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Innovating Innovation – Disruptive Innovation in China and the Low-Carbon Transition of Capitalism

David Tyfield
Lancaster Environment Centre, Lancaster University, UK
& Joint Institute for the Environment (JIE), Guangzhou, China

Abstract
Disruptive innovation offers significant promise regarding expedited global low-carbon transition, set against currently inadequate efforts. In order to appreciate its significance, however, disruptive low-carbon innovation must be analysed in the light of three key shifts in perspective: to an analysis of system transition and low-carbon innovation itself in terms of power/knowledge; to appraisal of the significance of digital innovation (similarly reconceptualised) and its embryonic convergence with disruptive innovation; and to a geographical focus on innovation happening not (just) in locations usually presumed as leading in hi-tech, but to developing countries and especially China. Indeed, exploring disruptive innovation in this way shows that assenting to the commonplace discourse through which Silicon Valley Tech innovation is identified as 'disruptive' is to conflate problem with solution. Conversely, this approach shows just how significant disruptive innovation is likely to prove to low-carbon transition, effecting a disruption of innovation itself, and thence of capitalism, from which any such transition must ultimately emerge.

1 Disruptive Low-Carbon Innovation revisited

Wholesale low-carbon transition is urgently needed to stay within 1.5^{o}C limits, but remains elusive (Parson 2017). Could disruptive low-carbon innovation (DLCI) help regarding this imperative?

The idea of DLCI was first raised 10 years ago (Willis et al. 2007), and subsequently taken up with special focus on developing countries (Kaplinsky 2011), especially China (Tyfield et al. 2010, Tyfield & Jin 2010). What is DLCI and why is it important? Against the stream of current discussion (Wilson 2017), our starting point here is the seminal work of Christensen (1997). While addressing a business strategy readership and not specifically concerned with low-carbon transition, Christensen's work nonetheless furnishes a broad but rigorous definition of 'disruptive innovation' (DI). This concerns "cheaper, easier-to-use alternatives to existing products or services often produced by non-traditional players that target previously ignored customers" (Willis et al. 2007) and/or their use in novel contexts and combinations. This contrasts disruptive innovation with 'sustaining innovation' along existing, stabilized techno-economic trajectories. The former thus effects a *social* redefinition of existing technologies through recombination, thereby offering possibly *lower* functionality against existing metrics initially. Over time, though, such innovation may 'disrupt' at varying levels, as new low-cost offerings attract not only users previously unable to afford these technological affordances, but also increasingly the incumbent 'mainstream' market.

The particular promise of *low-carbon* DI rests in precisely these characteristics: low-cost, rapid (driven by its own spontaneous demand) global deployment of existing technologies in novel combinations (and incremental improvements thereof) can be favourably compared with the default (and stalling) model of low-carbon transition. The latter focuses on supply or production of high-cost new-to-the-world technologies from high-risk, slow and uncertain RDD&D processes. Aligning with and corroborating criticisms of this dominant techno-fetishistic narrative, a focus on such DLCI, and its *social* redefinition of (probably existing) technologies, also directly opens up the importance of *socio*-technological and *systems* issues (Elzen et al. 2004).

These arguments are still pertinent today, and I welcome that DLCI is getting a new and arguably more high-profile hearing, amplified through Future Earth and this SI. But in this paper I also want to go beyond restatement of this original case to update and extend that argument in light of both more recent, clearer evidence of challenges and positive trends, and developments in theoretical understanding. In brief, this involves three key steps, set out in much greater detail in Tyfield (2017):

- Reframing understanding of low-carbon transition and innovation, including DI, as not just a socio-technical system process but one of *power/knowledge*.
- From this perspective, appraising the nature and importance of *digital* innovation to both low-carbon innovation and disruptive innovation (and their conjunction).
- Illustrating and developing these arguments with the contemporary geographical exemplar of such disruptive (digital and/or low-carbon) innovation, namely China.

Along the way I also not only reaffirm the Christensen point that there is a specific *form* of innovation that merits its own label – 'disruptive innovation' – and that conflating this with innovation *per se* is to evacuate the term of any useful rigorous analytical meaning. But also, and stronger, I argue that the predominant contemporary manifestation of that conceptual

laxity – in which Silicon Valley 'Tech' is widely imagined as the archetype of 'disruptive innovation' – is not merely obfuscating but actively complicit in reproducing the problem low-carbon transition is trying to tackle. In short, if we accept this commonplace (mis)interpretation, then 'disruptive innovation' is part of the problem, not the 'solution'.

Given that the public sphere is (rightly!) more powerful in determining the meanings of terms than academic argument (which may of course participate in the former), it is tempting to drop 'disruptive' innovation altogether and replace it with another term (e.g. 'game-changing', or, in Chinese, '*poju*' (see Tyfield et al. 2010)[1]). But given that this special issue – and broader initiative – is aiming to illuminate the crucial role that DLCI could play in the greatest challenge of our time – let alone that it was Christensen's coining initially – it seems legitimate still to fight for the meaning of 'disruptive innovation', as I do here.

2 Complex power/knowledge systems, their government and their transition

Our first contention is that to understand DLCI and its importance, and indeed low-carbon transition itself, we need to adopt a complex power/knowledge systems (CPKS) perspective. This conceptualizes the problem field of low-carbon transition, and innovation more generally, not just as multi-agent, multi-factorial (and hence socio-technical) and multi-levelled (e.g. Geels 2002, hence 'MLP') systems, as is increasingly the orthodoxy in innovation studies. They are also, and essentially, composed of complex, dynamic assemblages of relatively sedimented *relations and technologies of power/knowledge* (Tyfield et al. 2015, Foucault 2009, Flyvbjerg et al. 2012).

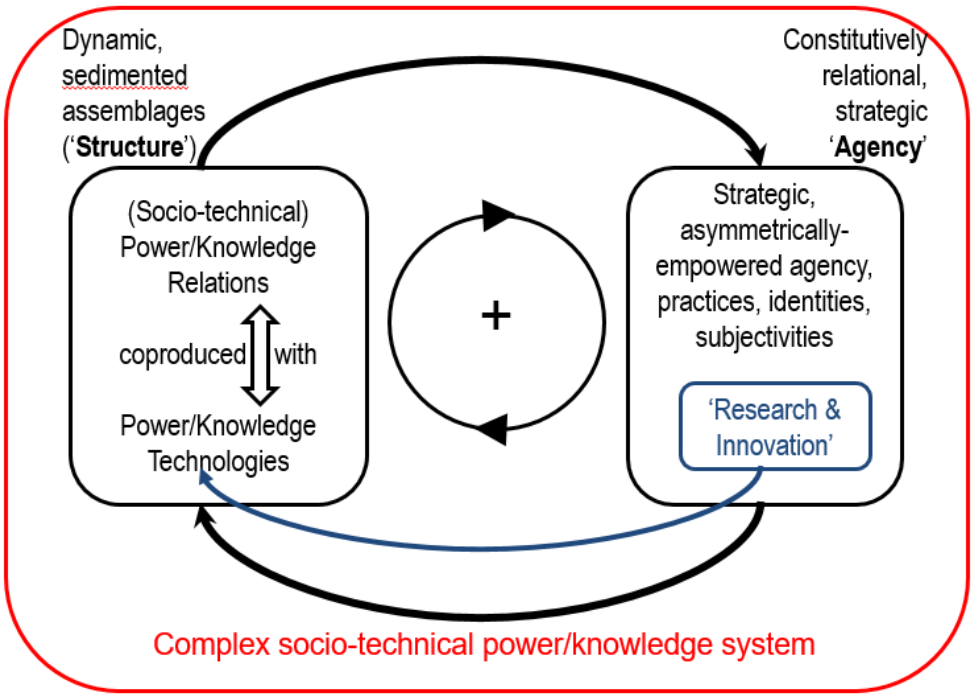
I use the combined term 'power/knowledge' to indicate the specific conceptualisation of power drawn on in this perspective, inspired by the later work of Michel Foucault. In brief, this presentation aims to shorthand how power and knowledge are different but inseparable aspects of the same (strategic, relational and practiced) phenomenon, not completely different issues. Hence even academic knowledge must be primarily assessed in terms of what it *does* and *enables* (or disables) in the world and *how*, not just in terms of the representative truth of what it *says*; while conversely, even the heights of 'power politics' must be analysed in terms of *how* they manipulate and successfully dominate others, not least through their deployment and development of particular knowledge claims and practices, as 'power/knowledge technologies'. For example, Google's or Facebook's proprietary algorithms and software are essential to their domination of their respective aspects of the digital political economy. International IP laws, technoeconomic paradigms, sociotechnical imaginaries of development or norms of high-status consumption are also all power/knowledge technologies.

