‘The exact nature of the relationship between the bourgeois and the scientific revolutions in England is undecided. But they were clearly a good deal more than just good friends’ (Thompson 1965: 334). Thus the neoliberal era did not witness the first coupling between science and capitalism – this happened at least from the seventeenth century onwards. However, while science and capitalism may have emerged together, the science that emerged played little role in the direct development of capitalism’s productive forces at this stage (Toulmin 1992); rather, the relationship in this early period points the other way, with technical achievements providing inspiration for more esoteric theorizing (Hessen 1971, Freudenthal and McLaughlin 2009). Science was therefore an autonomous realm within the developing capitalist society – and still characterized by the efforts of the gentleman amateur. At the same time, as a correlative of this observation, in the development of the technologies of the first industrial revolution a far more decisive role was played by practise, trial and error, and the reflexive processes of collective 'tinkering' by many hands and brains located throughout the productive process. Indeed the actual role of 'science' in techno-economic change is argued to have often been either more limited, or different to the imaginings of science as a fecund productive force (Edgerton 2006). It is possible to uncover the more 'mundane' innovations that underlay most eras of imagined technoscientific revolution.

However, the second industrial revolution that began in the late nineteenth and early twentieth centuries marked the enrolment of science (or technoscientific practices and knowledge) ever more directly into the process of production. This was exemplified by the twentieth-century chemicals industry, with its mass of chemists engaged in the innovation of new materials, polymers, pharmaceuticals, agrochemicals, etc. Here, corporate R&D labs and universities were essential in the production of new products and production processes (Mowery and Rosenberg 1989). This was the period of organized capitalism, which had an affinity with the scientific organization of production, welfare and reproduction. Science was reorganized to fit more with this Fordist phase – in terms of its scale (big science) and its industrialized division of labour. Yet at the same time it still kept many of the qualities of being a (relatively) autonomous part of this process – observing its own norms and rituals and not yet commodified in the neoliberal mode we will describe shortly.

Therefore in terms of the direct enrolment of scientific labour as a productive force, the early and mid-twentieth century period of the second industrial revolution saw something of a zenith or high water mark. This stands in contrast to what was to follow from the final quarter of the twentieth century onwards. This new post-1973 period (dubbed variously as 'neoliberalism', 'postmodernity', etc.) was initially imagined as an acceleration of the scientization (or scientific intensification) of the production process, where a third technological revolution would lead to an 'information society' and a 'new economy'. Scientific R&D, it was assumed, would play an increasingly direct role in the innovation of new products and processes. However, as we have argued, the neoliberal era did not see the transcendence of the second industrial revolution by a third, or anything resembling the scale and pace of the techno-economic changes associated with our earlier period. Instead, as we have touched upon above, neoliberal science became caught up in a different dynamic of accumulation. While of course science in the neoliberal period did contribute to some new products and processes, this is eclipsed by another phenomenon – that of science becoming a product itself.

Thus we can provisionally divide the history of the relationship between science and capitalism into three phases, ones which can be specified by drawing on and developing Marx's language of subsumption. In the first volume of *Capital*, Marx (1976) distinguished between the *formal* subsumption of labour to capital – for example, in the 'putting out' system, where there is little attempt by capitalists to shape and optimise artisanal labour taking place in people's homes – and its *real* subsumption – such as in a factory setting, in which complex labour is simplified and there is a huge pressure towards increasing productivity. Such language is helpful in thinking about the changing relations between capitalism and science. In the first phase of this relationship described above, that of the scientific revolution and the first industrial revolution, science is a connected but autonomous realm, one which we could say is only *formally* subsumed to capital. The second phase, that ran from the late nineteenth century up to the 1970s, could be said to be characterized by the increasingly *real* subsumption of science, as scientific research is made central to the process of technological change in the economy, and the scientific labour process is broken up and reorganized under organized capitalism – though retaining its Mertonian norms and thus not totally subsumed under the commodity form. Finally, the third phase, the current one of neoliberalism, has been one in which, on the one hand, science and capitalism have been relatively divorced – a technological revolution without science, and a science without new productive forces – but on the other we have seen the *further* subsumption of science, as science itself is brought under the commodity form, but at the same time the scientific commons becomes even more important to capital, as an extra-capitalist commons generated within capitalism that is 'harvested' rather than totally enclosed.[3]

