Stranded assets: then and now

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1. Introduction

This chapter examines the issue of stranded assets and the likely energy transition from a macro-economic perspective. Given the lack of historical evidence on this issue, it will compare past macro-economy drivers of change and rates of asset stranding with those observable today and forecasted for the future. It will ask what pace of asset stranding can be expected normally and during economywide transitions. What could be an optimal rate of asset stranding? Could environment-related factors be generating a different rate and scale of asset stranding? It will also discuss why stranded assets can be seen as an opportunity – refreshing capital stocks, reducing pollution, and moving closer to technological frontiers.

The first two sections look at how economies change, using the period running up to and after the Industrial Revolution in the UK as a case study in how embracing change can lead to technological and structural transformation and rapid growth and development. The subsequent sections look at the historical limitations to resource-based development and the importance of managing change effectively before introducing the risks associated with a more rapid and contagious shift to a low-carbon network, which can leave companies, sectors, and regions caught out with stranded and unproductive assets. The next sections will examine how the main barriers to yielding the opportunities and limiting

the risks from transformative change are mainly institutional and come from vested interests seeking to delay change and propagate inertia. The final section concludes and offers policy recommendations drawn from this historical analysis.

2. Economies always change

The structure of any economy is subject to continual flux. Possibilities for production evolve as new technologies, techniques, and materials are discovered while demands also shift in line with evolving tastes, preferences, and behaviours. Institutions and cultures will then reflect and reinforce these changes. These so-called disruptive changes can happen surprisingly quickly in historical terms.

Joseph Schumpeter (Schumpeter 1942, p. 82) described an economic structure "incessantly destroying the old one, incessantly creating a new one. The process of Creative Destruction is the essential fact about capitalism." Throughout history, economies have suffered from major phases of economic stagnation and decline interrupting periods of strong growth (Fouquet and Broadberry 2015). This chapter shows that these periods of decline have been associated with a lack of inclusive institutions, failure to adapt to changing markets while allowing vested interests to delay vital structural transformations (Olson 1983).

Governance structures that are most resilient to inevitable change are those that recognise and plan for it. In particular, economies which allow resources to be reallocated from old, declining, low-productivity sectors to new, fast-growing, high-productivity sectors are likely to be more resilient. A hundred years ago, several haircuts, a holiday weekend, or a seven-course gourmet meal might have been exchanged for an accurate water resistant watch. Today such a watch can be picked up across the world often for less than the price of a cup of coffee, while the relative price of labour-intensive services has gone up. Meanwhile internet-enabled devices have only recently been conceived and invented. VHS recorders and analogue cameras have gone from non-existent to near saturation and back again in a matter of decades. These shifts are part of

the diversity and innovation associated with economic dynamism. Indeed, changes happen faster and faster in the era of mass communications and rapid global diffusion of knowledge capital. It took 25 years for the fixed-line telephone and 30 years for electricity to penetrate 10% of the US market and decades more to reach 50% saturation (DeGusta 2012). By contrast, tablets, smartphones, and the internet are reaching such penetration rates in years. More recent innovations are being adopted more quickly in a readily connected globalised communication and trading environment.

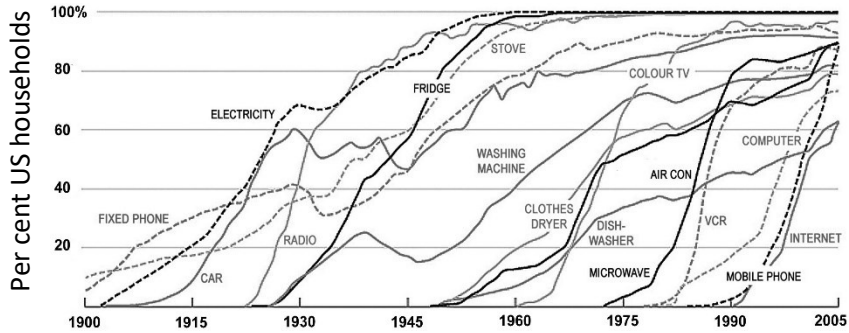

Figure 2.1 Diffusion/adoption rates

Source: Nicholas Felton, The New York Times
www.nytimes.com/imagepages/2008/02/10/opinion/10op.graphic.ready.html

For the most part, such shifts cause little economic strain. Resources are re-allocated from sector to sector; people are reskilled and retrained; capital depreciates and is replaced. This is part of a healthy dynamic economy; half of the companies listed in the fortune 500 in 2000 no longer exist (Nanterme 2016). However, every so often the shift is so large or so sudden (or both) that substantial economic assets are rendered stranded. Most vulnerable to such changes are goods and services that rely on integrated networks, more especially mass transport, communication, and energy. Decisions on long-lived capital investment and the adoption of new integrated networks affect a country's wealth for decades or even centuries.

For instance, over the space of 150 years, canals in Britain experienced rapid success, then stagnation, and eventually major decline. From the mid-18th century, canals played an important role in the supply of heavy goods, such as coal and iron, between strategic economic centres. As the network of canals expanded between the 1780s and the 1820s, the cost of freighting heavy goods fell substantially. Canal barges increasingly supplied lighter goods and carried passengers, too. However, competition from railways meant that, by the mid-19th century, only the heaviest goods were profitable to freight using canal barges (Jackman 1960).

The growing success of railway companies and the declining value of canals meant that the former began to own the latter's assets. During the 'Railway Mania' of the 1840s, canal owners, anticipating the stranding of their assets, offered their waterways at low prices (Bagwell 1974). Railway operators seeking to integrate services were happy to snap them up. Concern about the monopolistic powers of the railways led to the creation of the Canal Carriers Act in 1845, which stipulated that only existing canal companies were allowed to acquire or lease waterways. The next year, before the Act was in force, railway companies bought almost 20% of the whole canal network. Many railway companies changed their names to reflect their business on the waterways, expanding their ownership of an increasingly unattractive business – by 1865, they owned one-third of the canal network. In 1873, mergers were forbidden except by Parliament's consent (Bagwell 1974).

However, ultimately, this protectionism accelerated the demise of the canals. Because railway owners struggled to acquire certain stretches of canals, they were unable to integrate their distribution networks effectively. This barrier encouraged them to concentrate their distribution through the railways. Over time, they failed to maintain their canals, which often needed repair due to ice damage. This made them less usable and drove up the cost of freight along the canals. The overall level of freighting activity on the waterways remained broadly the same during the second half of the 19th century and then declined after the First World War (Bagwell 1974).

This chapter seeks to investigate the likelihood and impact of a rapid transition to new energy and transport networks. The risk is big oil companies become the canal companies, Kodaks, and Blockbusters of the next century, with significant stranding of physical, human, and knowledge assets.

3. UK case study: structural transformation the key to growth and development

In this section we turn to a classic case study of how structural transformation is crucial to economic growth and development. It is the story of the Industrial Revolution in the UK. After the decline of the Roman Empire, Britain lost a great deal of its economic structure and, over the subsequent centuries, became the subject of a number of invasions that redefined it (Dyer 2002). Then, from the 12th century, England, in particular, transformed itself from an economic backwater to the leading global economy by the 19th century. Lessons will be drawn from this section throughout the remainder of this chapter.

The early periods of growth in England were associated with its development of a cloth industry. For centuries, England had manufactured its own woollen cloth, which was considered of high quality but relatively expensive (van der Wee 2003). However, by the 13th century, England had become a major exporter of wool, especially to Flanders, which was very efficient in the production of textiles, and then importing much of its demand for manufactured woollen textiles (Carus-Wilson 1950). Following a series of wars, in the second half of the 14th century, the English woollen textile manufacturers began regaining their market and even started exporting textiles, particularly to Gascony, which sold wine in return (Carus-Wilson and Colman 1963). By the 16th century, England had fully converted to a cloth-manufacturing and -exporting economy. Increases in England's per-capita GDP around the 1370s and the 1480s can be discerned from Figure 2.2.