These complex assemblages (or dynamic 'structures') of power/knowledge relations and technologies are then co-produced, in interactive parallel, with strategic agency, including (everyday) practices and even the very subjectivities of agents themselves (Figure 1). The systems are thus not just transformed or 'transitioned', but *constituted and conducted* through the constant cycling of this co-production of 'structure' and 'agency', where both are conceptualized as constitutively relational, dynamic and strategic.

As such, it is not that 'power' enters the picture only to 'change' a system already there and conceptualized as stable, nor that it is just a nefarious force responsible for lock-in to dysfunctional systems. Rather, the prior stabilization and emergence of that system *in the first place* is itself a matter of never-ending, ongoing, dynamic strategic jockeying. Moreover, in this perspective innovation emerges as a key process of this perpetual reconstitution and

governing of these systems, as itself a power/knowledge process that we may call innovation-as-politics.

Figure 1
Complex Socio-technical Power/Knowledge Systems



The red box denotes the system as a whole.
The two black boxes denote the constant relational co-production of 'structure' and 'agency' (black arrows), with the former including the co-production, in turn, of power/knowledge relations and technologies.
The blue box denotes R&I as a subset of 'agency' that directly acts on and transforms socio-technical power/knowledge technologies (blue arrow).
In the case of system transition, cycles of positive feedback can generate increasing power momentum over time.

This is not the place to argue the advantages of this change in perspective in detail (Tyfield 2014, Tyfield et al. 2015, Tyfield & Zuev forthcoming, Tyfield 2017). In brief, though, reframed as systems of power/knowledge, analytical purchase is afforded on persistently problematic issues for MLP (and cognate) perspectives (Smith et al. 2010). For instance, how can analysis illuminate system transition and potential trajectories for upscaling of existing 'niches' to the level of 'regime' discontinuity, and not just *post hoc* but prospectively and in real-time? Of course, this approach also places issues of power, politics and culture – likewise issues repeatedly noted as crucial gaps in the MLP (e.g. Avelino & Rotmans 2009, Kern 2011, Kern et al. 2014, Shove and Walker 2009, Geels & Verhees 2011) – at the very heart of theoretical understanding, not seeking to patch them in at a later stage.

More importantly for our purposes, this shift in perspective underpins each of the sets of insights that follow here. We start with the crucial one of reappraising what exactly (the challenge of) low-carbon transition is, and likewise for its corollary, low-carbon innovation. Conceptualized this way, it becomes clear that the challenge of low-carbon transition consists

of transforming the power/knowledge relational 'structure', and the strategic agency/ies mediating and mediated by it, such that both are increasingly 'sustainability-oriented' (*Cf* Altenburg & Pegels 2012). Likewise, low-carbon innovation is *primarily* a power/knowledge process through which diverse power/knowledge technologies of system government are progressively made ecologically-attentive. In short, system transition is a process by and through which innovation-as-politics transforms not just the socio-technical furniture but the dynamic and mutually mediating phenomena – power/knowledge relations and technologies alongside subjectivities, identities and communities – that *constitute* given 'societies', *including* the dominant model of innovation itself.

Low-carbon innovation is thus primarily challenged with conjuring, cajoling and amassing the 'power momentum' (Tyfield et al. 2015) through which a new dynamic regime of (power/knowledge) system government may finally emerge: transition is a *power/knowledge* transition. And it is thus by exploring empirical evidence of specific low-carbon innovations displaying embryonic emergence of such power momentum, which may then be qualitatively but uncertainly extrapolated into 'plausible' (Wilkinson et al. 2013) scenarios, that this approach affords insightful strategic foresight of real-time transitions (see Tyfield 2017).

These abstract insights thus profoundly reframe transition studies in productive ways. But they are also illuminating regarding an analysis of the substantive characteristics of the contemporary predicament facing low-carbon transition in at least two key respects, regarding the abstract challenge (or 'where we need to get to') and the concrete predicament (or 'from where').

Regarding the former, low-carbon innovation is still too readily discussed in terms that presume the one-for-one and one-off replacement of existing 'high-carbon' technologies with better 'green' ones. It is clear, though, that low-carbon transition will not be (and cannot be) such a superficial technological substitution, leaving the substance of contemporary high-carbon ways of life as they are. Rather it must be an iterative and medium/long-term process of profound socio-technical change. Moreover, this process must itself prominently feature – and will be most effective and expeditious to the extent it consists of – profitable, competitive innovations, capable of both rapid adoption and cumulative growth of (power) momentum; all considerations strongly favouring DLCI, as already noted.

But a CPKS perspective illuminates this problematic further, allowing us to see that low-carbon transition is not a single 'problem' at all, not even a 'system' one. Rather it is merely one lens on a whole set of existential contemporary challenges – including for innovation itself – that simply cannot be analytically separated, let alone meaningfully addressed, in isolation, notwithstanding the ubiquitous attempts to do so.

For alongside climate change, there are not only the whole wider set of planetary boundaries (Rockström et al. 2009, Steffen et al. 2015) and the socio-environmental challenges of the Anthropocene (e.g. Bonneuil & Fressoz 2016). But these are interwoven also with the emergence of cosmopolitized globalism (e.g. Beck 2016, Duara 2014) and of new horizons of post- or trans-human innovation from massive networks of cheap interconnected learning machines (e.g. Harari 2017, Mason 2015). As such, 'low-carbon transition' is simply the name for a much wider challenge for contemporary innovation-as-politics insofar as it is seen specifically through environmental glasses (and of anthropogenic climate change).

This wider challenge concerns a new global predicament of learning how to do the 'complex government of complex systems' well (Tyfield 2017). For each of these sub-challenges are different (and overlapping) manifestations of the inadequacy of current systems for the government of proliferating global complexity and inter-dependence. Such adept government of complexity, however, is mediated precisely by the prevailing relations and technologies of power/knowledge systems, demanding their iterative, incremental transformation and upgrading in real-time. And this reflexive transformation of power/knowledge relations is exactly what is meant by 'innovation'(-as-politics). Contemporary innovation, including low-carbon, is thus primarily charged with transforming the processes and capacities for system governance that are capable of harnessing, rather than being overwhelmed by, proliferating complexity, ultimately towards the emergence of qualitatively new and productive dynamics at (global) system level.