Conclusion

When what came to be called neoliberalism emerged in the decades of restructuring following the crisis of the 1970s, it was imagined as a new period of technological innovation – a 'new economy' based on an

[3] Here we thus depart from both Hardt and Negri's talk of the 'real subsumption of society under capital' (2000: 365), and Liodakis's description of the 'universal (tending to a total) subsumption not only of labour but also of science and nature under capital' (2010: 25). On the subsumption of nature see also Pellizzoni and Ylönen this volume.

‘information society’, even a ‘third industrial revolution’. Yet despite this high-tech imaginary, we have uncovered a contrary story – of an ‘innovation plateau’ where this promised new technological base revolutionizing the means of production has largely failed to materialize. In this counter-narrative, ‘second industrial revolution’ technologies continue to predominate, with forms of energy and labour processes already familiar by the mid-twentieth century still producing the bulk of the world’s tangible commodities. In his early 1970s work *Late Capitalism* Ernest Mandel (1975) traced the tendency of the abolition of living labour from the labour process by new technology and automation. However, for Mandel the completion of this process of automation was impossible, representing the ‘absolute inner limit of the capitalist mode of production’ as the elimination of living labour would not only increase the ‘organic composition of capital’ but abolish the source of surplus value altogether. Commenting on this, Morris-Suzuki (1984) argued that this tendency towards automation would push capital to open up new zones of surplus-value generation where living labour would still be required, namely the innovation process itself, where creativity and science would be key, calling this a ‘perpetual innovation economy’.

However, the ‘inner limit’ of capitalism was not in fact reached; neither did its supersession or amelioration via perpetual innovation unfold. Rather than the 1970s utopian (and dystopian) visions of fully automated production where living labour is abolished or marginalized, a new but ‘mundane’ ensemble of transportation technologies enabled the global respatialization of the second industrial revolution. Living labour in the form of new working classes in South East Asia and China remains at the centre of neoliberal capitalism. At the same time, while this respatialization accounts for much of the growth in trade and global productivity in the neoliberal period, it does not on its own account for restoration of the rate of profit. Instead, the apparent return to health in the ‘boom years’ of neoliberalism involved financialization, economies of debt and a succession of speculative bubbles. The financial and broader economic crisis post 2008 represents the shattering of this mirage of the robust health of neoliberal capitalism, suggesting an ultimate failure to escape the problems identified in the 1970s.

This story of an innovation plateau therefore helps us contextualize the role of science in the neoliberal period. Rather than accelerating the tendency of the second industrial revolution to enrol science as a new force of production in a division of labour associated with the vertical corporation, science itself becomes a product. Here it is either enclosed as intellectual property (harvested from a ‘maintained commons’) or made into the base of (unrealized) promise, producing little more tangible than successful initial public offerings (IPOs) on the stock exchange in the form of 'venture science' (Rajan 2006). Thus science has become locked into the immaterial and speculative economies of neoliberalism's bubbles, in a society that appears unable to innovate its way beyond its economic and ecological crisis in any substantial way. We are left with a picture of neoliberalism involving a relatively mundane or 'low-tech' economic 'revolution' (epitomized by the shipping container) which failed to engage science fully as a productive force on the one hand, and a 'high-tech' world of science that becomes cannibalized and privatized as a commodity on the other hand. This suggests the failure of the modernist dream of the mid-twentieth century; instead of a close articulation between the spheres of scientific knowledge production and economic activity, we see a society stalled on an innovation plateau and consuming itself in cannibalistic privatizations while it entertains itself with the simulation of its once promised high-tech future.