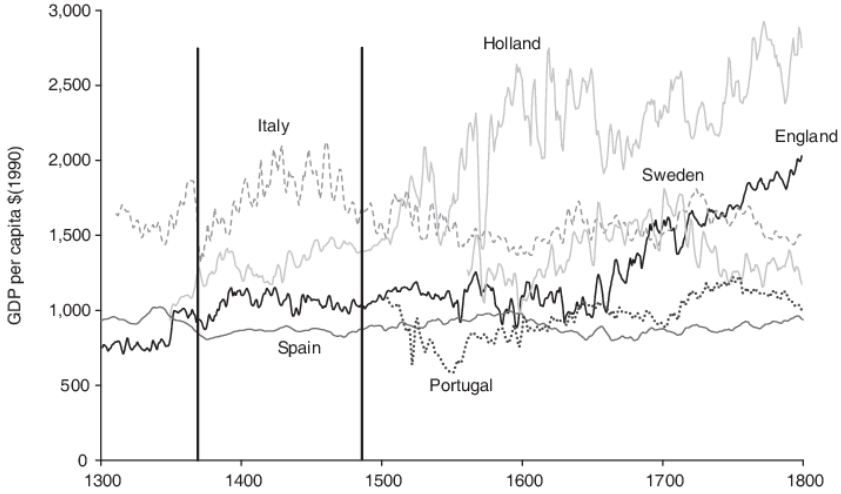

Figure 2.2 GDP per capita in selected European Economies, 1300–1800[2,3]

Source: Fouquet and Broadberry (2015). Original sources: Broadberry et al. (2011), Malanima (2011), van Zanden and van Leeuwen (2012), Schön and Krantz (2012), Alvarez-Nogel and Prados de la Escosura (2013), Palma and Reis (2014). *3-year average; Spain: 11-year average.

The 16th century saw the expansion of two other sectors of the English economy, iron and coal, which would become the pillars of economic growth. In the 1490s, a number of French Huguenot families, escaping religious repression, were welcomed and settled in the Weald in Sussex. They introduced the furnace, which produced faster, cheaper, and generally better quality iron. Pig iron production in the Weald, which centred on meeting military demands for cannons and cannon balls, increased 28-fold between 1530 and 1590.[4] Furnace pig iron production outside the Weald, which provided tools and smaller items, took off, and, throughout England, pig iron production increased 30-fold between 1540 and 1620 (King 2005). Since the 16th century, many ironmasters had tried to use coal-based fuels to smelt iron but failed until Abraham Darby's invention in the early 18th century and, still, the fuel needs made coke iron too expensive except for specific purposes (King 2011). Then improvements in the efficiency of coke-iron furnaces transformed the industry in the second half of the 18th century, reducing variable costs of

production and increasing the incentive to build coke iron furnaces – between 1755 and 1760, coke pig iron production tripled, and it more than doubled again between 1760 and 1780 (King 2005).

The main pillar, which fuelled the iron industry and the cotton industry during the Industrial Revolution, was the coal industry. Yet the introduction of mineral fuels reduced the burden imposed by land constraints resulting from a growing population with rising standards of living since the 16th century (Allen 2009). As the price of woodfuels rose in London, shipments down the East coast grew substantially throughout the 16th century. With rising incomes, as well as improvements in the grates and fireplaces necessary to burn coal in homes, demand grew rapidly (Fouquet 2008). From the 15th century to the end of the 17th century, the coal mining industry expanded from a niche business to the main generator of wealth in the North-East of England (Hatcher 1993). Despite only a few technical improvements in production methods, large and accessible reserves, a diversity of types and qualities of coal, a big labour force to draw from, and improving means of transportation enabled coal supply to expand in line with the growing demand (Church 1986). This ensured that real prices remained relatively stable from the 15th to the 19th century. The ability to meet highly elastic demands for energy-intensive products and energy services over hundreds of years was arguably Britain's source of ascendency (Allen 2009).

Thus, the Industrial Revolution in Britain was driven by coal. But Britain was not the only country with an ample and readily accessible supply of fossil fuels. What drove the rapid development and industrialisation in the UK was a political system limiting the absolute rule of monarchy with legally enshrined political rights, which allowed the free flow of ideas and the ownership of ideas. The search for profits and new markets drove the British development, and the development of new and flexible institutions propelled change and drove forward innovation. Although still influenced by powerful groups, successive British governments tended to be less directed by these vested interests than in other countries, particularly in policies related to industrial activities (Moe 2007).

4. Resource-based development; curse or blessing?

The UK story suggests that managing change is the key to economic success. However, shifting comparative advantages and climbing the economic value chain is harder when the bulk of an economy's production is already tied up in low-skilled, low-technology sectors extracting rent from selling natural resources. Since the Industrial Revolution, increasing economic dependence on natural resource exploitation as a source of income appears to often have been a hindrance to economic development in low- and mid-income countries in the world (Barbier 2005). There is considerable evidence for a negative relationship between GDP per-capita growth and measures of non-renewable natural capital – known as the 'resource curse' (Sachs and Warner (1995), Auty (2001)).[5] However, there are a number of conflicting forces influencing the likelihood of a 'resource curse'.

Badia-Miró et al. (2015) propose numerous factors that influence how resource availability might affect economic performance – either positively or negatively. The curse can manifest itself through changes in the productive structure of the economy, including the crowding out of more productive sectors and a less dynamically efficient allocation of factor endowments and institutions. On the other hand, resources can be a 'blessing'. In many situations, trade has developed as a means to generate wealth and economic growth from unexploited natural resources (Barbier 2005). The quality of institutions is seen as central to whether resource abundance has a positive or negative effect on economic performance.

For instance, Wright and Czelusta (2007) have shown how, in the US, resource and, in particular, coal abundance led to the establishment of a number of major educational institutions and knowledge for other sectors of the economy. Norway (Sanders and Sandvic 2015) and Botswana (Hillbom 2015) are other examples in which resource abundance led to favourable outcomes, in large part due to prudent state management. Indeed, natural resources have been a blessing when the increasing tax revenue following the associated booms has been used carefully (Badia-Miró and Duciong 2015).

However, there is ample historical evidence of the vulnerability of resource-based development (supported by theory – Lundahl 1998) – indeed, resource-based development is often likely to be successful initially but not in the long run (Badia-Miró et al. 2015). For instance, in the late 19th and early 20th centuries, a number of economies specialised in primary exports. During this period, global economic expansion led to a boom in the demand for primary products, and prices reflected this. As a consequence, resource-dependent economies grew considerably. However, these economies were vulnerable to economic contractions (as triggered by the First World War and later the Great Depression), as well as competition from new producers of natural resources and substitutions to alternatives stimulated by high prices.

These economies were highly vulnerable to the decline in international commodity prices relative to manufactured goods and the introduction of cheaper sources or substitutes. As Willebald et al put it,

This form of economic life, which is typical of 'new' economies, was able to offer high standards of living but only for as long as supplies and world demand remained dynamic. Declines in demand or increases in supply would have severe consequences for internal political economy, leaving it weakly positioned to react to the challenge of finding a new basic product to trade. These economies face the risks of the 'staple' trap . . . where the export orientation of some economies presents lock-in effects whereby the main primary specialisation blocks structural change and impedes economic growth.

(Willebald et al. 2015, pp. 10–11)

For instance, during the 19th century, the Amazonian region was one of the wealthiest parts of Brazil (Leff 1997), because it produced 90% of the world's rubber (Barham and Coomes 1994). Given the increasing value placed on rubber in the global economy, by the end of the century, international competitors (especially from today's Malaysia and Indonesia) began to enter the market, developing more intensive and cheaper methods of producing rubber. However, Amazonia failed to adapt to new market pressures or alter its production methods (Barham and Coomes 1994). Following the drop in demand associated with the

First World War, the Brazilian rubber industry never recovered. Thus, the whole Amazonian region, which was once the greatest source of wealth in the country, went into decline.

