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Innovation paths in Europe and Asia: Divergence or convergence?

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Abstract

This paper asks what insights the literature provides on divergence versus convergence of innovation paths in Europe and Asia. It contrasts the abundant literature on determinants of innovation paths with the scarcity of studies that are explicitly comparative across countries or continents. Implicit conclusions however emerge from several lines of work including evolutionary perspectives which stress differences in national conditions, and other perspectives which stress latecomer and globalisation effects. This paper distils and draws together the main conclusions on why innovation paths can be expected to diverge or converge. Its contribution lies in spelling out and bringing together implicit and explicit insights from a wide range of literatures. It also provides an analytical backdrop for some of the other papers in this special issue of *Science and Public Policy* which provide comparative empirical analyses of low carbon innovation paths.

Key words: innovation path; divergence; convergence; carbon lock-in; low carbon innovation; dominant design.

1 Introduction

The current technological shift from high to low carbon innovation coincides with a geographical shift: the rapid expansion of production and innovation capacity in China and India. This constellation gives rise to the question: to what extent, how and why do the innovation paths in Europe and Asia differ? Are they likely to diverge or converge in the future? Most papers in this special issue of *Science and Public Policy* focus on these questions and present the findings of new comparative research on renewable energy and electromobility. This paper steps back and asks what can be learnt from the literature on why innovation paths converge or diverge.

Whether a diversity of pathways emerges or a small number of designs becomes globally dominant has important implications. First, for the natural environment: continued diversity would help to mobilise a wide range of talents and resources and is likely to lead to more context-specific solutions. Convergence, on the other hand, is more likely to provide economies of scale, enabling fast cost reduction which allows new low carbon technologies to compete with, and ultimately replace, unsustainable technologies. Second, it matters for competition and for distribution of the gains in the global green economy: sustained diversity may provide niches for many firms, whereas a globally dominant design is likely to favour concentration in a few global firms and value chains. In the latter case it makes a considerable difference whether the incumbents in old industrialised countries maintain or even strengthen their global position or, whether they will be outcompeted by newcomers, especially if those come from newly industrialising economies. Comparing European incumbents with Asian newcomers is particularly interesting, because the latter are increasingly important investors in green technology.[1] This gives rise to a third reason for probing the diversity (or otherwise) of innovation paths. Since the country context influences innovation paths, are innovations coming out of countries such as China or India more appropriate for other countries which are at lower levels of economic development? Convergence between European and Asian innovation paths would make this less likely.

This paper reviews what we can learn from the literature. Why would innovation paths converge or diverge: between countries in general and between Europe and Asia in particular? Many different strands of literature offer insights into this topic, among them: neoclassical and evolutionary economics, innovation systems research, transformation and transition studies, and management and entrepreneurship research. In most cases, however, the implications for convergence or divergence are only implicit. Relevant debates refer to the relative power of entrepreneurial *agency* vs. socio-economic *structure* in shaping pathways; to the dynamics of cumulative causation, path creation and path disruption; or the differences between early movers and latecomers; or the effects of the organisational decomposition of the innovation processes. There are several layers of determinants buried in dispersed bodies of literature. This paper aims to spell out the (often implicit) conclusions and bring them together in one place.

In extracting insights on why pathways are likely to converge or diverge we faced problems of terminology. The bodies of literature we reviewed use different terms. In this paper we have opted for 'innovation paths'. Others, for example Dosi (1982), prefer 'technological trajectories'. There is no substantial difference, we are all concerned with the direction of technological change (and its determinants). Sometimes the cumulative changes result in a 'dominant design' (Utterback and Abernathy 1975), reducing incentives for exploring alternative innovation paths.

The remainder of this paper is structured as follows. Section 2 reviews what different strands of academic literature tell us about the drivers of convergence or divergence of innovation paths. This section distils the different determinants and effects to be considered in general terms in inter-country comparisons. Section 3 then adds three layers of complexity that need to be taken into account in the kind of empirical comparisons undertaken in other papers of this special issue of *Science and Public Policy*. We ask what difference it makes if:

- One compares long-established industrial countries in Europe with latecomer countries like China and India.
- One takes into account recent changes in the global architecture of innovation activities.
- One takes into account the extra challenges that arise in low carbon innovation.

How do they affect the divergence versus convergence trends? Section 4 brings together all the drivers of divergence and convergence which can be elicited from the literature.

2 Drivers of convergence and divergence of innovation paths

Why would innovation paths be different (or similar) between countries? There is a considerable body of work which focuses on specific determinants of innovation paths. These include characteristics of the socio-economic structure (mostly focusing on the immediate regional or national environment) such as: factor endowment, the size and nature of the home market, the maturity and diversity of related industries and supporting institutions, and the role of economic governance. However, much research also focuses on the entrepreneurs, management teams and firms as the agency which has considerable leeway for making its own technology choices and influencing institutions within the opportunity spaces delimited by the given structure.