References

Aglietta, M. 1979. *A Theory of Capitalist Regulation: The US Experience*. London: New Left Books.

Arthur, W. 1994. *Increasing Returns and Path Dependency in the Economy*. Ann Arbor: University of Michigan Press.

Baudrillard, J. 1984. On Nihilism. *On the Beach*, 6, 38–9.

Bell, D. 1973. *The Coming of Post-Industrial Society: A Venture in Social Forecasting*. New York: Basic Books.

Brenner, R. 2002a. *The Boom and the Bubble: The US in the World Economy*. London: Verso.

Brenner, R. 2002b. The boom, the bubble, and the future: Interview with Robert Brenner. *Challenge*, 45(4), 6–19.

Bresnahan, T.and Trajtenberg, M. 1995. General purpose technologies: 'Engines of Growth'. *Journal of Econometrics*, 65(1), 83–108.

Moulier-Boutang, Y. 2012. *Cognitive Capitalism*. Cambridge: Polity.

Bukharin, N.I. [1918] 1972. *Imperialism and World Economy*. London: Merlin Press.

Castells, M. 2000. *The Rise of the Network Society*. Oxford: Blackwell.

Cerny, P.G. 1990. *The Changing Architecture of Politics: Structure, Agency, and the Future of the State*. London: Sage.

Cowen, T. 2011. *The Great Stagnation: How America Ate All the Low-Hanging Fruit of Modern History, Got Sick, and Will (Eventually) Feel Better*. New York: Dutton Books.

David, P.1990. The dynamo and the computer: An historical perspective on the modern productivity paradox. *American Economic Review*, 80(2), 355–61.

De Angelis, M. 2007. *The Beginning of History: Value Struggles and Global Capital*. London: Pluto.

DG Research. 2005. *New Perspectives on the Knowledge-Based Bio-Economy*. Conference report. Brussels: European Commission, Directorate-General for Research & Innovation

Drucker, P.F. 1969. *The Age of Discontinuity: Guidelines to Our Changing Society*. New York: Harper & Row.

Edgerton, D. 2006. *The Shock of the Old: Technology and Global History Since 1900*. London: Profile Books.

Etzkowitz, H., Webster, A. and Healey, P. 1998. *Capitalizing Knowledge: The Intersection of Industry and Academia*. Albany: State University of New York Press.

EuropaBio. 2005. *About the Bio-Based Economy*. Available at: http://www.bio-economy.net/bioeconomy/about_bioeconomy/index_aboutbioeconomy.html [accessed: 2 January 2012].

Field, A. 2006. Technical change and US economic growth: The interwar period and the 1990s, in *The Global Economy in the 1990s: A Long Run Perspective*, edited by P.W. Rhode and G. Toniolo. Cambridge: Cambridge University Press, 89–117.

Fishlow, A. 1965. *American Railroads and the Transformation of the American Economy*. Cambridge, MA: Harvard University Press.

Fogel, R. 1964. *Railroads and American Economic Growth*: *Essays in Econometric History*. Baltimore: Johns Hopkins University Press.

Freeman, C. and Louçã, F. 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press.

Freudenthal, G. and McLaughlin, P. 2009. *The Social and Economic Roots of the Scientific Revolution*. Dordrecht: Springer.

Gisler, M., Sornette, D. and Woodard, R. 2010. *Exuberant Innovation: The Human Genome Project*. Swiss Finance Institute Research Paper No. 10-12. Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1573682 [accessed: 2 January 2012].

Gordon, R. 2000. Does the 'new economy' measure up to the great inventions of the past?. *Journal of Economic Perspectives*, 14(4), 49–74.

Hardt, M. and Negri, A. 2000. *Empire*. Cambridge, MA: Harvard University Press.

Harvey, D. 1982. *The Limits to Capital*, London: Verso.