Similarly, Malaysia would eventually face declining demand for its rubber and needed to transform its economy to develop. In the 1920s and 1930s, it was the wealthiest economy in Asia due to its key role in rubber production. However, during the Second World War, the US managed to develop synthetic rubber, which captured close to 50% of the global market by 1960 and 70% of the market by 1980. While improving productivity, Malaysia could no longer rely on rubber revenue for economic growth and development. Instead, it diversified, becoming the world's leader in palm oil production, and, in the 1970s and 1980s, expanded its oil and natural gas industry. There were also developments in manufacturing, such as electronics and textiles (Drabble 2000). Despite modest growth in domestic rubber production until the mid-1970s, Malaysia would have experienced major economic decline without its structural transformation. Indeed, the important increases in GDP per capita occurred only after diversification.

Furthermore, in the late 19th and 20th centuries, numerous countries, such as Mexico, Venezuela, Chile, and Indonesia, failed to shift away from their specialisation in primary exports and manufacture.[6] Bertola (2015) shows how an economy can become unable to invest returns in more dynamic and productive sectors. In the long run, this inability led to stagnation and decline of these economies.

History teaches us that 'curses' and 'blessings' are constructions – they are the result of the socioeconomic system – . . . Thus, successful experiences of economic development in countries like Australia and Canada highlights the fact that institutions promoting interaction between enabling and receiving sectors are fundamental to science-based and innovation-driven growth in resource-based economies. It is crucial, therefore, to develop institutional structures to support knowledge capabilities in the growth of natural resource–based industries.

(Willebald et al. 2015, p. 24)

Asset diversification, it turns out, matters more to the success of an economy than output diversification and export diversification. The results mentioned suggest that what matters for development is not so much what a country makes at home and sells abroad but how it goes about making those goods and services. World Bank analysis shows a strong correlation between economic performance – measured as an index of productivity growth, job creation, and output stability – and a country's assets – measured as an index of natural resources, built capital, and public institutions (World Economic Forum 2017). Building strong public institutions at an early stage of development is particularly important. For example, Gelb (2010) argues that Algeria struggled to diversify away from oil-based activities due to a lack of rules-based institutions and a poor business environment. By contrast, Botswana's economy has performed well despite limited export diversification. He attributes this in part to the meritocratic government and strong institutions which governed the use of rents associated with diamond extraction. Chile provides a Latin American example of a country that successfully pursued asset diversification strategies in the 1980s.

5. Low-carbon transition risks stranding assets

The chapter now turns to the future, looking at the likely scale and impact of global decarbonisation and the mounting risks of asset stranding. The reason for this is that greenhouse gases (GHGs) stay in the atmosphere for tens and in some cases hundreds of years. Thus, it is the stock of GHGs that drives temperature change, not the annual flows or emissions. In other words, fossil carbon emissions have to be reduced to zero if global temperature is to be stabilised – no matter what the temperature at which we seek to stabilise (whether two degrees warmer or a disastrous six degrees). Climate modelling by the Intergovernmental Panel on Climate Change (IPCC) shows that to have a likely chance of holding warming to 2°C, carbon emissions must be cut to net zero by 2065–2085 (IPCC 2014).

This will require a fundamental structural transformation in all economies. Carbon from fossil fuels has powered most of the world's

economic activity for more than 200 years, since the use of coal to fire steam engines generated the Industrial Revolution. Oil, gas, and coal currently make up almost 80% of global primary energy use (International Energy Agency 2016). It is impossible to foresee every technology or process that will be involved in the future, but we are beginning to understand the outlines of how such a transformation might evolve.[7] Fossil fuels for energy will have to be more or less phased out (with some role for carbon capture and storage) and replaced by nuclear and renewable energy combined with electricity storage. In transport, this will mean almost complete electrification of vehicles and/or the widespread use of hydrogen fuel cells.

To accommodate much higher energy demand, the efficiency of energy consumption in all its uses will have to increase dramatically, which will require using digital and information technologies to manage energy demand in 'real time' and 'dematerialise' economic output. The design and functioning of cities as a whole will have to change very significantly. As Carlota Perez recently described, this is a technological revolution on a par with those which have disrupted and transformed economic systems in the past (Jacobs and Mazzucato 2016). In the same volume, Mariana Mazzucato showed that the direction of innovation is not pre-ordained. The challenge of shifting the fossil fuel–based infrastructure of present production and consumption to low-carbon forms will require strong government direction, what Mazzucato describes as "mission-oriented" policy.

To decarbonise, economies, nation states, and the private sector need to build new energy, transport, industrial, agricultural, and urban systems, which are likely to be more expensive in the short term. In doing so, they will inevitably cause current assets and activities based on fossil energy to decline in value and profitability. The likely resistance encountered shall be discussed in what follows. Because carbon is so central to the global economy it is a much larger task, involving a fundamental reshaping not just of individual technologies but of entire systems of production, distribution, and consumption. For this to be a practical reality, it is necessary to understand not just the latest technical innovations but the underlying drivers of innovation, not just in

technologies but in institutions and behaviours, and the role of path dependence in system transformation. To do this one must draw on the history of economic development and the dynamics of change in economic systems.

6. The low-carbon transition may reflect a gear change

History shows that innovation activity tends to be focussed towards the dominant technologies in which returns on incremental improvements are easily observed and understood. Acemoglu et al. (2012) provide empirical evidence both for geographical knowledge spillovers (a firm's decision to innovate in clean technologies is influenced by the presence of associated researchers and inventors in their local region) and for path dependence (firms tend to direct innovation towards what they are already good at – see also Aghion et al. 2011).

Nevertheless, disruptive innovation can manifest itself in tipping points where new networks rapidly displace old. There is a risk of a rapid process of decarbonisation being triggered by policies, technologies, or litigation generating a change in the demand and supply of goods and services and leading to a rapid revaluation of assets. The recent signing of the Paris Climate Accord can be seen as early evidence of such risks materialising as policy makers agree to national decarbonisation plans (many of these driven by an enhanced perception of national self-interest, for example from managing economic transitions, benefiting from associated gains in efficiency and reductions in air pollution, and opportunities in developing low-cost renewable technologies).

There is no way to estimate the optimal rate of asset stranding, but we know it is not zero. The future is unpredictable, and mistakes will inevitably be made when planning for decades ahead. Occasional redundancy has to be expected. Kielder Water (McCulloch 2006) in Northumberland, England, is the biggest manmade reservoir in Northern Europe. It was built in the 1970s on the expectation of ever-expanding industrial demand for water in the north of England. By the time it opened in 1982, the recession had markedly reduced the demand for

water, and permanent changes in the structure of the UK economy meant industrial demand never recovered. The reservoir was almost immediately stranded as an asset, but that does not mean it should not have been built. It's in the nature of infrastructure projects that some forecasts will be wrong.

Yet some stranding is predictable, when it comes to technological transitions, and can be guarded against. It is increasingly clear that only a small proportion of existing fossil fuel reserves can be commercially exploited if global climate goals are to be realised. A paper published in Nature shows that a third of global oil reserves, half of gas reserves, and more than 80% of current coal reserves should remain in the ground from 2010 to 2050 (McGlade and Ekins 2015). Carbon-intensive infrastructure also risks being stranded. Pfeiffer et al. (2016) analyse concentrations of greenhouse gases in the atmosphere and conclude that in order to meet the two-degree target (with 50% probability) no new emitting-electricity infrastructure can be built after 2017, unless other electricity infrastructure is retired early or retrofitted with carbon capture technologies. This highlights the gap between what politicians have signed up to in Paris and what markets and fossil fuel companies are assuming. This gap should alarm policy makers and central bankers: it suggests either asymmetric information or a lack of credibility in policies.

The speed at which such re-pricing occurs is uncertain and could be decisive for economic and financial stability. If the transition is orderly then financial markets will likely cope. But as Bank of England governor Mark Carney recently noted "there have already been a few high profile examples of jump-to-distress pricing because of shifts in environmental policy or performance" (Bank of England 2015). Moreover, it is clear that the risks of a transition to a low-carbon economy co-vary and indeed are mutually reinforcing. Most obviously, a focused policy effort can lead to enhanced deployment of new technologies whose costs would be expected to come down as a result.