In the following paragraphs we briefly discuss the main individual determinants and extract what they imply for the questions of convergence or divergence of innovation paths. We then add one layer of complexity, addressing the interdependencies among these factors and how cumulative causation among all the individual determinants leads to context-specific pathways. Here again, we ask under which conditions such pathways can be expected to converge, and when divergence is more likely.

2.1 Main groups of determining factors

Factor endowments: a nation's or region's endowment of factors of production has a major influence on its techno-institutional specialisation. The abundance or scarcity of labour and capital as well as physical resources (land, water and raw materials) influences the search for new processes and products. Following the Ricardian model of comparative advantages, the relative cost of capital vs. labour explains much of the patterns of technological specialisation, particularly the division of labour between capital-rich early industrialisers and labour-abundant latecomer economies. Early neoclassical economists expected convergence assuming that specialisation on the basis of existing comparative advantages would drive the cost of the abundant production factors up and thereby reduce the cost differentials. Physical resources can, of course, sustain long-term specialisation (e.g. abundant agricultural or mineral resources may shape a country's economic specialisation for centuries). The relative importance of these resources will normally diminish as economies mature and diversify into manufacturing and services, but even then, the initial physical resource endowment sometimes predetermines the direction of change.

More surprisingly, empirical evidence has shown that pathways diverge even among countries with fairly similar factor costs for capital and labour and in industries that do not depend on local availability of physical resources. As countries become more similar in terms of factor endowments, they specialise within industries, where factor cost differentials cannot explain the specific profile (Krugman 1981). The New Trade Theory explains this with increasing returns to scale and network effects: a country that enters a new product, technology or subsector earlier than competing countries with similar initial conditions (in economic terms: the same opportunity costs) may build up scale and network advantages so that the other countries can no longer compete. Scale and network effects thus limit competition in favour of early movers (Krugman 1979). Likewise, the seminal book *The Competitive Advantage of Nations* (Porter 1990) started as an endeavour to explain specialisation among similar economies: why the Swiss are market leaders for watches, Japan is particularly strong in optical instruments and Germany a leading innovator in luxury cars cannot be explained by current capital and labour cost differentials.

Hence there is wide agreement that endowment with traditional factors of production is important at early stages of development, but becomes less important as economies advance from 'factor-driven' to 'innovation-driven', according to a classification proposed by the World Economic Forum's annual Global Competitiveness Report (World Economic Forum 2015). The latter depend on other factors which we discuss in turn.

Among the most important factors are *economies of scale and scope*. Traditional economic theory ignored the importance of increasing returns to scale, which allow volume producers to increase their average costs per unit such that new market entrants cannot compete with them. Similarly, economies of scope (Panzar and Willig 1981) can be exploited, enabling producers to set up new lines of production that, building on previously established indivisible physical or knowledge assets, also benefit from lower unit costs.

The same principle applies to agglomerations of firms. Firms in geographic clusters can produce at scale and scope exploiting complementarities and joint assets (Porter 1998; Schmitz 1999). The more a firm can draw on related firms and/or supporting institutions to provide complementary assets and increase the scales of the cluster's production, the more it can build man-made competitive advantages in a specific field and deepen its competitive advantage. As firms, or agglomerations of firms, accumulate their skills and network effects building on specific initial investments, early patterns of specialisation are consolidated, and pathways diverge over time.

The size and nature of the home market is another important driver of specialisation. Small internal markets are unable to sustain the minimum scale of certain industries, such as the production of cars. Likewise, large markets are better able to attract foreign

investment, governments of large countries can negotiate better technology transfer deals, and firms can exploit economies of scale. The nature of the home market demand—which is determined by purchasing power as well as culturally embedded preferences—is an important driver of differentiation. Mowery and Rosenberg (1979) had already identified 'demand pull' as a major determinant and differentiator of innovation. Porter (1990) highlighted the importance of demanding customers as drivers of innovation: these customers often anticipate future demand trends and push firms to continuously improve. Firms catering to the needs of the most demanding customers are therefore often ahead of the competition and able to exploit early mover advantages. All these market characteristics call for context-specific adaptation and are therefore drivers of divergence. Economic globalisation, however, is a countervailing power as it often supports the global diffusion of certain values and demand patterns.