As such, on the one hand, we can now specify that the goal of low-carbon transition is the emergence of such productive dynamics at system level for the *ongoing* and *unending* improvement and maintenance of resilient government of complexity, NOT a new and restabilized "post-transition" green socio-technical system. But, on the other, this also means that we must accept and embrace that *there is no 'there'* to which low-carbon transition is seeking to move, no specifiable or imaginable future (utopian?) end-state – and that (acknowledging) this irreducible future uncertainty is an essential element of constructing *better futures*, not an unfortunate or defeatist concession to reduced rational mastery. We thus need new dominant models of innovation that, like DI, are likewise adept at surfing rising waves of complexity and uncertainty – as crucial tools and resources of just such complex system government.

But this perspective also usefully illuminates the converse: the concrete, actual (meso-level) 'here' of these, overlapping system failures and crises, the aspiration of escape from which is given the name 'low-carbon transition'. This concerns the overarching crisis of the specific regime that is currently dominant at global scale, at the heart of which – being a power/knowledge system – is its particular model of power/knowledge government: the hegemonic model of neoliberal innovation(-as-politics). Neoliberalism is a regime of system government that has dominated global capitalism for some four decades. It is fundamentally oriented to expansion without limit of the rule of the market, which is conceptualized as the supreme decision-maker (Mirowski 2011). At its heart, in turn, is a specific model of innovation, focusing on highly proprietary, consumer and labour-substituting hi-tech with a view to maximized concentrated corporate control of all spheres of socio-economic life (Birch et al. 2016, Lazonick et al. 2017, Pagano & Rossi 2017, Tyfield et al. 2017).

In recent years, as the 'digital revolution' has taken hold, this has mutated into a 'late' phase, in which internet giants have claimed the dominant models of innovation and corporate power (Schiller & Yeo 2017). This mutation of neoliberalism poses as its antithesis, emphasising its 'open' innovation credentials and free access to its services while carefully concealing the ways in which it depends upon a radical intensification of key neoliberal elements (Morozov 2013, Lanier 2013, Taplin 2017, Lanchester 2017), in a 'Googliberalism' (Tyfield 2013).

In particular, these platforms enact a model of innovation that depends, more so even than archetypal neoliberal biotech, on growing speculative investment in its financialized assets (Birch 2017), betting on the exponential growth of super-proprietary rents from monopoly control of markets for the exploitation of existing resources. Googliberal innovation is thus

essentially parasitic and un-creative, intrinsically built upon the zero-sum Ponzi-like exploitation of current assets and resources, including the incumbent oil-based socio-technical system. It also thus divides societies ever more clearly into few spectacular winners – the asset-owning rentier, global, tax-dodging and increasingly politically-enabled elite – and a growing majority of system losers – a debt-laden, wage-stagnant, insecure and increasingly system-rejecting precariat – in mutual co-production to the former's deepening personal advantage. Completing the cycle, then, winners pursue innovation that will further secure their advantage, not least through more Googliberal innovation, substituting productive, living-waged labour with cheap information technology. Googliberalism thus fundamentally underpins power/knowledge lock-in *against* system transition.

This characterization is necessarily far too brief. But it is sufficient to suggest how this dominant model of innovation-as-politics is a key dynamic in the power/knowledge government of the incumbent system, including its multiple overlapping and existentially-threatening crises (Tyfield 2017: Chs. 2&3). Yet it follows immediately that such innovation is not merely a different issue, comparatively irrelevant, to low-carbon transition – though it is hard to miss the terrible waste of ingenuity and finance currently invested in creating the next Killer App for some existing (if not environmentally problematic) consumption practice, rather than in tackling our planetary emergency. Rather, such innovation is in fact a key pillar of the problem. For it both actively discourages and obstructs significant low-carbon innovation while itself continually *re*-constructing and reproducing the high-carbon power/knowledge system and its extreme and worsening power asymmetries that we need to transcend. Furthermore, it follows that to the extent that we assent to the self-satisfied appropriation of the high-cachet label of 'disruptive innovation' ("the new rock and roll", as the T-shirt declaims) by Silicon Valley Big Tech, we are also confusing the problem for the solution.

In short, then, a complex power/knowledge systems perspective alerts us to the siren song of Silicon Valley 'disruptive innovation', and spells out much more clearly even than socio-technical systems literature the nature and scale of the challenge for low-carbon innovation. To be of any relevance to low-carbon transition, in other words, what "disruptive innovation" has to disrupt is innovation(-as-politics) itself.

3 The convergence of digital and disruptive innovation towards complexity capitalism

None of the foregoing should be mistaken, though, for arguing that digital innovation is irrelevant to disruptive low-carbon innovation, even as the issues are orthogonal and analytically distinguishable. To the contrary – and a development that is now categorically clearer than when discussions of DLCI began roughly a decade ago – digital innovation is key to the prospects of disruptive low-carbon innovation making a significant impact, in at least two ways. These go beyond reversing how digital innovation in its current dominant form is a key element of the problem, as just described. Rather, they concern the potentially seismic productive impacts as digital innovation comes to converge, first, with low-carbon transition *per se*; and then with *disruptive* low-carbon innovation specifically.

It must first be noted, though, that the advent of digital innovation is – *per se* not just in Googliberal form – a key element of the *challenge*, in terms of constructing complex government of complex systems. For, itself conceived as a power/knowledge process, digital innovation sits at a key node in the cycles of the contemporary capitalist system and its (currently overflowing, uncontrolled) proliferation of complexity (see Figure 2, especially

2c). Digitization, and/or its flipside of informationalization, fundamentally consists of introducing a novel (i.e. ICT-based) mediation to processes of power/knowledge. For instance, manufacturing becomes mediated by software that, in turn, collects constant real-time data for further optimization; so too for information search, listening to music, ride-hailed journeys, even friendship. This novel mediation affords the reflexive and recursive measurement, transformation, interconnection and expansion of these power/knowledge processes at hitherto unprecedented rates and scales, while these digital innovations also thereby constantly and reflexively upgrade themselves – the very acme of the positive feedback loops constitutive of *complex* systems. In short, digital innovation is singularly productive of the *problem-field* of complex system government, even as it is generally evangelized as its panacea.

But there is no going back, no putting the digital genie back in the bottle or closing Pandora's Box. The only way forward, thus, is to develop new models of digital innovation that can work *with* its capacity for proliferation of complexity but to more system-productive outcomes. In this respect alone, we can immediately see how a different (non-Googliberal) digital innovation necessarily must form a key element of any low-carbon transition. But conceived as a power/knowledge process, digital innovation also emerges as a clear, if as yet underexplored and seemingly tangential, aspect of low-carbon innovation itself.

This hinges precisely on how the digital is the would-be meta-mediator of all power/knowledge processes. For it follows not only that socio-environmental relations, technologies and practices (likewise conceptualized in power/knowledge terms) can be thus mediated, and thereby progressively transformed. But also that viewing any and every ecological problem-field in this way also immediately makes it (much *more*, if never perfectly or 'correctly', and indeed, likely problematically) amenable to capitalist ingenuity: pragmatically but avariciously exploring ways in which collation, mastery, ownership and possible construction of the relevant socio-environmental data – the 'new oil' (Economist 2017a) – can be of service to paying customers (and/or hopefully publics and state institutions) and hence profitable.[2]

In this way, then, the field of low-carbon innovation can be transformed from that of committed green pioneers worthily and laboriously constructing low(er)-carbon technologies, to a more generalized 'greenrush'… with all that implies, both positive *and negative*. In other words, digital intermediation enables a process that harnesses the exceptional productivity (for good and/or ill – see conclusion) of capitalist innovation into a growing power momentum of low-carbon transition, and *from here*, in this late-neoliberal, unequivocally capitalist present.