The potential for unit costs to fall as new technologies are developed and benefit from learning and experience, and as engineers learn how to cheaply install, connect, and repair technology, is higher for many new technologies than for long-established incumbents. This has already

allowed solar photovoltaic and onshore wind technologies to become competitive with gas and coal in a number of global locations, even without a strong carbon price. As planning guidelines are updated and new networks are built, and especially if consumers change behaviour and demand support for resource efficiency, recycling and pedestrianisation, then it is possible that the costs of new energy systems will fall further, closing the gaps with conventional energy sources.[8]

Strong policy can set in train a new positive dynamic. For example, the EU in 2008 required all member states to adopt renewable energy targets, amounting to 20% of primary energy demand by 2020. German subsidies were required for the installation of photovoltaic (PV) solar power, initially at very high cost, in the early 1990s. But as demand rose, prices fell, and incentives were created for further technical innovation in addition to 'learning by doing' as new firms entered the market. Mass manufacture – in China as well as Europe – pushed costs down further, leading to higher global demand. The result was a 90% reduction in the cost of PV modules in just six years from 2009 to 2015. Installed solar power is now at cost parity with fossil fuels in many parts of the world and close to it even in parts of northern Europe. Consumer behaviour has correspondingly changed, with solar power now a relatively normal household investment. Having attained such momentum, PV subsidies have radically declined and are on their way to being unnecessary.

Lower technology costs in turn make the application of decarbonisation policies more politically and economically palatable. New lobbies for climate policy among both businesses and consumers have been created. Positive feedback loops in the innovation chain interact across the economy, prompting institutional and behavioural change and the emergence of new scale economies. The trigger could come from climate policies or from a breakthrough technology (such as cheap and effective energy storage) or something else; the point being that policies, institutions, and technologies reinforce each other in a positive feedback that leads to rapid step-changes.

Conceptually, a variety of studies have identified that innovation and deployment of new technologies at times of structural change is 'path dependent'.[9] This means that at first, innovation and research tend to

focus on further improving technologies and networks that are already established. However, if change is pushed, say, by technological breakthroughs (the shift from horses to combustion engines, canals to railways, kerosene to electricity) or credible and deliberate mission-orientated policy, feedback loops in the innovation process interact across the economy, prompting institutional and behavioural change and the possible emergence of new scale economies (Aghion et al. 2014). If few people own electric cars, charging stations will be rare and few will want to buy electric cars. But if most cars are electric, petrol stations will be rare and few will want to buy petrol-fuel cars. This is the network effect.

Tipping dynamics further result from the fact that the perceived payoff to action to decarbonise by any single agent will be a function of what others are expected to do. Once a critical mass of players shifts, for example in markets such as China, the US, and the EU, the rest will quickly follow. The US–China agreement to reduce emissions signed by Xi Jinping and Barack Obama in 2014 paved the way for a successful international agreement at the Paris Accord the following year.[10] Technology and finance costs are expected to fall, while markets are expected to grow. This is why such risks are often termed 'transition risks,' which is intended to portray a sense of the dynamic process in which paths become reinforcing.

However, the alignment or anchoring of expectations on the likely shape of future energy networks and innovations can lead to a 'tipping point' where the nature and direction of mainstream innovation activity can switch quickly. This becomes self-reinforcing through new network effects: so long as one network technology is dominant, products and services linked to the use of that network will receive the bulk of innovation activity, and there will be less effort committed to developing an alternative; but if a new technology network becomes dominant, then innovation activity can shift quickly. The recent rapid development of energy storage technologies in the wake of the growth of renewables – storage being a principal means to cope with the intermittency of solar and wind power – provides a powerful example. This revolution has only just begun and has yet to play out.

The gains from disruptive innovation can be widespread and extend beyond the sector in question. A striking finding of recent research is that the potential spillovers from low-carbon innovation to other sectors – one of the factors which help to drive overall growth – may be higher than for other technologies.[11] Using data on 1 million patents and 3 million citations, Dechezleprêtre et al. suggest that spillovers from low-carbon innovation in the energy production and transportation sectors are more than 40% greater than in conventional technologies (Dechezleprêtre et al. 2013) At the same time Acemoglu et al. provide a powerful theoretical case to suggest that once systems of clean innovation have been switched on, they may be more productive than conventional alternatives based on existing technologies (Acemoglu et al. 2012).

The point here is not that such tipping dynamics are about to happen, they might or might not. But if they do, change could be rapid. This provides an accelerated risk of asset stranding in a range of assets from infrastructure to human skills, knowledge capital, and institutions. Investors will rightly demand that firms make appropriate contingency plans for such potential rapid changes, even if such changes remain one scenario among many. Put another way, it is becoming increasingly risky to pin all strategies on the assumption that extensive decarbonisation will not happen, for example, on the basis of (mostly backward-looking) lack of political will.

7. Social norms – another tipping point?

Tipping points apply to social norms as much as to institutions and technologies, and these are already forming a key part of the propagating dynamics. Formal institutions struggle to enforce collectively desirable outcomes without popular support. Social norms are defined as the predominant behaviour within a society, supported by a shared understanding of acceptable actions and sustained through social interactions (Ostrom 2000). Social feedbacks help make norms self-reinforcing and therefore stable, but when norms change, that can happen abruptly.

Permitting slavery, denying voting rights to women, mining asbestos, smoking in public places, not wearing seatbelts, and driving after consuming alcohol were all once considered normal practices. Today, robust global moral norms socially condition many states and their citizens to see these practices as morally wrong and to regulate them accordingly.[12] Policy can modify prevalent self-reinforcing feedbacks. For example, regulations, taxes, subsidies, or infrastructure investment such as cycle lanes or dense housing and public transport can aid the process of shifting norms. When people prefer to behave like others, changed expectations can abruptly change behaviour. Thus a potential powerful role for policy is to provide reasons for people to change their expectations and behaviours (Young 2015).

Emitting carbon with full knowledge of the damage it causes is increasingly seen in the same light (Green forthcoming). This applies in particular to fossil fuels (especially coal and unconventional oil and gas) and/or particular activities in fossil fuel supply chains (especially investment, production, and large-scale consumption, for example in coal-fired power stations). The concept of 'unburnable carbon'[13] has become widely acknowledged along with civil society actions targeting the exploitation of new fossil fuel deposits.[14] The concept of fossil fuel divestment aimed at major institutional investors has also garnered traction.[15]

Anti–fossil fuel norms are already concentrating moral pressure on the largest culprits of climate change (Collier and Venables 2015). Following pressure by the Obama administration, 34 member states of the OECD agreed to end state subsidies for financing the export of technologies to build coal-fired power plants.[16] Following pressure from divestment campaigners, the Norwegian Parliament voted to require Norway's sovereign wealth fund to divest from coal companies (defined as companies that generate more than 30% of their revenue from coal – Carrington 2016). The leaders of 14 Pacific Island countries agreed in July 2016 to consider a proposed Pacific Climate Treaty, which would ban new coal mines, the expansion of existing coal mines, and the provision of fossil fuel production and consumption subsidies (Slezak 2016). In 2016, the United States imposed a three-year moratorium on the allocation of

new coal mining leases on federal land, and the Chinese central government also imposed three-year moratoria on new coal mines and coal-fired power stations.

These actions suggest that we are in fact already starting to see the emergence of an anti-coal norm in the international community. The implementation of norms is likely to be influenced by the ease with which norm-compliance can be monitored by third parties, since third-party verification makes it harder for responsibilities to be sidestepped (Bell et al. 2012). Effective disclosure of carbon emissions at the company and public jurisdiction levels (cities, countries, and regions) is vital. Actual or expected changes in policy, technology, and physical risks – as well as the threat of litigation – could prompt a rapid reassessment of the value of a large range of assets as changing costs and opportunities become apparent (Stern and Zenghelis 2016). This enhances the risk of early yet avoidable financial loss and the locking in to stranded assets.