Economic governance is another determining factor which favours diversity and divergence across jurisdictions. Governments can influence innovation through explicit or implicit policies and can intervene early or late in the innovation cycle. They can use a wide range of instruments to encourage or discourage economic activities, including: taxes, subsidies, regulations, and all sorts of coordinating and facilitating services. Mazzucato (2013) highlights the role of state funding of R&D in opening up innovation paths. The degree to which governments are willing and able to intervene in markets and shape their innovation paths is very different, as expressed in different public expenditure quotas, different ratios of R&D to gross domestic product, and different attitudes to industrial policy. Likewise government objectives vary, with different priorities attached to geo-political, economic, social and environmental targets and different preferences for certain technologies and policy instruments. Moreover, government policy is co-influenced by non-government actors, including business and civil society. The degree to which non-government actors are involved in policy-making, the way their involvement is managed and the societal objectives such arrangements try to achieve differ greatly across countries. Hence, economic governance is a strong driver of divergence. Here again, some countervailing trends exist trying to harmonise economic decision-making internationally via international trade and investment agreements as well as 'softer' peer learning and benchmarking activities.

All these determining factors relate to socio-economic and political structure. While structuralists see the above factors as the main drivers, management sciences, behavioural sciences and entrepreneurship research emphasise the determining power of agency, that is, the capacity of individual entrepreneurs or management teams to make their own choices without being fully determined by structural limitations and even shaping the given structure through their actions (Giddens 1979). This raises the fundamental question: to what extent are country-specific innovation paths shaped by national structures, as the national innovation systems literature assumes. A counterview is that the key decisions are taken at the enterprise level and that, above all, innovation paths have company-specific, rather than country-specific, features. This view has a long history. Schumpeter (1942) saw big corporations leading the process of creative destruction. Likewise, the corporation-specificity of the innovation path is clearly expressed in the work by Utterback and Abernathy (1975) on the 'dominant design' which emerges from battles between corporations. When these corporations are multinational (in ownership and operation) the case for distinguishing between company and country-specific innovation paths becomes even more relevant (Ariffin and Bell 1999). With the emergence of global value chains spanning many countries and the emergence of lead firms governing these chains (Gereffi et al. 2005), the loci of where pathways are defined may shift from national systems to globalised chains. The power of individual firms may thus even up existing cross-country divergence—but at the same time create new divergence between competing global value chains.

2.2 Interplay of determinants

There is a general recognition that none of the determining factors is, on its own, sufficient to shape the evolution of innovation paths. The need for a 'multi-variables approach to the theory of innovation and technical change' has long been recognised (Dosi 1982: 161, drawing on Mowery and Rosenberg 1979).

Porter's (1990) analysis also recognised the interplay of specific determinants and the resulting inter-country differences. While his dependent variable is competitiveness, it can be applied to innovation analysis precisely because innovation activities are conducted in the pursuit of competitive advantage:

> Competitive advantage in sophisticated industries depends fundamentally on the rate of improvement and innovation. (Porter 1990: 145)

His central proposition—relevant for this paper—is that:

> … the national environment does play a central role in the competitive success of firms. (Porter 1990: xii)

And that:

> …the individual determinants combine into a dynamic system. (Porter 1990: 132)

He calls this the 'diamond' (Porter 1990: 132). The Porter diamond sparkles when all the factors reinforce each other. But it can sparkle in different ways: the way the factors combine tends to be country-specific. As a result the innovation paths tend to differ between countries.

The importance of understanding the interplay of determinants, especially processes of mutual reinforcement, is also recognised in other lines of work, notably innovation systems research. The latter has explored how the 'co-evolution of technology, industrial structure, and supporting institutions' (Nelson 1994) works in practice and knowledge evolves over time. Innovation is seen as an outcome of evolutionary and systemic change as opposed to the more static view of standard neoclassical economics. It stresses that innovation is an historically contingent and incremental process of cumulative causation with lots of feedback loops, especially between producers and users (Lundvall 1988).[2] Increasing returns, sunk costs and network effects favour path-dependent investments over other options that might have been better before the current pathway was established. As knowledge cannot be entirely codified and therefore is not readily transferable between places and networks, technological and institutional learning are also context-specific and deepen the respective local or national trajectory. Politically, vested interests defend their assets and seek to shape discourses, mindsets and expectations about the future.

Whether these processes foster convergence or divergence depends on the degree of interpenetration of markets and the maturity of technologies. In nation states with their own idiosyncratic structures and history, national pathways are likely to emerge and diverge from pathways in other nation states due to specific processes

of cumulative causation. But, as international trade and investment links intensify competition, certain solutions are likely to gain the upper hand in the market place and outcompete alternatives. Over time, they may become dominant designs in the way described by Utterback and Abernathy (1975). These authors show how certain products, building on technological superiority, economies of scale, network economies and/or strategic moves to develop a strong brand, become the *de facto* standards to which all competitors have to adhere. For example, Microsoft Windows has become the dominant design in PC operating systems. Utterback (1994) documents the emergence of dominant designs in many different industries, from nuclear reactors to video cassette recorders and watches. As Srinivasan et al. (2006: 1) observe:

> … competition before the emergence of a dominant design is between different designs, whereas after its emergence, competition is within the more circumscribed domain of a dominant design.