Here the qualitatively tighter feedback loop of digital innovation (see Figure 2c *Cf* 2b), as power/knowledge technologies reflexively upgrading *themselves*, also flips from problem to opportunity. While this dynamic is currently causing proliferating, untamed and destructive complexity, a digital greenrush would instead harness it into acceleration of productive innovation; and, indeed, a growing power momentum of sufficient heft that it can even break out of the profound current socio-technical system 'carbon lock-in' (Unruh 2000) (see Figure 2d).

But what has any of this to do with *disruptive* low-carbon innovation? The answer is, everything, in that this (system-) productive, low-carbon, complexity-adept capitalism, this new harnessing of digital innovation to such productive effect, is entirely dependent upon the

latter's convergence with disruptive innovation. Regarding the productivity and results of innovation, the convergence of disruptive and digital innovation – now just beginning, as both 'disruptive digital innovation' and 'digitized disruptive innovation' – promises to effect an exponential boost in the significance of both, including for low-carbon transition.

On the one hand, digital innovation adds a quantum boost to disruptive innovation. DLCI is already *per se* enabled – by its targeting of massive ready demand for low-cost but novel functionalities – to provide fast-growing goods and services disruptive of existing modes of practice. But combining this with digital innovation compounds this dynamism. This is not just because it furnishes disruptive innovation with a whole new momentum, drawing on both the digitized opening up of innovation (if not quite or necessarily its 'democratisation') and the dynamic of 'exponential technology' described (and mistakenly conflated *as* 'disruptive innovation') by Silicon Valley futurist gurus (Myronuk 2017) – though these factors undoubtedly matter, and show how (a future) Silicon Valley could yet be a significant part of the *transition*, not just the problem. But also because, where environmental innovation is increasingly mediated by digitization and datafication, these processes and projects of innovation are opened up to productive capitalist exploration and exploitation, as described above, thoroughly transforming the prospects and momentum of such innovation. Low-carbon innovation, in short, is productively reframed as primarily a challenge *not* of emissions and energy but of data and complexity and its harnessing for productive system government. This thereby transforms low-carbon transition from expensive problem dependent on ethical vision and political will to a strategic opportunity for business.

Moreover, in classic complex system positive feedback loops, this does not just apply to individual low-carbon ventures, but promises to transform the broader taskscape and possibility space of low-carbon innovation *per se*. For both the greater hubbub of innovation activity generated by the combination of digital and disruptive (low-carbon) innovation, across a wide range of issues, and the nature of the disruptive innovation model itself – adept precisely at working rapidly, flexibly and resiliently with and within complex, uncertain and shifting milieux – combine to create a situation in which combinations of disruptive innovations (or recombinations of recombinations) are not just likely, but actively and relentlessly sought out.

In this context, then, it is also likely that the investment climate and innovation zeitgeist would change. Finance would no longer focus on unicorns, pursuing the 'next Uber' (of cooked meals, DIY tools or whatever…) that promises sure-fire returns for maximally monopolized exploitation of existing assets. Instead, the game would become one of risky competitive investing in the disruptive innovation that best promises to be a pivotal (but maybe not 'central') node in an as-yet-nonexistent and irreducibly uncertain but credible future networked assemblage of firms and customers – where disruption of existing systems of provision in *some* form is the base common-sense.

Interlocking with other still-to-be-developed innovations, then, these disruptive digital innovations will altogether mediate, and so govern anew, crucial complex processes of global socio-environmental metabolism. And with disruptive low-carbon innovation now 'speaking the same language' (i.e. of data and its ICT intermediation) as digital innovation, there is a new bridge and lubricant for cross-fertilization. In this way, too, innovation can be imagined (if, of course, not guaranteed) that is progressively more capable of dealing with socio-environmental challenges in all their geographical specificity, complication and complexity, not just proffering an (entirely unrealistic and strategically self-defeating) one-size-fits-all

'green technology' future. And this is especially the case since this is disruptive innovation-*as-politics*, meaning that these disruptive digital low-carbon innovations will very likely be profoundly contested and *thereby* made into effective power/knowledge technologies of system government (e.g. see Table 1, below).

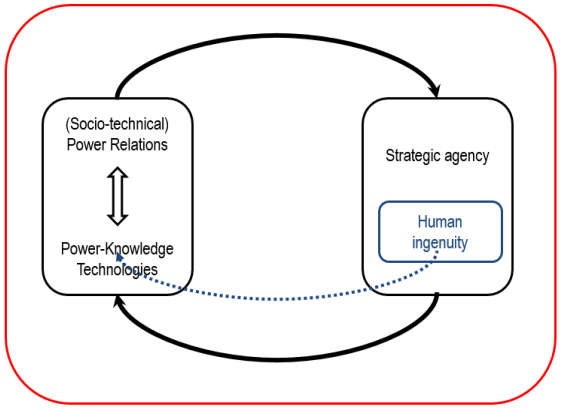
In short, then, digital disruptive innovation allows at least the *conceptualization* of a transformed *capitalism*, in the medium-term, in which crystallizing clusters of actual system transition are increasingly observable and so themselves become the focus of competitive innovation and investment. In other words, if DI (and DLCI) to date has already shown promise working on 'real world' socio-technologies, as it comes to be combined with and mediated through digitization it could well become revolutionary – or, rather, 'transformational' (*Cf* Smith et al. 2005).

On the other hand, disruptive innovation reciprocally transforms digital innovation. In particular, disruptive innovation offers a model of low-cost, hence *capital*-substituting, and labour-*creating* innovation capable of harnessing digital innovation to productive ends (regarding new commodities/services, sectors and even systems), not merely parasitic, exploitative and *labour-destroying* ones. Consider, for instance, disruptive innovation regarding low-cost heart surgery in India (*Economist* 2010) or solar water heaters in China (Yu 2017, Urban et al. 2015). A DI model thus enables digital innovation to reap parallel transformation of the 'structure' of power/knowledge relations such that it can begin to match, keep up with and newly regulate the transformations it is already driving in agency, practices and power/knowledge technologies (Figure 2d).

As such, disruptive (and disrupt*ed*, post-Googliberal) digital innovation(as-politics) can indeed become the key element of low-carbon transition mentioned above; constantly, dynamically and cumulatively transforming both power/knowledge relations and technologies towards marshalling the necessary power momentum for a new complexity-adept capitalism (in the first instance) that can avert climate catastrophe in the next few decades.