Harvey, D. 1989. *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change*, Oxford: Blackwell.

Harvey, D. 2003. *The New Imperialism*, Oxford: Oxford University Press.

Harvey, D. 2005. *A Brief History of Neoliberalism*, Oxford: Oxford University Press.

Hessen, B. 1971. The social and economic roots of Newton's 'Principia', in *Science at the Crossroads*, edited by N.I. Bukharin. London: Frank Cass, 149–212.

Hilferding, R. [1910] 1981. *Finance Capital: A Study of the Latest Phase of Capitalist Development*. London: Routledge & Kegan Paul.

Huws, U. 2012. Crisis as capitalist opportunity: New accumulation through public service commodification. *Socialist Register* [Online], 48.

Jameson, F. 1991. *Postmodernism, or, the Cultural Logic of Late Capitalism*. Durham, NC: Duke University Press.

Jencks, C. 1986. *What is Post-Modernism?* London: Academy Editions.

Jessop, B. 1992. Fordism and post-Fordism: A critical reformulation, in *Pathways to Industrialization and Regional Development*, edited by M. Storper and A. Scott. London: Routledge, 46–69.

Jessop, B. 2000. The state and the contradictions of the knowledge-driven economy, in *Knowledge, Space, Economy*, edited by J.R. Bryson, P.W. Daniels, N. Henry and J. Pollard. London: Routledge, 63–78.

Jessop, B. 2002. *The Future of the Capitalist State*. Cambridge: Polity Press.

Jessop, B. 2006. Spatial fixes, temporal fixes and spatio-temporal fixes, in *David Harvey: A Critical Reader*, edited by N. Castree and D. Gregory. Oxford: Blackwell, 142–66.

Kennedy, D. 2006. The rule of law, development choices, and political common sense, in *The New Law and Economic Development: A Critical Appraisal*, edited by D.M. Trubek and A. Santos. New York: Cambridge University Press, 95–173.

Kenney, M. 1986. *Biotechnology: The University Industrial Complex*, New Haven, CT: Yale University Press.

Kleinman, D. 2003. *Impure Cultures: University Biology and the World of Commerce*. Madison, WI: University of Wisconsin Press.

Kleinman, D. and Vallas, S. 2001. Science, capitalism, and the rise of the 'knowledge worker': The changing structure of knowledge production in the United States. *Theory and Society*, 30(4), 451–92.

Kondratieff, N. 1925. Long business cycles. *Problems of Economic Fluctuations*, 1, 28–79.

Landes, D. 2003. *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to Present*, second edition. Cambridge: Cambridge University Press.

Lash, S. and Urry, J. 1987. *The End of Organized Capitalism*. Cambridge: Polity Press.

Levinson, M. 2006. *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*. Princeton: Princeton University Press.

Liodakis, G. 2010. *Totalitarian Capitalism and Beyond*. Farnham: Ashgate.

Lipietz, A. 1982. Towards global Fordism?. *New Left Review*, 132, 33–47.

Lyotard, J-F. 1984. *The Postmodern Condition: A Report on Knowledge*. Minneapolis: University of Minnesota Press.

Mandel, E. 1975. *Late Capitalism*. London: NLB.

Mandel, E. 1995. *Long Waves of Capitalist Development: A Marxist Interpretation*, revised edition, London: Verso.

Marglin, S. and Schor, J. 1992. (Eds.) *The Golden Age of Capitalism: Reinterpreting the Postwar Experience*. Oxford: Clarendon.

Marx, K. 1976. *Capital*, Vol. 1, tr. Ben Fowkes, New York: Vintage.

Marx, K. 1981. *Capital*, Vol. 3, tr. David Fernbach, New York: Vintage.

McMillan, G., Narin, F. and Deeds, D. 2000. An analysis of the critical role of public science in innovation: The case of biotechnology. *Research Policy*, 29, 1–8.