The presence of low-cost alternatives to emitting greenhouse gases is facilitating the spread of changing social norms and forms another part of the feedback mechanism that could yield a rapid transition. The availability of low-cost solar PV and wind power has enabled anti-coal campaigns to point to economically affordable – often superior – energy alternatives. Normative political interventions affect institutions, interests, power relations, capabilities, identities, and ideas.[17] Even legalised global norms are reliant on states implementing them 'voluntarily,' the likelihood of which increases with pressure from civil society and from other states (Dai 2010). This virtuous spiral helped form the basis of the Paris Agreement.

8. Inertia, politics, and resistance to change

History suggests that if an alternative technology is superior, players will tend to move towards the new technologies and new networks as the comparative advantages shift (Fouquet 2010). But the costs of shifting from an existing network can also delay transitions for some time. For

example, some countries may continue to commit to fossil fuel infrastructure while others move entirely to renewables.

Many incumbent producers, investors, workers, and institutions have strong incentives to impart inertia on the system to preserve markets and influence. There is a wide range of historical examples in which the success or failure of overcoming vested interests has proved crucial to facilitating appropriate asset-allocation decisions. For example, the Ottoman Empire banned the use of the printing press in part for fear of loss of control (partly having observed its effects in Europe – Hippe 2015). In contrast, European cities in which printing presses were used grew 60% faster than those without presses between 1500 and 1600 (Dittmar 2011).

The success story of the UK in the Industrial Revolution also reflected economic and institutional flexibility. In 1774, the British government's ability to overcome pressures from the textile industry and repeal the protectionist Calico Act spurred the mechanisation of the cotton industry, which kick-started the First Industrial Revolution (Broadberry and Gupta 2009). In 1846, the British government's repeal of the Corn Law and abolishment of tariffs on many manufacturing goods, which land owners had blocked for decades, ushered in a new era of free trade and the first wave of globalization (Chang 2002).

Similarly, land owners lobbied in many European countries for keeping the status quo and against growth-inducing policies, in particular the provision of mass education, which they considered a threat.[18] The successful lobbying for protection of the landed elites to deter industrialisation has also been considered as an important factor in explaining the lower economic performance of Argentina vis-à-vis Canada in the 20th century (Adamopoulos 2008).

Mancur Olson (1983) and more recently Acemoglu and Robinson (2012) have stressed the importance of powerful extractive or rent-seeking institutions. They have argued that vested interests limited the potential for economies to transform and are a likely source of stagnation. During the status quo, they are in a position of primacy. Change, especially structural change, may put their position of power in jeopardy. Thus, one

could propose that incumbents tend to impose (for want of a better word) a 'dynamic' externality upon the economy – equivalent to the divergence between the actual and potential levels of economic development (for the duration of the divergence). For example, Moe (2007) explored the role of governments in influencing long run economic performance since the Industrial Revolution. Looking at Britain, France, Germany, the United States, and Japan, he found that the most successful economies had governments that did not prioritise excessively the demands of powerful incumbent interest groups.

Other economies, such as the Northern and Central Italian States, Flanders, and Holland (as well as Spain and Portugal), failed to build on their early successes and transform their economies. The relatively modest periods of growth from the mid-14th century and from the mid-15th century in England were associated with the growth of the raw wool trade and then the woollen cloth trade. In a sense, the woollen cloth manufacturers were allowed to grow and gain power from the raw wool industry, possibly because it also could benefit the incumbents, the raw wool business. Then, in the 17th century, England experienced a more substantial period of growth and structural change. The change may well have been, in part, stimulated by the Tudor government's Big Push, identified by Joan Thirsk (1976), in which the government coordinated the expansion of a number of industries simultaneously to generate the increase in aggregate demand necessary to ensure a market for the higher industrial production and create synergies between industries. In the 18th century, woollen cloth manufacturers sought to protect their market share of the textile industry from Indian cotton through protectionism, and instead created an even more powerful competitor, the Lancashire cotton mills. So the history of English economic development shows how vested interests at times were open to change and at other times were not (although the incumbent may not necessarily manage to impose permanent 'dynamic' externalities).

Another example is Britain's ban on slave trading in 1807 (slavery, however, continued to exist throughout the British Empire until the 1830s). The eventual end to slavery did not mean that owners had to bear the entire financial cost of emancipation, as the British government paid

compensation to slave owners. As Draper (2007) outlines, the compensation scheme and thus a financial incentive was key to ending the system of slavery. The Slavery Abolition Act in 1833 set up a total of £20 million for 'slave property' in the colonies, which was close to 10% of British government expenditure (Draper 2007, p. 79). In addition, former slaves had to work unpaid for an 'apprenticeship' period of several years at their former owner's plant. In other words, this period was also intended to provide some necessary education and skills to 'cope' with the subsequent freedom. Overall, while government policy was successful, it was a costly financial burden for the state.

The history of the slave trade also shows us that bans in particular countries tend to lead to initially reduced demand and supply. However, other markets emerge. While prices for slaves significantly fell in British-dominated West Africa due to depleted demand after the 1807 ban, prices in other African areas such as Portuguese-controlled Angola remained stable and even increased over time (Fenske and Kala 2014; Richardson 1995). Thus, for several decades, the total slave trade was higher after 1807 than before (see Figure 2.3). Indeed, the Portuguese took up much of the slack, and the Spanish, who did not trade slaves before, became major traders afterwards. However, as Acemoglu, Johnson, and Robinson's (Acemoglu et al. 2002) study suggests, this did not imply that those economies did better. In fact, they find that those that were stuck in an old paradigm were going to experience a reversal of fortunes.

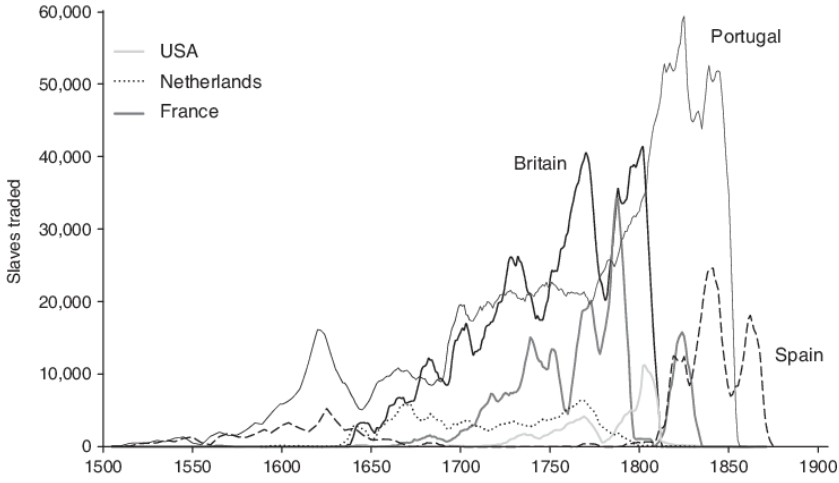

Figure 2.3 Number of slaves traded by selected countries, 1500–1900

Source: Emory University. *10-year average.

The history of container shipping offers additional aspects on the impact of new technologies on local, regional, and national competitiveness. The ports of New York and London both struggled to respond to the new technology in the 1950s and 1960s and ultimately met with decline (Levinson 2006). In this example, resistance to change also meant wasted sunk investments, which could have been spent in managing the structural change and providing opportunities for other industries. This fact highlights the importance of comprehending the fundamentals underlying changing economic conditions, which is not an easy task, but long-term analysis may offer some clues. The success of newly emerging technologies and more efficient industries shows the need for sufficiently flexible regulation. It also highlights that major investments in new infrastructure for a novel technology – constructing specialized ports (and railways) for containers – can pay off in the medium and long run.