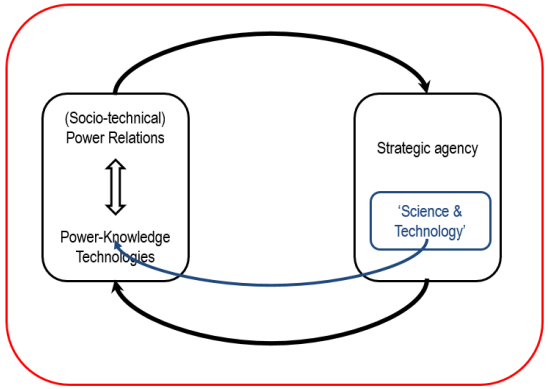
Figure 2: Historical Evolution of Complex Socio-technical Power/Knowledge Systems

a) Pre-capitalism



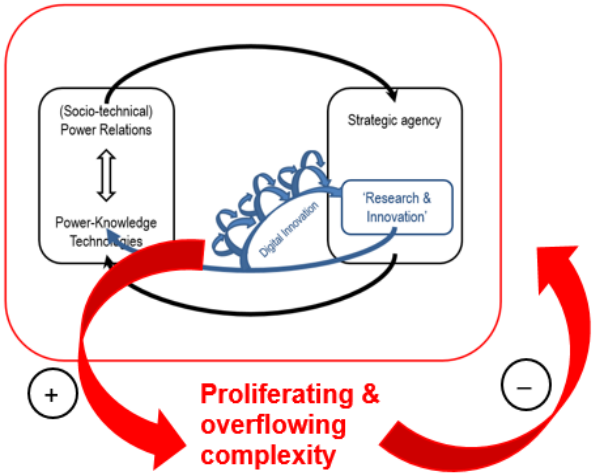
Pre-capitalist systems do not lack for human ingenuity applied to the upgrading of P/K technologies but this generally does not take institutionalized forms

b) Industrial capitalism (Late C18 to late C20)



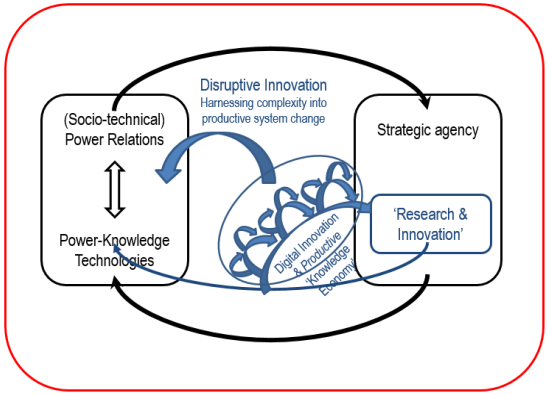
With industrial capitalism comes progressively more formal & institutionalized practices of 'science' and 'technology'

c) Digital Googliberal capitalism (Turn of C20/21 to now)



The emergence of the specific form of *digital* innovation enables tighter (and recursive) feedback loops of 'research & innovation' acting on *itself*, generating unmanaged & unmanageable complexity, which in turn negatively affects system integrity

d) Re-settled complexity capitalism (Now embryonic?)



Combined with DI, digital innovation also begins to transform P/K relations – not just P/K technologies and practices of R&I – thereby harnessing the proliferating complexity to constitution of upgraded institutions & 'structures' for the governance of complexity.

4 Changing the game from top to bottom - the Chinese disrupters

The final step I chart here, though, concerns the all-important question of existing empirical evidence for this abstractly characterizable dynamic. Or, to put it slightly differently, *where* is this happening? The answer redirects our attention one final time, and again away from the faux 'disruptive' innovation of Silicon Valley, to the constantly orthodoxy-defying case of the rising centre of global capitalism, China. Again, it is a complex power/knowledge systems perspective that is crucial for this insight in terms of offering a deeper understanding of the dynamics and capacities, and so prospects and (global, historical) significance, of Chinese innovation; and, in particular, of the mutual illumination of DI and Chinese innovation (Tyfield 2017).

China's strength, and arguably global leadership, in DI has long been noted (Zeng & Williamson 2007, Breznitz & Murphree 2011) and is increasingly focused on as the very key to China's historically unprecedented economic growth over the past 30 years and its continuing dynamism today (Tse 2016, Rein 2016, Yip & McKern 2016, Atherton & Newman 2017). Moreover, this not only increasingly includes, as now archetypical examples, China's digital giants (e.g. Baidu, Alibaba and Tencent) – as *genuinely* 'disruptive' in ways that Silicon Valley are not – which also happen to be the most famous of China's comparatively few global brands, notwithstanding the barriers of the 'Great Firewall'. But it also includes disruptive *low-carbon* innovations. These are both high-profile, as arguably in fields of wind and solar PV innovation, where Chinese companies now consistently rank amongst the biggest firms in the world; and, no less importantly, lower-profile but massively adopted innovations (Tyfield et al. 2010), such as solar thermal (Urban et al. 2015) and electric two-wheelers (Cherry et al. 2016).

From the perspective of low-carbon transition itself, too, this Chinese disruptive low-carbon innovation is prima facie of great significance. China is now the world's largest emitter of GHGs in absolute terms (more than the US and EU combined) and with fast growing *per capita* emissions too (already greater than the EU). So low-carbon transition in China is clearly an urgent global priority; indeed, a *sine qua non*. Yet China, for all its spectacular development and burgeoning hypermodern megacities, remains a country with significant challenges of poverty and socio-economic development still ahead.

In these circumstances, then, the low-cost and ready-technology focus of DLCI appears particularly appropriate and promising for the rapid mass adoption needed to effect low-carbon transition now, and not in a generation or two's time when it will be too late. Moreover, China sits at a crucial juncture in the global predicament of low-carbon transition. For it must develop low-carbon innovations that address both the problems of the rich, developed, urban and poor, developing, rural worlds. Its propagation of low-carbon innovations that 'work' in this unique context, thus, is well-placed to be of global impact – as is necessary for low-carbon transition – and with disruptive low-carbon innovations likely to feature heavily.

The significance of disruptive innovation, *digital* disruptive innovation and China for each other and for low-carbon transition, however, is particularly illuminated when studying this field from a CPKS perspective. For this furnishes an analysis that argues against both the usual presumption that disruptive (low-carbon) innovation is an interesting but peripheral issue – so that DLCI must be raised rather apologetically, like a pet project –, and its cognate

misunderstanding that Chinese innovation capacity remains profoundly weak (especially in comparison with the heights of the presumed benchmark of Silicon Valley). This concerns several key points.

First, contemporary Chinese innovation capacity is essentially contested (e.g. Lewin et al. 2016). Profoundly negative assessments, based on its weak record of global-leading hi-tech companies and political analyses of the profound structural impediments to their incubation, are set against positive assessments, which provide a litany of impressive statistics (of national R&D expenditure, patent filings, scientific publications and citations etc…). But a CPKS perspective can accommodate the half-truths of both positions to illuminate the inauspicious but nonetheless extraordinary productivity of contemporary Chinese innovation.

This concerns the characterisation of Chinese processes of innovation, and innovation upgrade, as 'non-linear' (Kierkegaard 2016) and, surging from balloon to bust (ten Brink & Butollo 2016), but ending up with the construction nonetheless of new industries and sectors. Chinese disruptive innovation is central to this process, being especially well suited to working with and within not only the broader conditions of overflowing complexity of (late) neoliberal globalization, but also to the particular turbulence and uncertain business climate of China (Tse 2016). It is thus disruptive innovations specifically, focusing on strategies of maximal 'tempo, volume and cost' for customers (Nahm & Steinfeld 2014), that have ended up prospering in China as they flexibly, responsively incubate new firms, industries – and thence sectors and socio-technical systems. The key strategy here is to target good-enough, low-cost disruptive innovation that is particularly attractive to the under-institutionalized, massive but cash-constrained domestic market (Breznitz & Murphree 2011, Brandt & Thun 2010).

This dynamic is not just a techno-economic one of familiar Schumpeterian creative destruction and dynamic capitalist disequilibrium. Chinese disruptive innovation may be understood this way, but what this analysis misses is the broader process, beyond the firm level to the 'national innovation system' as a whole, through which China's ostensible *weaknesses* – when assessed against contemporary orthodoxy – serve to incubate its particular *strengths*, while, *vice versa*, seeming strengths are actually medium-term processual weaknesses and liabilities.