Hence we see relative convergence as there are fewer differences between available alternatives. Thus, innovation theory implicitly suggests divergence in segmented markets and at initial stages of a technological life cycle, but convergence when markets integrate and product maturity favours the establishment of dominant industry players and designs.

2.3 Path dependency vs. disruption and creation of alternative pathways

While the mechanisms of cumulative causation favour path dependency, empirical evidence also shows that paths are sometimes disrupted and unexpected new pathways emerge. Both Marx and Schumpeter remind us that change is built into the capitalist system. Schumpeter (1942) has interpreted capitalist development as a process of newcomers continuously challenging, and eventually outcompeting, established ways of doing business. Perez (2002, 2010) took this a step further showing that the large technological changes have common phases.

Applications of the innovation systems approach, referred to above, have enormous merits in explaining *ex post* why and how initial decisions led to certain pathways and excluded alternatives. It is much weaker at understanding—let alone predicting—how and why established pathways collapse and new innovation paths emerge. It is therefore worth drawing on an emerging strand of literature dealing with path disruption and the creation of new pathways. This literature is of particular relevance at times when new ways are needed to break free from environmentally unsustainable situations of carbon lock-in (Unruh 2000). This is also where the burgeoning literature on sustainability transitions (<http://www.transitionsnetwork.org/> accessed 15 Jan 2015.) comes into play.

As stated by Lovio et al. (2011: 274):

> … the evolution of technologies and industries can be described as a battle between the old and the new, that is, between the path dependence forces of the old path and attempts to create new paths. Path dependence and path creation are thus competing processes in times of technological transition.

Path creation implies agency. Smith et al. (2005) and Lovio et al. (2011) suggest that potential change agents fall into four groups:

- new market entrants, spin-offs and venture capital
- incumbents deciding to change or diversify
- civic actors such as environmental and consumer associations
- government actors with powers to regulate, tax, subsidise or invest

The key point is that none of these actors can bring about the required changes on their own. This is recognised by Garud and Karnøe (2001) when they stress the importance of engaging a distributed network of actors and by Karnøe and Buchhorn (2008) when they analyse the role of policy coalitions in path creation. In our own work we have pushed this further, suggesting that public–private–civic alliances are essential for understanding and fostering transformations (Schmitz 2015). Such alliances can be seen as vehicles for bundling diverse interests for a particular purpose such as influencing legislation, policies, or technological projects.

There is a recent line of research which questions the juxtaposition of path dependence and path creation and concentrates on the spectrum in between:

> The focus is on the dynamics within a path and the way actors use the narrowed down or the limited range of choice of a well-established institutional setting in creative ways for the development of innovation without breaking out of the path. Research under such a perspective might contribute to the understanding why some paths have remained dynamic in the long run while others become stuck in negative lock-in effects. (Strambach and Halkier 2013: 1)

In other words, adaptations to existing paths are significant and need to be put under the analytical lens. Strambach (2010) does this by calling attention to 'combinatorial knowledge production' which provides unprecedented possibilities for 'path plasticity'. The insight behind this is that substantial path adaptations become possible by combining and integrating competences from different horizontal domains (e.g. hydraulics, aero-dynamics, financing and marketing) and vertical domains (industrial sectors), sometimes helped by involving knowledge-intensive business services.

The possibilities for combinatorial knowledge production have increased substantially over the last two decades with the twin tendency of focusing on core competence and the organisational decomposition of the innovation process. However, path plasticity is not a new experience. Sushandoyo et al. (2012) have documented how sailing ship manufacturers adapted to the emergence of a new, and ultimately superior, technological design, the steam ship:

> The 'old' type of sailing ship was improved dramatically when steam ships emerged during the nineteenth century. These improvements concerned nearly all of the components and materials of the sailing ship, which was transformed from a wooden to a metallic structure with a massively improved carrying capacity and speed performance. (Sushandoyo et al. 2012: 107)

Examining path plasticity and adaptation within established pathways and by incumbent lead firms seems highly relevant for inter-country comparisons of innovation paths. It entails a hypothesis that the shear threat of a new technological trajectory might bring about substantial adaptations to the existing trajectory. In turn, this opens up a scenario of increasing diversity within a broad overall trajectory.

The 'multi-level perspective' put forward by Geels and Schot (Geels 2010; Geels and Schot 2010) makes an ambitious attempt to explain how systems break out of path dependence. It distinguishes three analytical levels: niches which are the locus of radical innovations, socio-technical regimes which are locked-in and path-dependent, and landscapes which are exogenous. Regime shifts are brought about through interactions between these levels. They do

not come about easily because the existing regime is locked-in and adjusts through incremental innovations along predictable trajectories. Radical innovations taking place in niches can destabilise the regime and break through more widely if changes in the external landscape (for example the global financial crisis or the Fukushima disaster) create pressures on the regime that lead to cracks and windows of opportunity. As a result, the existing regime might be replaced—or it might be strengthened if it can adapt—recall our earlier discussion of path plasticity and the 'sailing ship effect'.