Political risk will apply more to the losses of incumbents than to the equally valuable opportunities of new entrants. This is because, in any representative political system, the losers will be more effective at lobbying politicians than potential winners (Baldwin and Robert-Nicoud

2007). From the perspective of overall economic and financial risks, winners and losers should be treated equally, with the valuation of new sectors exploiting opportunities offsetting the decline in value of less productive and slow-growing sectors. This crucial political economy aspect will be revisited in the sections on institutions and policies.

Incumbents often claim, in particular, that stronger climate policy will put them at a competitive disadvantage relative to those in other countries or even cause them to relocate elsewhere: the result, it is argued, will be the transfer ('leakage') of emissions from the more strongly regulated economy to the weaker one, with no net reduction in total. But the evidence does not support these fears. Recent studies of European climate policy, particularly of the EU emissions trading system, suggest that the impacts have thus far been small, whether in terms of carbon leakage, economic growth, employment, or consumer prices, with only a few energy-intensive sectors (such as steel and cement) at risk of significant adverse effects even if policy is strengthened (Bassi and Zenghelis 2014). Policy makers should largely resist giving in to incumbent lobbies.

Indeed, this is not just a problem of distribution between winners and losers. Even those who perceive themselves as losers may in fact be acting against their own interests by opposing or delaying change. Policies and regulations which affected firms complain will damage them can turn out to incentivise innovation once implemented (Combes and Zenghelis 2014). For example, EU fuel efficiency targets for cars helped induce technological improvements which have improved the global competitiveness of European cars. In 2009 the EU introduced a fleet average target of 130 g/km by 2015. This was widely opposed by the motor industry, but it was met two years early. In the US, by contrast, car- and consumer-industry pressures kept gasoline taxation low such that improvements in fuel efficiency have been slower. As a consequence, the US car industry was much less prepared for higher oil prices and the global financial crisis, an important but largely unheralded factor in the bankruptcies of Chrysler and General Motors in 2009 (Bassi and Zenghelis 2014).

Perhaps the single most important feature of climate policy is consistency. Switching to lower-carbon forms of production requires investment in heavily regulated markets; but investment and finance requires confidence on the part of businesses and investors that the policy framework will be implemented and sustained (Romani et al. 2011). There is now considerable evidence that environmental policy uncertainty is associated with negative effects at both firm level, in terms of lower investment and hiring, and country level in terms of lost GDP and unemployment (Baker et al. 2012). Maintaining credible and consistent policy signals over time maximises the cost effectiveness of decarbonisation.

Credibly steering expectations is key to a cost-effective transition. No player wants to move early into new technologies when they are expensive, subject to expensive niche financing, and the market has yet to evolve, let alone mature. Risks are high and profitable opportunities few. But if whole markets are expected to move at scale, then technology and financing costs will be expected to fall and profits rise. Investment will breed investment and expectations will become self-fulfilling. A virtuous circle is therefore possible; but it requires policy makers to set clear goals and to hold their nerve when temporary political resistance is encountered. Changing policy too late and in response to events only increases risk and raises costs. A leading economic historian concludes,

What matters is the state[’s . . .] ability to and willingness to pursue policies of structural change. And hence, what matters is whether or not the state is in possession of sufficient political consensus and social cohesion for political elites to be able to go against powerful vested interests resisting change.

(Moe 2007, p. 268)

Rapid decarbonisation also generates negative economic feedback effects which serve to slow down adjustment. Lower demand for fossil fuels reduces the price, making burning these fuels more attractive in countries which have not invested in alternatives. The knowledge that fossil fuels may not be burnt also provides incentives to owners of reserves to pump as much out and sell it as quickly as they can, before

the stocks become stranded as policies tighten and alternative technologies become competitive (the so-called green paradox – Sinn 2008). There is the further risk that the kind of normative interventions outlined in the previous section might stigmatise fossil fuels and alienate some of the constituencies (e.g. workers, unions, communities in fossil fuel–dependent regions). These groups will need to be brought 'onside' in order to deliver an effective and just transition away from fossil fuels.

A current example of the difficulty in overcoming such lock-in is the challenge of developing electric vehicle infrastructure (Eberle and Von Helmolt 2010). For electric vehicle infrastructure to become established, the incentives to conduct research and development on electric cars must increase substantially relative to fuel cell or combustion engine vehicles. Since the Industrial Revolution, firms have been routinely exploiting path dependence in technology adoption and network effects in order to diffuse their innovations and create new markets (Bessen 2014). For instance, realising that fossil-driven networks are hard to dislodge, in June 2014 Tesla Motors announced they would make their electric vehicle patents public. Toyota followed. Urban development provides another example of how feedback loops can interact. For example, dense urban development based on public transport will breed political support for pedestrianisation, congestion charging, cycle lanes, and investment in public transport.

9. Institutions make the difference

Adaptable institutions can ease a shift in economic activity in a country following the onset of a global transformation by applying necessary changes to regulatory frameworks and the rule of law and provision of sound competition policy. The World Bank defines institutions as "the mechanisms to manage resource rents, administer social services, and regulate economic production" (Gill et al. 2014, p. 9) and identifies that the strengths or weaknesses of these mechanisms are crucial for long-term economic performance. This is because high-quality institutions are crucial for making the right decisions over the quantity and mix of assets in which the economy invests. Indeed, institutions themselves can be

thought of as assets: their development requires policy makers to devote time and monetary resources to ensure that these rules and mechanisms exist and are adhered to, but with the pay-off from this effort primarily seen in the future. The UN's Sustainable Development Goals recognise the role of strong institutions in countries across the world, calling for 'effective, accountable and inclusive institutions at all levels' by 2030 (United Nations 2015).

Strong institutions can help to overcome opposition to structural change. Vested interests are less likely to emerge and block structural change when competition between firms and technologies is promoted. For instance, Crafts (2012) argues that England only lost its economic and technological leadership when it failed to enforce its competition policies, leading to the formation of cartels and low rates of competition. Another example is gas market liberalisation. While the advent of shale gas in the US, a highly disruptive energy technology, can be attributed to a number of factors, it is notable that in the last decades of the 20th century, the US actively regulated and promoted competition in a market that is often characterised by the existence of natural monopolies. This led to a wide variety of smaller and larger companies and competitive markets. By contrast, in the EU, despite regulatory rules by the European Commission, the gas sector is dominated by large and integrated 'national champions' with wide political influence.

10. Inertia or tipping point – what next for the low-carbon economy?

Recent decades have witnessed much inertia and resistance to the transition to a low-carbon economy, along familiar historical lines. But a pertinent question is whether the global economy is about to reach or already has reached a tipping point. The costs of key low-carbon technologies have been falling sharply. Meanwhile, the impact of policy action on the behaviour of producers and consumers is likely to grow, with incentives to develop and scale up low-carbon technologies increasing. As the United Nations Framework Convention on Climate Change (UNFCCC) negotiations are advancing, climate policies are being

enacted at an accelerating pace. Forty countries and 24 sub-national regions covering 13% of global GHG emissions have adopted or are planning to adopt carbon pricing (World Bank 2016). In the 2016 Global Climate Legislation Study, 850 pieces of national legislation relevant for climate change were analysed across 99 countries (both developing and developed) which, taken together, account for 93% of global emissions. According to the study, the number of climate laws has approximately doubled every four to five years: there were 50 in 1997 (at the time of the Kyoto agreement) and 400 in 2009 (at the time of the Copenhagen Accord) and more than 800 in 2016 (Nachmany et al. 2015).

This includes action by some of the largest economies. For example, China embraced high-technology, low-carbon growth in its outline for the 12th five-year plan which sets strong targets, identifying seven 'Magic Growth sectors' of which three are low-carbon industries: clean energy, energy efficiency, and clean-energy vehicles. Germany, Europe's leading economy, is set on a path to zero net carbon by mid-century. Global cities are actively adopting decarbonisation plans of their own, through organisations such as the C40. Norway's Sovereign Wealth Fund has recently declared its intention to entirely divest coal, while divestment of US coal also gathers pace (Grunwald 2015). Share prices of heavily fossil fuel–dependent sectors have lagged the S&P500 average, while sustainable companies have outperformed their peers by 9.1% over the past four years (New Climate Economy 2015). The evidence suggests the prospect of a rapidly propagating tipping set to a low-carbon economy cannot be dismissed, and those that place their bets on a linear and steady transformation or no transformation at all potentially stand to lose.