This analysis, however, is only possible when the 'innovation system' is explored in terms of a complex and dynamic system of power/knowledge relations. For this opens up the possibility of exploring not only the direct effects of innovation policy and regulation, in terms of the *techno-economic* 'outputs' of innovation (e.g. technologies, capacities, firms, clusters etc…), both intended and positive, and inadvertent and negative. But also the indirect effects of China's contradictory innovation system in terms of the constitution of *new political economic agencies and subjectivities*. Again, these may be both welcome and possibly unwelcome vis-à-vis the incumbent party-state regime. But, regardless, the constitution of such new agencies and power nuclei is crucial for any prospect of low-carbon (power) transition (see Table 1). It is thus not *just* that the dynamic of Chinese innovation is observably 'non-linear' regarding the development of new firms and technologies, but also that it is non-linear regarding the broader, national (if geographically clustered) incubation of (novel forms of) empowered capacity for and through innovation-as-politics.

Table 1 [about here]
The Quadrant of Chinese Disruptive Innovation-as-Politics – the Case of Urban e-Mobility

	Direct effects (at agent level)	***Indirect effects (at system level)***
Intended (immoveable object)	**'China Optimist' analyses:** Increasing globally significant state investment and support for innovation at unrivalled scale and pace e.g. **Electric car** 'overtaking around the corner'; World No.1 in EV sales (by 2015)	'**China Disruptor' analyses:** Constraints and opportunities feed private/ hybrid-overseas disruptive innovators creating resilient, highly dynamic and competitive firms of increasing systemic importance and innovation capacity e.g. **Electric 2-wheelers /micro-EV** as specifically Chinese disruptive innovation BUT neglected and proscribed by Government
Responded (unstoppable force)	**'China Pessimist' analyses:** Misallocation and hamstrung central planning, plus unwarranted focus on hi-tech supply/push, generating deepening political economic imbalances, in China and globally e.g. Slow & relatively minuscule EV sales, dependent on expensive and gamed government subsidies (being phased out) and disinterest amongst state-owned enterprise auto majors vs. deepening **ICE** automobility system	**'Disruptive Innovation-as-politics' analysis:** Increasing capacity bridging domestic and global demand, and responding to immanent demand to 'move up the value chain', not least into new emerging industry sectors; together with deepening systemic dysfunction, pushing beyond the incumbent CPKSs of both China and global capitalism e.g. Evolving Chinese digital **Mobility-as-a-Service** innovation-as-politics in co-productive parallel with middle class emergence

Source: adapted from Tyfield (2017)

In other words, the specific strength of disruptive innovation in China becomes both explicable in terms of, and thereby in turn further illuminates, China's *unique constellation* of power/knowledge relations. This conditions its exceptional constraints and enablings, pressures and openings, for capitalist innovation and the relentless pursuit of continual upgrading, all within a national project widely understood as existential. It is thus not just notwithstanding the constraints of the overbearing state and its multiple frustrations of entrepreneurship – undoubtedly characteristic of contemporary China (Fuller 2016) –, but in some key respects *because of* these, that China specifically has developed a growing *culture* of *disruptive* innovators; and, vice versa, that disruptive innovation has emerged as the singular strength of Chinese innovation.

Yet the profound, 'structural' and landscape (in the MLP-sense) conditions underpinning these massively productive tensions remain very much in place. This therefore augurs the continuation of the turbulent dynamism of China's process of innovation upgrade through growing national pillars of disruptive innovators – and the increasingly apparent evidence of these firms and the socio-technical niches they are constructing – for the foreseeable future. And this is of the greatest significance regarding low-carbon transition, in several respects.

First, because of the exceptional intensity of environmental challenges in China, these innovators – and their core source of demand, amongst the burgeoning urban 'middle classes' (that likely include these entrepreneurs themselves) – are attuned to environmental issues in ways that are simply not in evidence amongst other innovative cultures around the world, especially Silicon Valley. Nor is this attention to the environment just in evidence amongst start-ups. China's digital disruptor giants are also notable for the explicit attention they are giving, in discourse and in practice, to environmental innovation (Tse 2016). And all of this has the significant and consequential backing of the highest levels of government, through slogans and policies of 'ecological civilization', the 'new normal', and 'China 2020' innovation upgrade.

Nor is disruptive innovation in China limited to a digital rearranging of ownership of existing assets. Rather, it has already shown itself capable of significant 'real-world' changes, as in the uniquely rapid uptake of cashless payments, and now with increasing evidence of dynamism even in some of the 'hardest cases' (Geels et al. 2013) of low-carbon transition, such as urban mobility (Tyfield & Zuev, forthcoming; see Table 1). In the latter, the parallel and unrivalled growth of China's capacity for heavy industry and infrastructure building, together with the state institutions and budgets for upscaling, both in China and increasingly (via the 'new Silk Roads' or 'One Belt, One Road' policies) overseas, are also likely to be significant boosts. There is thus a significant and growing dynamism amongst what is already a singularly dynamic wave of Chinese disruptive innovators towards increasing concern with low-carbon innovation.

But, secondly, and as intimated above, the growing momentum of these disruptive innovations and entrepreneurs in itself transforms the *possibility* and *conceivability* of system transition; and thereby, given that very momentum, renders it very likely indeed. In short, then, from this CPKS perspective, we can see today that the embryonic evidence of the convergence of digital and disruptive innovation in a rising (capitalist) China does not just make DLCI an important string to the bow of global efforts on climate change, but arguably the most important vehicle and agent apparent to date of low-carbon transition. And, to repeat, where this involves transition *from* the incumbent model of innovation and dominant global regime of capitalism and its high-carbon socio-technical system, at the apex of which sits 'disruptive' Silicon Valley.

5 Conclusion: A long strange trip still ahead

This paper set out to make the case for the key importance of disruptive low-carbon innovation in the urgent challenge of global low-carbon transition, while thereby drawing a strict distinction with the model of innovation that has largely usurped the moniker of 'disruptive' in recent years. Exploring disruptive innovation and low-carbon transition from the perspective of complex power/knowledge systems and their rolling governance, reproduction and transformation, I have argued that genuinely disruptive innovation when combined with digital innovation promises fruition of extraordinary and as-yet unforeseeable

beneficial developments in this regard; and that these are especially likely to emerge in, or least in collaboration with, Chinese enterprises. But we can hardly end on such a positive (complacent) note, without first noting some key and challenging further implications of a CPKS reading of DLCI. I mention three, though there are certainly others, all of which hinge on acknowledging that we are here discussing innovation-*as-politics*, which is likely to be *essentially* contested, especially in its digital disruptive form.

First, while the 'hardest' cases of low-carbon transition, such as urban (and thence *inter*-urban)[3] mobility, are beginning to be addressed now, as mentioned above, they are still very far from being resolved. Indeed, we are still far off from a viable alternative socio-technical system even crystallizing in the collective imagination, let alone in manifest actuality. Low-carbon transitions, in other words, are not just matters of individually swapping our film cameras for smart phones, as in seminal case studies of disruptive innovation. And this is not just because they require the parallel construction (and likely *re*-construction and continual upgrading) of infrastructures (Birch forthcoming), yielding thorny chicken-and-egg challenges or even 'wicked' problems. In terms of power/knowledge relations, too, the redesign of cities and their mobility systems, as well as the upending of profoundly locked-in factors – from hugely empowered concentrations of corporate-state power (e.g. 'carbon capital' (Urry 2013)) down to daily micro-practices, habits, expectations and identities of automobility (Sheller 2013) –, promises to be several orders of greater difficulty to achieve. Witness, for example, the current travails of Uber (Bull 2017), supposed poster-boy for such Googliberal mobility-as-a-service 'disruption'.