Most work adopting the multi-level perspective has focused on finding ways of piercing through the prevailing socio-technical regime by promoting specific niches (Kemp et al. 1998; Schot and Geels 2008). The niche concept presumes that new technologies are often disadvantaged and require strategic support to protect them against premature rejection by investors and users. Smith and Raven (2012) suggest a framework conceptualising the construction of protective space as consisting of three processes: shielding, nurturing and empowering. Screening the literature they find that innovation scholars have a lot to say on shielding and nurturing but little on empowering—stressing that this requires a more socio-political approach. In their most recent work they highlight:

> ... the importance of narratives as key devices in undertaking this socio-political work. (Raven et al. 2014: 26)

Such narratives are needed not just in promotion of new technologies but also in questioning the prevailing technologies. This is also the conclusion of Geels (2014) who suggests that the destabilisation of existing regimes requires equal attention. Referring to Schumpeter's notion of 'creative destruction' he stresses the need to better understand the 'destruction' part.

There is no easy conclusion that can be drawn from this literature on path dependence, creation and destruction as it does not explicitly address our main concern: convergence versus divergence. It is, however, an essential stepping stone for coming to grips with it. Section 3 sets out further layers of complexity that need to be grappled with as the centre of world economy's gravity is shifting from West to East and as innovation investments are shifting from high to low carbon.

3. Low carbon pathways in a globalising economy

The explicit and implicit conclusions distilled from the literature up to this point are relevant for inter-country comparisons in general and for any period since the Industrial Revolution. We now zoom into the current period. Its most remarkable feature is the power shift in the global economy. China and India, the rising powers of Asia, have grown very rapidly and accumulated significant innovation capabilities (Ernst 2009; Lema et al. 2012). Given that these countries' internal characteristics are very different from those of the old industrial countries in Europe one would expect their innovation paths to be different. But are they? This section asks which factors, other than those discussed above, need to be taken into account. What can we learn from the literature on why current Asian and European innovation paths would diverge or converge?

In order to address this question we need to unpack it and consider a number of effects: the rising powers of Asia did not build up their innovation capabilities in isolation. Being latecomers they learnt from the leaders in Europe (and elsewhere). There is a latecomer effect which has important implications for our central question. The rising powers, in building up their innovation capabilities, are participating in globalised innovation processes. Again, this globalisation effect has important implications for our central question. As in Section 2, we find that the literature offers numerous insights but they tend to be implicit rather than explicit.

Cutting through complexity and specifying the layers of complexity is a big challenge because there are several interconnected changes to be considered. Formerly relatively closed national economies have integrated into a globalised economy. Production is now largely organised in global value chains, and even innovation is increasingly arranged in transnational networks. The shift in global economic power towards Asia is fast and deep and is unprecedented in history. This coincides with pressures to bring about a shift from a high to a low carbon economy. Given this constellation of trends, what are the implications for innovation paths in China and India and can we expect them to differ from those in Europe?

As a contribution to unravelling this question we discuss the effects that arise from: first, China and India being latecomers; second, having huge and growing internal markets; third, participating in globalised innovation processes; and finally, having to address the low carbon challenge.[3]

3.1 Latecomer development

History matters, as has been stressed in earlier sections of this paper. In one respect, the history of the Asian countries is very different from that of the European countries: they are latecomers. This matters for our central issue of divergence vs. convergence.

There is a substantial literature on the drawbacks and advantages of being a latecomer (Gerschenkron 1962; Dore 1973; Hobday 2003). The main drawback is that they lag behind early industrialisers in their efforts to foster strong enterprises and supporting institutions and, above all, to create synergetic innovation systems in which highly specialised firms and institutions produce positive externalities for each other.

The advantages of being a latecomer have been captured well by Mathews (2006): countries and firms can exploit their late arrival by tapping into advanced technologies, rather than having to replicate the entire previous technological trajectory. Through inward foreign direct investment, imports, licensing, and acquisition of foreign companies they can incorporate existing knowledge assets developed elsewhere. They can insert themselves into global value chains, starting with simple tasks and then moving up the chain taking on increasingly complex tasks. Lema and Lema (2012) go a step further and show how some Chinese and Indian firms adopt innovative ways of acquiring capabilities through strategic acquisition of innovation teams from advanced countries and setting up their own R&D facilities in established industry clusters abroad.