11. Managing country risks and opportunities

A low-carbon transition puts the business models of different countries, sectors, and regions at risk and threatens the value they generate as new technologies and networks undercut incumbents. Across the globe, primary energy exporters are concerned that their major export markets will curb consumption of carbon-based fuels. Other countries with

carbon-intensive assets in energy generation and industry worry that revenues of these sectors may suffer if importers decide to impose some border tax adjustments related to the carbon content of manufacturing products. There is the prospect of a permanent loss of demand for fossil fuels or carbon-intensive goods and services. This can have an impact at the national level. It can lead to a loss of production and fiscal challenges as existing spending programs are increasingly difficult to finance and require a rapid reorganisation of physical and human capital. The future of climate policies and disruptive technology and social transformations is therefore characterised by deep uncertainty.

Coal is already undergoing substantial transition, while the low-carbon transition has the potential to put intense pressure on oil and gas markets. The IEA expects oil demand to contract by 21% in 2040 relative to current levels in the 450 scenario but gas demand to increase by 28% (International Energy Agency 2016), but a more rapid transition cannot be ruled out. Refineries, steel, cement, chemicals, and other high-carbon sectors are also at risk if they do not adjust their business models.

Firms that are fixed in their processes and seek to repeat a former recipe for success that no longer works are less likely to endure (Van Rooij 2014). For example, the brewing industry in Britain experienced a rapid boom in the last 20 years of the 19th century. Companies boosted by new developments in stock markets raised large amounts of capital and invested heavily in expected future revenue associated with continued rising demand. However, many companies failed to anticipate the slow-down in demand at the turn of the century and the emergence of the temperance movement as a reaction against the social impacts of this earlier growth, which led to a decline in consumption. Many companies, heavily indebted, went bankrupt only a couple of decades after a period of record growth (Acheson et al. 2016).

The ability to anticipate changes in market dynamics and adapt to the new circumstances is critical. European luxury industries, such as fashion and watchmakers, faced major contractions in the 1970s but instead underwent dramatic structural transformations which enabled them to enter the Japanese markets in the 1980s and 1990s and then Chinese markets from the beginning of the 21st century (Donzé and Fujioka 2015).

Similarly, recent experiences in the paper and pulp industry reflect the influence of corporate governance and long-term strategies in its ability to transform, particularly related to adapting production to new social and environmental demands. While the US paper and pulp companies were technologically locked in, Swedish firms took a more proactive approach to environmental research and development (R&D) and collaborative relationship with national policy makers associated with developing integrated abatement technology. Today, Swedish firms are technological leaders in the industry (Bergquist and Söderholm 2015). The ability to change and transform is a typical feature of the world's longest-surviving companies (Napolitano et al. 2015).

As with all structural transformations, the implications from any transition to a low-carbon future are impossible to fully predict. Fundamental uncertainties persist in relation to the speed of the transition, the technologies that will emerge, which countries are best able to harness those technologies, and how effectively any declining industries can be managed. Nonetheless, it is possible to identify characteristics that would make some countries more vulnerable to the challenges of the global low-carbon transition than others.

One way to do this is to look at countries' exposure and resilience to these shocks. Exposure indicates the share of the current activities of a country's economy that might be threatened by external climate policy or technology shocks. It represents the likely direct impact associated with low-carbon transition. A second criterion is resilience/flexibility. This captures how well positioned an economy is to respond to the threats posed by external climate policy and technology shocks. It describes its capacity to adjust to the risks and challenges associated with structural transformation. A country may be able to avert the potential negative impacts of structural change and realise the potential upsides if it is well positioned to adapt its economy in response to that shock.

The two are linked. Countries with a diverse structure to their economy dependent on a variety of sectors, together with a well-balanced and developed economic asset portfolio, tend to be better able to adapt to a new state of the world by generating new productive knowledge. This productive knowledge expresses itself in innovation and new capabilities

to produce and export goods and services. A country will be able to re-allocate factor resources and may discover new comparative advantages, enabling further economic growth and development. Within the asset portfolio, a number of key elements have a particularly strong influence on the capacity of an economy to develop in accordance with its comparative advantage – and, as such, its economic resilience (Lin 2012) – such as macroeconomic stability without external account problems, fiscal deficits, debt burdens, and financial fragility accumulate (IMF 2015). Countries must provide a set of appropriate conditions for technology transfer so that they can continuously upgrade their industry–technology structure and be open to international trade.

Economic diversification and flexibility will work in the interests of making any country resilient to change. However, climate change brings an additional layer of challenges to carbon-intensive countries, heavily dependent on the exports of fossil fuels and carbon-intensive goods and services. In many cases, they have faced challenges of using the resource rents smartly to diversify their products and exports. International efforts to reduce greenhouse gas emissions, amplified by disruptive technological changes, can trigger significant shifts in demand for fossil fuels and carbon-intensive commodities facilitating deep economic transformations. Unlike many cyclical economic shocks, such low-carbon transition impacts may be large scale, structural, and permanent.

The World Bank (Peszko et al. forthcoming) will use these criteria to identify the most vulnerable countries and suggest policies. A number of countries such as Venezuela, Russia, and Iran remain very vulnerable by these criteria. These countries may face a loss of production and export revenues, leading to fiscal challenges with access to external finance constrained. As a consequence, domestic poverty and inequality may increase, as the rich will be better able to adapt to new shocks, for example by transferring their accumulated wealth abroad. In addition, such countries may be challenged by political turmoil, conflicts, and migration, which will generate international contagion effects.

The clear and unambiguous lesson from history is that there always has been and will continue to be change. Indeed, the world economy appears to follow the dynamics of creative destruction that Joseph Schumpeter

proposed (Klimek et al. 2012). The ability to change and transform is a typical feature of long-surviving firms (Napolitano et al. 2015). Conversely, companies that are fixed in their processes and try to repeat former recipes for success are less likely to endure (Van Rooij 2014). Critical is the ability to anticipate changes in market dynamics. This ability to adjust is also crucial at a regional and national level. In the late 19th century, substantial differences in their per-capita income existed between the states in the US, but, by the late 20th century, they had largely vanished. The ability to catch up with leading states was based on the ability to transform the structure of the economy (Caselli and Coleman 2001). Ultimately, economies manage to grow and develop by upgrading the products they produce and export. "It is quite difficult for production to shift to [radically different] products . . . and therefore policies to promote large jumps are more challenging. Yet it is precisely these long jumps that generate subsequent structural transformation, convergence, and growth" (Hidalgo et al. 2007, p. 487).

Transformations will occur in all sectors and industries, including revolutions in the energy systems (Fouquet 2008). For policy makers, the task is to identify the likely direction and nature of changes and align policies with them (or at least not in opposition to them). Ultimately, declining demand for a resource implies that all the producers and suppliers are competing for a shrinking market. Prices will fall, which will help keep some of the buoyancy in the demand, but wherever possible, consumers will be shifting to ever-cheaper renewable energy sources. The implication of declining prices for producers and suppliers is declining revenue. Thus, only the most efficient and competitive fossil fuel opportunities will survive.

Fossil fuel–rich economies should see climate change as a blessing in disguise. Economies that have benefitted from natural resources need to see them as opportunities for transformation. Over-reliance on a single industry is a very unstable form of economic development. Climate change should act as a warning or a reminder that (i) they should not depend excessively on their fossil fuels and (ii) they should be using rents carefully to invest in the expansion of new skills, technologies, infrastructure, and industries.