Secondly, and similarly, it is hard to envisage how the ascent of China's disruptive (low-carbon) innovators as a *political* development, transforming incumbent systems of power/knowledge, will not be extremely turbulent, both globally and domestically. As regards the latter, for instance, the continued growth and transformation of the political economy that the rise of these innovators will represent is also likely China's best chance of escaping the 'middle income trap' (WB/DRC 2012), a key policy priority for the Chinese government.[4] Yet there is no historical case to date of a country that has successfully vaulted this imposing hurdle without having also enacted considerable political and constitutional reform (Lewin et al. 2016) – reforms that seem increasingly (not diminishingly) *un*likely in contemporary China at present (e.g. Shambaugh 2016). How these increasing tensions play out, thus, in an authoritarian party-state is thus uncertain, at best. In short, the most profound disruption of disruptive Chinese innovation(-as-politics) could yet prove to be (geo-)political.

Finally, though, in terms of politics, it is crucial to note that this analysis may acknowledge and seek to harness the exceptional dynamism and current dominance of capitalist competitive agency, but it need not, and does not, glorify it. Rather, DLCI, and the innovation model and revitalized hegemonic regime of capitalism to which it may yet give rise, raises profound political and normative questions regarding who will gain and lose, and to what future, qualitatively and socioculturally, a DLCI-driven transition may lead us. Moreover, as a process dominated by capitalism, the question is not whether but "*which* inequalities (old and new) this low-carbon transition could incubate?" And "what can be done about this?" Indeed, these are arguably the most important and urgent questions on which future research in transition studies should focus, especially since research democratically shaping disruptive innovation-as-politics presents a major strategic opportunity.

In short, then, the foregoing argument offers essentially qualified conclusions. It furnishes a hopeful message regarding DLCI's potentially definitive role in low-carbon transitions that in

2017 we cannot yet foresee and that could yet be pushed in significantly equitable directions. But it also augurs a turbulent, 'illogical', 'non-linear', profoundly contested and open-ended cultural-political-economic process, demanding persistent political engagement, with no realistic prospect of a tidy, rational and planned transition. Yet what innovation model is best placed to work with, and prosper from, precisely such disruptive times? Disruptive low-carbon innovation, of course.

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References

Altenburg T & A. Pegels (2012) 'Sustainability-oriented innovation systems: managing the green transformation', Innovation and Development 2(1):5–22.

Atherton, A. and A. Newman (2017) *Entrepreneurship in China: The Emergence of the Private Sector*, London: Routledge.

Avelino, F. and Rotmans, J. (2009) 'Power in transition. An interdisciplinary framework to study power in relation to structural change', *European Journal of Social Theory*, 12(4): 543-569

Beck, U. (2016) *The Metamorphosis of the World*, London: John Wiley & Sons.

Birch, K. (2017) 'Rethinking Value in the Bio-Economy: Finance, Assetization, and the Management of Value', *Science, Technology, & Human Values* 42(3): 460-490.

Birch, K. (forthcoming) 'Materiality and sustainability transitions: Integrating climate change into transport infrastructure in Ontario, Canada,' *Prometheus: Critical Studies in Innovation.*

Bonneuil, C and Fressoz, J-B . 2016. *The Shock of the Anthropocene: The Earth, History and Us*, London: Verso.

Brandt, L. and E. Thun (2010) 'The fight for the middle: upgrading, competition, and industrial development in China', *World Development* 38(11): 1555-1574.

Breznitz, D. and M. Murphree (2011) *Run of the Red Queen*, New Haven, CT: Yale University Press.

Bull, J. (2017) 'Understanding Uber: It's not about the app', *Reconnections*, 22nd September: https://www.londonreconnections.com/2017/understanding-uber-not-app/

Cherry, C., H. Yang, L. R. Jones and M. He (2016) 'Dynamics of electric bike ownership and use in Kunming, China.' *Transport Policy*. 45: 127-135

Christensen, C. (1997) *The Innovator's Dilemma*, Cambridge (MA): Harvard Business School Press.

Duara, P. (2014) *The Crisis of Global Modernity*. Cambridge: Cambridge University Press.

The Economist (2017a) 'The world's most valuable resource is no longer oil, but data', May 6th: https://www.economist.com/news/leaders/21721656-data-economy-demands-new-approach-antitrust-rules-worlds-most-valuable-resource

The Economist (2017b) 'Better to target zero emissions than 100% renewable energy', July 15th: https://www.economist.com/news/leaders/21725001-goal-after-all-curb-global-warming-not-favour-particular-technologies-better

The Economist (2010) 'First break all the rules: The charms of frugal innovation', April 15th: http://www.economist.com/node/15879359
Elzen, B., Geels, F. and Green, K. (Eds) (2004), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*, Edward Elgar, Cheltenham and Northampton, MA.
Flyvbjerg, B., T. Landman and S. Schram (2012*) Real Social Science – Applied Phronesis*, Cambridge: Cambridge University Press.
Foucault, M. (2009) *Security, Territory, Population: Lectures at the Collège de France 1977-1978*. Translated by Graham Burchell. Basingstoke: Palgrave Macmillan.
Fuller, D.B. (2016) *Paper Tigers, Hidden Dragons: Firms and the Political Economy of China's Technological Development*, Oxford: Oxford University Press.
Geels, F. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy* 31(8/9): 1257–1274.
Geels, F. and B. Verhees (2011) 'Cultural legitimacy and framing struggles in innovation journeys: A cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986)', *Technological Forecasting and Social Change* 78(6): 910–930
Geels, F., R. Kemp, G. Dudley and G. Lyons (eds) (2013), *Automobility in Transition?* Abingdon: Routledge.
Harari, Y.N. (2016) *Homo Deus: A Brief History of Tomorrow*, London: Vintage.
Kaplinsky, R. (2011) 'Schumacher meets Schumpeter: appropriate technology below the radar', *Research Policy* 40(2): 193–203.
Kern, F. (2011) 'Ideas, institutions, and interests: Explaining policy divergence in rostering `system innovations' towards sustainability', *Environment and Planning C* 29: 1116-34
Kern, F., Smith, A., Shaw, C., Raven, R.and Verhees, B. (2014) 'From laggard to leader: explaining offshore wind developments in the UK', *Energy Policy* 69: 635-646.
Kirkegaard, J.K. (2016) 'Rapid upgrading through experiment (self-)disruptive impasse: The case of China's wind turbine industry', paper presented to the *International Symposium on Innovation-Driven Development*, Sun Yat Sen University, Guangzhou, 13th-15th June.
Lanchester, J. (2017) 'You are the Product', *London Review of Books* 39(16): 3-10.
Lanier, J. (2013) *Who Owns the Future?*, London: Allen Lane.
Lazonick, W., M. Hopkins, K. Jacobson, M.E. Sakinç, O. Tulum (2017) 'US pharma's business model: Why it is broken, and how it can be fixed', in D. Tyfield, R. Lave, S. Randalls and C. Thorpe (eds), *The Routledge Handbook of the Political Economy of Science*, London: Routledge, pp.83-100.
Lewin A.Y., M. Kenney and J.P. Murmann (2016) 'Introduction', in *China's Innovation Challenge*, A.Y. Lewin, M. Kenney and J.P. Murmann (eds) Cambridge: Cambridge University Press. pp.1-31.
Mason, P. (2015) *Post-Capitalism*, London: Allen Lane.
Mirowski, P. (2014) *Never Let a Serious Crisis Go to Waste: How Neoliberalism Survived the Financial Meltdown*, London: Verso.
Morozov, E. (2014). *To Save Everything, Click Here*, London: Allen Lane.
Myronuk, K. (2017) 'Disruptive trends in exponential digital innovation', talk to the Innovator's Workshop on Disruptive Low-Carbon Innovation, London, 7th March (a similar talk is available to watch: https://thenextweb.com/insider/2017/05/29/kathryn-myronuk-singularity-university-convergence-lessons-silicon-valley/#.tnw_geAjuUCq)
Nahm, J. and E.S. Steinfeld (2014) 'Scale-up nation: China's specialization in innovative manufacturing', *World Development* 54: 288-300.