The latecomer effect has an important implication for the issue of the differences and similarities of innovation paths. Latecomers engaged in catching up and learning from firms in old industrialised countries follow similar paths rather than different ones. Imitation is an essential step in the acquisition of production capabilities and innovation capabilities. In the process of imitation they undertake adaptive innovation (due to their different factor conditions and markets) but this rarely amounts to the creation of new pathways. There is a substantial literature on imitation and adaptation by latecomer firms, in particular on the limited capability of latecomer firms embarking on their own innovation paths (Bell 2006; Figueiredo 2006; Hobday 1995). Our own review of the capabilities of China and India to make the transition from production to

innovation capabilities still showed few examples of 'breakthrough' (Altenburg et al. 2008). But this is changing. Recent research shows examples of systemic innovation emerging from the 'rising powers' (Lema et al. 2015). These examples, however, do not change our overall conclusion that the latecomer effect results in the technological developments of China and India being heavily influenced by technology imports from old industrialised countries.

3.2 Globalisation of innovation processes

The opportunities for China and India to enhance their domestic innovation capabilities and establish their own pathways benefit from ongoing changes in the way large companies in Europe (and elsewhere) organise their innovation processes. Innovation activities tended to be centralised at or near headquarters, but now they are more decentralised within the company. Globalised companies have moved some of their R&D operations overseas with a substantial share going to China and India (Sun et al. 2007). Equally significant, innovation activities that used to be carried out in-house by innovating firms themselves are carried out by independent suppliers of knowledge-intensive business services, or are transferred to key suppliers. Schmitz and Strambach (2009) have called this the organisational decomposition of the innovation process. It is a change in the architecture of the innovation process which has been well documented for Western Europe and North America (e.g. Chesborough 2003, 2006; Christensen et al. 2005; Strambach and Klement 2012). It is also becoming clear that this organisational decomposition has global repercussions. By making geographical dispersal of innovation activities to other parts of the globe easier it has contributed directly and indirectly to the build-up of innovation capabilities in the Asian latecomer firms, particularly China and India (Lema et al. 2012; Ernst 2009).

While the trends towards outsourcing and offshoring are clear, it is less clear to which degree latecomer countries, including China and India, will be able to exploit them in terms of opening up new innovation paths tailored to national conditions or whether they will largely remain functional for, and subordinated to, the strategies of long-established multinational companies. This will be crucial for the question of path divergence or convergence.

3.3 China and India: Large and growing markets with different demand profiles

As discussed earlier, demand conditions have a considerable influence on innovation paths. In China and India, demand conditions are radically different from those in the European comparator countries. One obvious difference stems from market size and growth. China and India are by far the world's most populous countries and thus increasingly important global markets, especially as their economies grow at rates far above the global average. Large markets offer economies of scale. This makes China (and to a lesser degree India) preferred investment sites for foreign firms. Inward foreign direct investment can be used as a shortcut to technology acquisitions, especially by China whose government applies a 'quid pro quo' policy requiring foreign investors to share technology with domestic firms in return for access to its national market (Holmes et al. 2013). In some cases, with or without pressure, subsidiaries of multinational corporations (MNC) develop specific products for Chinese and Indian markets to cater to the specific requirements of these countries' middle class consumers (Kharas 2010: 30ff). In practice it is sometimes difficult to unpack to what extent such innovations 'made in China or India' are rooted in the strengths of the national innovation systems of the host country or stem from the strengths of the innovation capabilities internal to a certain MNC network. This has important implications for the question of who appropriates the innovation rents. But in any case, the effect is the divergence of technological innovations across countries.

Furthermore, the nature of the demand is very different. China and India still display much lower productivity levels than the European countries, translating into comparatively low average incomes.[4] Hence there are rapidly growing markets for so-called 'frugal' innovations which are characterised by: high affordability due to low production costs and thin margins as well as by robustness and simplicity, being designed for volume-driven markets (Tiwari and Herstatt 2012). Again, it is not clear to what extent these innovations will be mainly created by local or by foreign firms, but it is clear that the type of innovations demanded by high- and low-income markets are quite different.

3.4 The specificity of low carbon pathways

The global power shift towards Asia coincides with pressures to shift towards low carbon innovation. Highlighting key features of the low carbon challenge and implications for innovation paths is the purpose of this brief section. The literature suggests three key features: first, path dependence is particularly severe. Unruh (2000) in particular has stressed that most countries are locked into fossil fuel-based energy and transport systems which he termed the 'carbon lock-in'. He also stressed that this carbon lock-in has globalised rapidly (Unruh and Carrillo-Hermosilla 2006). The existence and problems arising from such a carbon lock-in have been widely recognised in numerous contributions to the sustainability and climate change debate (WGBU 2011). Breaking out of the carbon lock-in is particularly challenging because technological uncertainties are high, time horizons for investment are long, yet action is urgently required (Lütkenhorst et al. 2014, Schmitz et al. 2015). Earth and climate sciences predict irreversible damage if such action is not taken (Intergovernmental Panel on Climate Change 2014). The urgency of this action is the second key feature of the low carbon challenge.