12. Conclusion and policy recommendations

The transition to a low-carbon economy associated with falling technology and network costs and ambitious policy support could be rapid when it comes. This is especially true in heavily regulated policy-driven sector networks, such as energy and transport, where reinforcing mechanisms can rapidly bring about change. This enhances the risk of locking into and eventually stranding assets. Some countries are vulnerable because the structure of their economies is reliant on the extraction of high-carbon commodities or production activities requiring their use, others because of the inflexibility and vulnerability of their institutional structures.

The historical evidence suggests a general approach to economic policy that encourages flexibility is important to economic resilience and development. Open trade, good governance, competition, and well-regulated labour markets facilitate the flow of resources from declining, high-carbon sectors to growing and more productive low-carbon activities more easily. The biggest risk to economic flexibility tends to be vested interests capturing institutions and generating economic inertia. Strong and credible policies backed by public support are often prerequisites to overcoming such obstacles. This in turn requires a common understanding of the opportunities associated with a transition and a recognition of where action is in the self-interest of individuals. History suggests the following key policies are requirements for economic resilience in the face of change, lowering the risks associated with asset stranding:

1 **Openness to international markets makes a country more sensitive to global transformational change through export sensitivity to shifts in demand for its products and services.** However, it also facilitates structural economic change through the diffusion of technology embedded in imports. Despite being politically contentious, this ultimately renders a country's industry more competitive. Increased trade in accordance with an economy's comparative advantage is therefore conducive to

growth, development, and poverty reduction. However, as many countries still have distortive policies in place, trade liberalisation often needs to be managed carefully to avoid adverse effects on certain actors in the economy.

2 **Policies to promote both the quantity and quality of human capital are strongly linked to economic growth and development.** Education is a core component of a human resource development strategy, but it also encompasses policies for promoting skill formation and retraining across age groups. Flexible institutions allow the government and the private sector to work closely together to anticipate or respond to the skills needs in the labour market.

3 **Productive, low-carbon infrastructure is key to economic resilience.** Poor infrastructure including roads, ports, and utilities can be a major impediment to business success, while efficient infrastructure which is resilient to the low-carbon transition can facilitate a business-led transition to new economic activity. Thinking ahead and locking into future-proof networks will allow an economy room to best manage a transition and limit the risk of asset stranding.

4 **Financial deepening is a key lubricant of any investment-led transition.** Previous empirical studies point to a causal relationship between financial deepening and economic growth. Lack of access to finance is a key constraint to capital accumulation, which is essential for building up new industries in response to shocks.

5 **Recognising and addressing distributional issues is crucial for political and economic traction.** Structural change has adverse effects on some industries, workers, and communities – notably those in high-carbon sectors such as coal, but also in production sectors such as steel, cement, and chemicals, which will need heavy investment to move towards lower-carbon production activities. Transitional support can enable investment through the reskilling and redeployment of labour to new sectors helping smooth the transformation process, both economically and politically.[19]

6 **Successful climate policy making requires a willingness to take on entrenched interests.** There is a well-established asymmetry in political economy which favours incumbents. Incumbents often claim, in particular, that stronger climate policy will put them at a competitive disadvantage relative to those in other countries, but the evidence in most cases does not support these fears. Policy makers should largely resist giving in to incumbent lobbies and spell out clearly the net costs and benefits to society.

7 **Policy must be believable and credible to lower risk premiums on low-carbon investment.** As noted, policy can modify or accelerate prevalent self-reinforcing feedback mechanisms and change expectations which drive transformation. Climate policy making is in this sense much to do with the creation and management of economic expectations through clear leadership. The greater the belief among economic actors that the world is shifting towards a low-carbon trajectory, the more likely it is to happen – and the more cost effective it will be. Anticipated returns to a business contemplating investment in, say, renewables or energy efficiency will depend on its expectations about how others are going to behave. If few others are expected to invest likewise, the markets will be smaller, the technologies more expensive, and the cost of capital higher.

8 **Support of innovation will be vital to maximise future economic returns.** The lesson for policy makers and economists here is an important one. The direction of innovation is not pre-ordained, and the challenge of shifting the fossil fuel–based infrastructure of present production and consumption to low-carbon forms will require strong government direction. In many cases this will need to overcome early high costs, which are likely to breed political resistance. But if a tipping point in investment and policy can be reached, feedback loops and network effects may kick in and accelerate the process of change, with positive spill-overs to the rest of the economy. The long-run costs may therefore be far less than some anticipate, and indeed negative. Learning the lessons from history and managing the transition could accelerate

growth, boost profits, and enhance well-being, leaving the world wealthier and more resilient than ever before.

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Notes

1 The views expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

2 Carus-Wilson, E. M. and Coleman, D. C. 1963. England's Export Trade, 1275–1547. Oxford: Oxford University Press.

3 Carus-Wilson, E. M. and Coleman, D. C. 1963. England's Export Trade, 1275–1547. Oxford: Oxford University Press.

4 Data is from Fouquet and Broadberry (2015). The original data sources are England: Broadberry et al. (2011, 2015); Holland: van Zanden and van Leeuwen (2012); Italy: Malanima (2011); Spain: Alvarez-Nogal and Prados de la Escosura (2013); Schön and Krantz (2012); Palma and Reis (2014).

5 See also Gylfason (2001).

6 See Badia-Miró and Ducoing (2015), Rubio-Varas (2015) and van der Eng (2015).

7 A useful account of some of the major transformations required can be found in Global Commission on the Economy and Climate. 2014. Better Growth, Better Climate. New Climate Economy. See also: World Energy Outlook Special Report 2015: Energy and Climate Change. International Energy Agency.

8 See, for example, Bloomberg New Energy Finance (BNEF). 2011. Onshore Wind Energy to Reach Parity With Fossil-Fuel Electricity by 2016. Press Release, November 10. [pdf] London: BNEF. Available at: www.bnef.com/Downloads/pressreleases/172/pdffile/ or European Photovoltaic Industry Association (EPIA). 2011. Solar Photovoltaics Competing in the Energy Sector – On the Road to Competitiveness. [pdf]. Brussels: EPIA. Available at: www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/publications/epia/Competing_Full_Report.pdf&t=1348056379&hash=e41a327fa13247bb3125bb2e79e41389

9 Seminal work includes Romer 1990; Aghion and Howitt 2009; Solow 1994; Krugman 1991; Matsuyama 1991.

10 See U.S.-China Joint Announcement on Climate Change 2014. The White House, Office of the Press Secretary https://obamawhitehouse.archives.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change

11 See Smulders 2005 and Popp 2002 which provides some evidence that these returns may be diminishing

12 At its most general, a norm can be defined as a standard of behaviour expected of an agent in a particular situation; see Finnemore, Martha and Sikkink, Kathryn. 1998. International Norm Dynamics and Political Change. International Organization, 52(4), 887–917.

13 See Carbon Tracker Initiative 2011, Griffin et al. 2015 and McGlade and Ekins 2015.

14 See Bradshaw 2015; Denniss 2015 and Hodges et al. 2016.

15 Accounts include Ansar, Atif et al. 2013; Apfel 2015; Ayling and Gunningham 2015; Grady-Benson and Sarathy 2015; Kiyar and Wittneben 2015; and Tollefson 2015.

16 An exception was made for so-called ultra super critical plants, but the OECD ban was estimated by the Obama administration to cover about 85% of coal power plants; see Sink, Justin and Nussbaum, Alex. 2015. In Coal Setback, Rich Nations Agree to End Export Credits. Bloomberg, November 18. Available at: www.bloomberg.com/news/articles/2015-11-18/in-latest-blow-to-coal-rich-nations-agree-to-end-export-credits.

17 For a discussion on “policy feedbacks” see Jordan et al. 2014; Lockwood 2013; Patashnik 2008; Pierson 1993 and Urpelainen 2013.

18 See Hippe 2015, Hippe and Baten 2018 and also Galor et al. 2009.

19 The concept of a ‘just transition’ has been used to promote policies designed to make decarbonisation more equitable for sectors and communities adversely affected.