Pagano. U, and M.A. Rossi (2017) 'The knowledge economy, the crash and the depression', in D. Tyfield, R. Lave, S. Randalls and C. Thorpe (eds), *The Routledge Handbook of the Political Economy of Science*, London: Routledge.
Parson, E. (2017) 'Climate policymakers and assessments must get serious about climate engineering', *Proceedings of the National Academy of Sciences*, early online: www.pnas.org/cgi/doi/10.1073/pnas.1713456114
Rein, S. (2015) *The End of Copycat China*, Hoboken, NJ: John Wiley & Sons, Inc.
Rockström J. et al. (2009) 'A safe operating space for humanity', *Nature* 461(7263): 472-475.
Schiller, D. and S.J. Yeo (2017) 'Science and engineering in digital capitalism', in D. Tyfield, R. Lave, S. Randalls and C. Thorpe (eds), *The Routledge Handbook of the Political Economy of Science*, London: Routledge, pp. 70-82.
Shambaugh, D. (2016) *China's Future*, Cambridge: Polity.
Sheller, M. (2013) 'The emergence of new cultures of mobility: Stability, openings and prospects', in F. Geels, R. Kemp, G. Dudley and G. Lyons (eds), *Automobility in Transition?* Abingdon: Routledge, pp.180-201.
Shove, E. and Walker, G. (2007) 'CAUTION! Transitions Ahead: Politics, Practice, and Sustainable Transition Management', *Environment and Planning A* 39: 763–770.
Smith, A., A. Stirling and F. Berkout (2005) 'The governance of sustainable socio-technical transitions', *Research Policy* 34(10): 1491-1510.
Smith, A., Voß, J. P., & Grin, J. (2010) 'Innovation studies and sustainability transitions: The allure of themulti-level perspective and its challenges', *Research Policy* 39 (4), 435–448
Steffen, W., K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, E. M., ... & Folke, C. (2015) 'Planetary boundaries: Guiding human development on a changing planet', *Science*, 347(6223): 1259855.
Taplin, J. (2017) *Move Fast and Break Things*, London: Macmillan.
ten Brink, T. and F. Butollo (2016) 'A new upgrading paradigm? Innovation policy and domestic demand in strategic emerging industries', paper presented to the *International Symposium on Innovation-Driven Development*, Sun Yat Sen University, Guangzhou, 13th-15th June.
Tse, E. (2016) *China's Disruptors*, London: Portfolio Penguin.
Tyfield, D. (2013) 'Low Carbon Transport and Development', in F. Urban and J. Nordensvard (eds), *Low Carbon Development: Key Issues*, London: Routledge.
Tyfield, D. (2014) 'Putting the power in "socio-technical regimes" – e-mobility transition in China as political process', *Mobilities* 9(4): 585-603.
Tyfield, D. (2017) *Liberalism 2.0 and the Rise of China: Global Crisis, Innovation and Urban Mobility*, London & New York: Routledge.
Tyfield, D. & J.Jin (2010) 'Low-carbon disruptive innovation in China', *Journal of Knowledge-based Innovation in China* 2(3): 269-282
Tyfield, D. & D. Zuev (forthcoming) 'Stasis, dynamism and emergence of the e-mobility system in China: a power relational perspective', *Technological Forecasting and Social Change*.
Tyfield, D., J. Jin and T. Rooker (2010) *Game-Changing China: Lessons from China about Disruptive Low-Carbon Innovation*, London: NESTA.
Tyfield, D., Ely, A. and Geall, A. (2015) 'Low carbon innovation in China: From overlooked opportunities and challenges to transitions in power relations and practices', *Sustainable Development* 23(4): 206-216.
Tyfield, D., R. Lave, S. Randalls and C. Thorpe (2017) 'Introduction', in D. Tyfield, R. Lave, S. Randalls and C. Thorpe (eds), *The Routledge handbook of the political economy of science*, London: Routledge, pp. 1-17.

Unruh, G. (2000) 'Understanding carbon lock-in', *Energy Policy* 28:817-830.
Urban, F., S. Geall and Y. Wang (2016) 'Solar PV and solar water heaters in China: Different pathways to low carbon energy', *Renewable and Sustainable Energy Reviews* 64: 531-542.
Urry, J. (2013) *Societies Beyond Oil*. London: Zed.
Wilkinson, A., R. Kupers and D. Mangalagiu (2013) 'How plausibility-based scenario practices are grappling with complexity to appreciate and address 21st century challenges', *Technological Forecasting and Social Change* 80: 699-710.
Willis, R., Webb, M. and Wilsdon, J. (2007) *The Disrupters*, NESTA, London.
Wilson, C. (2017) *Disruptive Low Carbon Innovation Workshops – Synthesis Report*, Tyndall Centre for Climate Change & Future Earth, Norwich, UK. April 2017. Tyndall Working Paper 164.
World Bank/Development Research Centre (DRC) of the State Council of the People's Republic of China (2012) *China 2030*, Washington: World Bank.
Yip, G.S. and B. McKern (2016) *China's Next Strategic Advantage: From Imitation to Innovation*, Cambridge, MA: MIT Press.
Yu, Z. (2017) 'Sustainability transitions and leapfrogging in latecomer cities: a case of the diffusion of solar thermal energy in China", *PhD thesis*, Hull University.
Zeng, M. and P. Williamson (2007) *Dragons at Your Door: How Chinese Cost Innovation is Disrupting Global Competition*, Cambridge, MA: Harvard Business School Press.

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[1] In the Chinese board game *Go*, a move that completely subverts the passage of play to that point is described as '*poju*' or, literally, 'game-breaking'.

[2] As an important aside, opportunities for 'post-capitalist' digital commons (e.g. Mason 2015) are likely to be parasitic in the first instance upon the much greater dynamism of such capitalist innovation. The very success of the latter, though, would likely also expand the former, so rendering them increasingly significant over the course of the century and a key rallying point of a progressive 21st century politics. Prospects of such commons themselves alone delivering timely low-carbon transition over the next few decades, though, seem remote.

[3] As *The Economist* (2017b) notes, low-carbon heavy-good vehicle logistics, tankers and flight are still but pipedreams.

[4] The 'middle-income trap' refers to the inductive finding that historically most countries develop relatively rapidly to middle-income status but then get stuck at this level and are unable to continue their growth into highly-developed economies. This has been associated with the exhaustion of surplus migrant labour, called the 'Lewis turning point'.