The third feature is the scale of government intervention and political support required to meet the challenge. The way this plays out at national level varies enormously between countries and this has implications for the innovation paths pursued in these countries. This is a key point which requires elaboration.

Markets do not work properly in the field of low carbon technologies. This led Stern (2007) to declare that climate change is the result of the biggest market failure of all time. The most obvious market failure refers to the fact that the social costs of carbon emissions are not (sufficiently, if at all) reflected in prices. But there are other particularly severe market failures holding back the transition to low carbon development. These relate to information and coordination failure: investors do not know whether carbon taxes will accrue in the future, what low carbon production systems would look like, which technological alternatives will win the competition and whether other investors make complementary investments which may be necessary for one's own return on investment.

Against this background, governments and other non-market actors have a particularly important role in promoting low carbon development. They develop new narratives, objectives and incentives; they define which technologies and institutions they deem appropriate and which ones not; and how much they are willing to pay for creating new pathways and disrupting old ones. At the same time, high-carbon incumbents defend their vested interests, and the

Table 1. Determinants of techno-institutional divergence vs. convergence

Determinants . . .	. . . of divergence	. . . of convergence
Endowment with capital and labour	Initially cost differentials foster divergent paths, but becomes less important over time	. . . but specialisation based on comparative advantages should reduce cost differentials in the long run
Endowment with physical resources	Explains divergence at early stages, can still influence specific pathways when countries industrialise	
Economies of scale and scope	Explain intra-industry divergence	. . . but favour emergence of dominant designs (convergence) as technologies mature
Related firms and/or near by supporting institutions	Strong driver of divergence	
Market size	Increasing market size creates scope for diversity	. . . but stimulates search for dominant design
Characteristics of demand	Culturally embedded preferences and differences in purchasing power drive divergence	
National differences in economic governance	Strong driver of divergence	
International harmonisation of economic governance		Fosters convergence, but so far weak relative to national governance
External crises	Can destabilise locked-in pathways and initiate new rounds of experimentation	
Technology life cycles	Initial 'eras of ferment' produce divergence	Technological maturity favours establishment of dominant designs
Latecomer situation	Explains initial inter-industry difference *vis-à-vis* early industrialisers	. . . but enables imitation, use of licenses, import of technologies, and therefore convergence
Economic globalisation		Favours diffusion of dominant designs and oligopolistic competition, facilitates technology import and imitation
Organisational decomposition of innovation	Potential to specialise in specific steps of knowledge creation	Facilitates acquisition of research teams of leaders by followers
Green industrial policy: experimentation in protected niche markets	Can create new options if there are cracks in prevailing path	
Low carbon transformation	Triggers paradigm change and new 'era of ferment', moreover different political constellations lead to cross-country differences	

actual transition depends on the power relations between old and new. All this implies that national low carbon pathways are highly political and context-specific. Countries tend to vary with regard to: ranking of decarbonisation on the agendas of governments and societies; degree of environmental awareness; society's readiness to accept the risks of technological alternatives (like nuclear power and carbon capture and storage); the power balance between high and low carbon industry lobbies, and many other factors. Such political variations are likely to lead to the divergence of innovation paths across countries (Altenburg and Pegels 2012). Other papers in this special issue of *Science and Public Policy* examine in detail the extent to which this is the case. The Introduction to this special issue (XXXXXX, this issue) provides a summary of the findings.

4. Conclusions

The question driving this paper is why innovation paths would diverge or converge between countries, paying special attention to the comparison of pathways in leading European countries and in the rising powers of Asia. In pulling together what the literature says on this question we found plenty of material on the determinants of innovation paths, but much less inter-country comparative material. Many of the insights pulled together in this paper should therefore be taken as implicit rather explicit conclusions. Our central objective was to spell out and bring together these explicit and implicit conclusions from a wide range of literatures.

This paper proceeded from the general to the specific. Section 2 brought together those insights relevant for the issue of divergence vs. convergence which are applicable to any period since the Industrial Revolution. Section 3 distilled those insights that are particularly pertinent for the current era in which the old industrial leaders of Europe are challenged by the rising new powers of Asia. The question of divergence vs. convergence of their innovation paths is relevant for the reasons spelt out in Section 1.