Merton, R. 1973. The normative structure of science, in *The Sociology of Science*. Chicago: University of Chicago Press, 267–78.

Morris-Suzuki, T. 1984. Robots and capitalism. *New Left Review*, 147, 109–21.

Mowery, D. and Rosenberg, N. 1989. *Technology and the Pursuit of Economic Growth*. Cambridge: Cambridge University Press.

Nightingale, P. and Martin, P. 2004. The myth of the biotech revolution. *TRENDS in Biotechnology*, 22(11), 564–9.

Oliver, R. 2003 *The Biotech Age: The Business of Biotech and How to Profit from It*. New York: McGraw-Hill.

OECD. 1996. *The Knowledge-Based Economy*. Paris: Organization for Economic Cooperation and Development OECD.

OECD. 2005. *The Bioeconomy to 2030: Designing a Policy Agenda*. Paris: Organization for Economic Cooperation and Development.

Perez, C. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham: Elgar.

Piore, M. and Sabel, C. 1984. *The Second Industrial Divide: Possibilities for Prosperity*. New York: Basic Books.

Rhode, P. and Toniolo, G. 2006. Understanding the 1990s: A long-run perspective, in *The Global Economy in the 1990s: A Long-Run Perspective*, edited by P.W. Rhode and G. Toniolo. Cambridge: Cambridge University Press, 1–20.

Rifkin, J. 1998. *The Biotech Century: Harnessing the Gene and Remaking the World*. New York: Jeremy P. Tarcher/Putnam.

Rostow, W. 1978. *The World Economy*. Austin: University of Texas Press.

Ruggie, J. 1982. International regimes, transactions, and change: Embedded liberalism in the postwar economic order. *International Organization*, 36(2), 379–415.

Schumpeter, J. 1934. *The Theory of Economic Development*. Cambridge, MA: Harvard University Press.

Shapiro, C. 2001. *Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard-Setting, Innovation Policy and the Economy*, Volume 1, edited by A.B. Jaffe, J. Lerner and S. Stern. Cambridge, MA: MIT Press, 119–50.

Slaughter, S. and Rhoades, G. 2004. *Academic Capitalism and the New Economy: Markets, State, and Higher Education*. Baltimore: Johns Hopkins University Press.

Smil V. 2005. *Creating the Twentieth Century: Technical Innovations of 1867–1914 and Their Lasting Impact*. New York: Oxford University Press.

Smil, V. 2006. *Transforming the Twentieth Century: Technical Innovations and Their Consequences*. New York: Oxford University Press.

Smil, V. 2010. *Prime Movers of Globalization: The History and Impact of Diesel Engines and Gas Turbines*. Cambridge, MA: MIT Press.

Solow, R. 1987. We'd better watch out. *New York Times*, Book Review (July 12), 36.

Rajan, K.S. 2006. *Biocapital: The Constitution of Postgenomic Life*, Durham, NC: Duke University Press.

Thompson. E. 1965. The peculiarities of the English. *Socialist Register*, 2, 311–362.

Toffler, A. 1970. *Future Shock*. New York: Random House.

Toulmin, S. 1992. *Cosmopolis: The Hidden Agenda of Modernity*. Chicago, IL: University of Chicago Press.

Tronti, M. 1966. *Operai e Capitale*, Torino: Einaudi.

Vallas, S. and Kleinman, D. 2008. Contradiction, convergence, and the knowledge economy: The co-evolution of academic and commercial biotechnology. *Socio-Economic Review*, 6(2), 283–311.

Virno, P. 2001. General intellect, in *Lessico Postfordista*, edited by A. Zanini and U. Fadini. Milano: Feltrinelli.

Wallace, H. 2010. *Bioscience for Life? Who Decides What Research Is Done in Health and Agriculture?*. Buxton: GeneWatch UK.

Webber, M. and Rigby, D. 1996. *The Golden Age Illusion: Rethinking Postwar Capitalism*, New York: Guilford Press.