Section 2 brought together the numerous arguments which stress that innovation activities are interconnected, embedded and sticky. They suggest that different initial conditions set location-specific processes in motion which, through cumulative causation, evolve along certain directions: choices made at the beginning systematically confine the option space available at later stages. As the initial conditions are always context-specific and unique, this dynamic of path dependence and lock-in implicitly favours the divergence of innovation paths. But the literature also acknowledges that dominant designs may emerge which give a premium to economies of scale, thereby crowding out alternatives that, without the same scale advantages, can no longer compete. This trend towards dominant designs implies convergence, although it is not necessarily one single design that clearly dominates the market. The market for wind turbines is currently split between two designs, and in the automotive industry it may well be that the current paradigm change leads to the establishment of two or three new engine technologies (just as diesel and petrol engines co-existed in the past).

After some time of market dominance and technological lock-in, new systems may again emerge and destabilise the previously dominant design(s), but this presupposes specific conditions—external crises challenging the established pathway, successful niche experiments nurturing alternatives, and coalitions of change. However, the capabilities of incumbents to adapt under pressure without exiting the established pathway should not be underestimated. All these forces have been at work for a very long time. Section 3, concentrating on the current era, has brought together further determinants that need to be considered. The global changes—shift in geography from old to newly industrialised countries and shift in focus from high to low carbon—are recent, but they also unleash forces pulling in opposing directions: some towards divergence others towards convergence.

This paper has cut through the various layers of complexity but cannot provide easy answers. Pulling together what the literature tells us about path convergence and divergence in general and the specific characteristics of low carbon development in a globalising world with changing economic power relations, it is clear that there is no simple formula that would help to explain, let alone predict, when innovation paths converge or diverge. Table 1 provides a synopsis of the most relevant determinants. Those that are relevant in general terms are at the top and those that are particularly relevant in the current turbulent period are nearer the bottom.

Table 1 cannot do justice to the dynamics that unfold. Determinants may change over time. As stressed earlier, there tends to be a lot of experimentation in design and performance features in the early phases, but as technologies mature economies of scale, network effects and sunk investments become more important. Thus, certain market actors achieve cost reduction and gain market shares at the expense of competitors (Utterback and Abernathy 1975). Hence, technological developments become locked-in and the initial plurality of options is reduced. Anderson and Tushman (1990: 604) show empirically for several industries how technological discontinuities give rise to what they call 'eras of ferment' with lots of technical variation before a dominant design emerges. Even the most dominant designs, however, are again and again challenged by newcomers and, sooner or later, their dominance erodes, giving rise to a new techno-institutional discontinuity and opening up new rounds of experimentation and divergence.

Overall, we have seen that there is a rich and growing literature on the determinants of innovation paths but little explicit discussion of inter-country divergence and convergence. Perhaps this is explained by the sheer complexity of investigating this issue. In order to deal with complexity it is essential to disentangle connections and decompose the picture. This is what this paper has sought to do, by identifying the causal relationships which are prioritised in different literatures. The task of recomposing the picture has yet to be accomplished. Comparative empirical research is an essential step in this task. Other papers in this special issue of *Science and Public Policy* conduct such comparative research across the divide between old Europe and new Asia, but focused on low carbon innovation paths. An overview of these papers is provided in the introduction to this special issue (XXXXXX this issue).

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Notes

1. Of course, both Asia and Europe are very heterogeneous. In this paper 'Europe' is shorthand for long-established industrial countries, such as Germany, France or Denmark, which are innovation leaders in specific sectors. 'Asia' is shorthand for major newly industrialised countries, notably China and India, catching up not only in production but also in innovation capabilities.

2. The density and quality of relationships is a key feature of innovation systems. Firms and supporting institutions have strong ties with some actors and weak ties with others. Some mainly interact within their respective value chains, others with firms in their neighbourhood. For some, the immediate geographic environment confines their economic relations, others use their cluster as a base for connecting globally. Some mainly interact within clearly defined industrial subsectors, others offer services across a range of subsectors. Accordingly, scholars have defined system boundaries in different ways, depending on their research focus. Hence a range of innovation system concepts has emerged, focusing on national (Lundvall 1988; Freeman 1995), regional (Cooke 2001), sectoral (Malerba 2002) or technological (Hekkert et al. 2007) innovation systems. Each of these concepts can be useful, depending on the research question one wants to answer. As we are concerned with comparing national pathways, we take national innovation systems as our starting point, but are well aware of the concept's limitations.
3. Berkhout et al. (2009) bring together most of these dimensions when they discuss whether sustainability transitions are likely in developing Asia. They ask whether Asia can avoid the high-carbon model of high-income countries (to which their answer is a cautious yes), whereas we seek to compare carbon-reducing pathways in both the high-income countries of Europe and lower-income countries of Asia.
4. Per capita income in purchasing power parity terms in 2014 was US$5,708 in India, US$13,217 in China and US$45,616 in Germany (World Bank, World Development Indicators) <http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?order=wbapi_data_value_2014+wbapi_data_value+wbapi_data_value-last&sort=asc>, last accessed 3 Nov 2015.

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