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Low-carbon transition risks for finance[*]

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Abstract

The transition to a low-carbon economy will entail a large-scale structural change. Some industries will have to expand their relative economic weight, while other industries, especially those directly linked to fossil fuel production and consumption, will have to decline. Such a systemic shift may have major repercussions on the stability of financial systems, via abrupt asset revaluations, defaults on debt and the creation of bubbles. Studies on previous industrial transitions have shed light on the financial transition risks originating from rapidly rising 'sunrise' industries. In contrast, we argue here, based on a critical review of the literature, that a comprehensive theoretical framework to analyse how declining 'sunset' industries might affect financial stability in the current low-carbon transition, via stranded assets or otherwise, is still lacking. We contribute to filling this research gap by developing a consistent theoretical framework of the drivers, transmission channels and impacts of the phase-out of carbon-intensive industries on the financial system as well as its feedback into the rest of the economy.

Keywords: Transition risks, low-carbon economy, sunset industries, stranded assets, financial stability, structural change

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1. INTRODUCTION

Climate-change mitigation requires the rapid decarbonisation of the economy. Climate change is already threatening society through altered patterns of extreme weather events and impacts on critical ecosystems, and the best climate projections to date indicate that catastrophic impacts could arise in the near future from nonlinear effects leading to 'tipping-points' in the Earth system, such as the collapse of ice sheets or tropical rainforests (Lenton et al., 2008). The 2015 Paris agreement enshrines the need to avoid such consequences with a goal of stabilizing temperature increases well below 2°C above pre-industrial levels, with the aim of limiting negative climate change impacts at manageable levels, although substantial climate variability would still remain (Holden et al., 2018). To avoid warming of the global average temperature exceeding 1.5°C, evidence gathered by the Intergovernmental Panel on Climate Change suggests that decreasing net carbon emissions to zero by mid-century is likely to be necessary (IPCC, 2018). Consequently, governments and sub-national entities have started adopting laws requiring carbon neutrality by or before mid-century.

Decarbonising the economy quickly is not trivial. It will involve large-scale structural change, with some sectors having to rapidly expand their relative production/market shares, and others having to entirely transform their technological basis or, alternatively, shrink and potentially disappear. This last category of sectors comprises activities directly related to the extraction and distribution of fossil fuels, but also, and perhaps most importantly because it implicates a far larger proportion of the economy, sectors producing goods and services using fossil fuels as a crucial input in their production process. In some cases, such as power production, a low-carbon alternative is available that is increasingly competitive with the incumbent (Lazard, 2019). Increasing electrification of end-use technologies, such as passenger transport, also points towards promising paths for decarbonisation (IEA, 2019). But in other industries, such as steel or air travel, development is only at an early stage, and a significant proportion of firms still lack a strategic plan to face the low-carbon transition (Dietz et al., 2020).

A fast transformation of economic structure is likely to have significant financial impacts. A lively debate has been developing around the threats of a low-carbon transition for the stability of financial institutions, and for the financial system as a whole, with central banks occupying a prominent position. While there has been a rapid expansion of concepts and evidence concerning transition risks from academia, private industry and regulators (Bolton, Despres, Pereira Da Silva, Samama, & Svartzman, 2020; NGFS, 2019), a comprehensive theoretical framework linking the low-carbon structural change to financial dynamics is still missing. It is not yet clear what the risk drivers, sectoral origins and transmission channels will be, or how their effects will propagate to the wider macroeconomy.

The aim of this paper is to shed some light on how risks for financial stability relate to the transition's underlying structural change. First, we survey the literature for insights on the general links between structural change and finance. The low-carbon transition is certainly not the first systemic technological shift in recent history, and several authors have discussed the issue of how these paradigm shifts are linked to finance (Freeman & Louca, 2001; Perez, 1983; Schumpeter, 1939). We find that the overwhelming majority of this literature has focused on the financial risks stemming from the sunrise industries, i.e. the rising sectors, where bubbles could develop and then burst, with detrimental impacts on the rest of society.

Turning to the low-carbon transition, we notice how, contrary to this historical perspective, most of the current debate on transition-related financial risks focuses on the risks raised by sunset industries (carbon-intensive ones, in this case). For instance, a widespread preoccupation concerns the financial repercussions of asset stranding, i.e. the devaluation or write-off of assets from the balance sheets of economic agents (Caldecott, 2018; van der Ploeg & Rezai, 2019). We argue that this difference is likely because the transition has not yet advanced far enough for low-carbon investment opportunities to be able to stabilize the financial system, while climate-change mitigation policy remains focused on attempts to accelerate the phase-out of high carbon sectors. Be that as it may, the 'focus shift' between past literature on transitions and the current debate leaves us without a well-defined comprehensive framework to understand and address low-carbon transition financial risks.

To advance the debate and contribute to filling this conceptual gap, we develop a minimal but consistent framework of low-carbon risks for finance originating in sunset industries. We distinguish: i) drivers of transition risks; ii) the economic costs that the transition could impose on non-financial agents in terms of loss of income and asset stranding; iii) the impacts that these costs would create on financial institutions and financial stability, in terms of non-performing loans, loss in portfolio values and higher expenditures; and iv) the wider macroeconomic effects leading to a loss of aggregate demand and recession. Finally, we outline and comment on the current state of policies seeking to stabilize the financial system without interfering with the transition itself pursed by central banks and other actors in the fast-evolving policy community on climate-related financial risks.

The remainder of the article is organised as follows. Section 2 discusses the economic literature linking structural change, innovation and finance. Section 3 focuses on the ongoing debate around the risks of a low-carbon transition. Section 4 presents our conceptual framework on transition risks for finance originating in sunset industries. Section 5 discusses actual and possible policies aimed at mitigating transition risks. Section 6 concludes.

2. THREATS TO FINANCIAL STABILITY FROM THE RISE AND FALL OF INDUSTRIES

For the purposes of analysing transition risks to finance, we define the low-carbon transition as structural economic change: some parts of the economy grow and others decline in relative importance, as a result of deliberate policy, changing preferences and ongoing technological change.[1] To meet emissions-reduction targets, low-carbon sunrise industries must grow rapidly, while high-carbon sunset industries must decline rapidly. This process can precipitate and interact with other structural changes in the economy (Ciarli & Savona, 2019). Low-carbon transition risks for finance can then be defined as the threat to financial stability from this specific type of (rapid) structural change. For a conceptual

[1] Cherp et al. (2018) show that for other purposes adopting a more multi-disciplinary definition can be productive.

understanding of this process, we turn to the literatures on financial crises and on innovation as the process underlying structural change.

2.1 Finance and innovation: A neglected subfield

At the outset, it is important to note the relative conceptual neglect of the problem. Scholars studying financial crises rarely venture into the details of technological change, but focus on aggregate fluctuations. Kindleberger (1978), the classic reference on historical financial crises, eschews the details of the technical change that underlies several of his documented financial *manias*. The only technological change Reinhart and Rogoff (2009) refer to is the *financial* innovation of changing from coin to paper money. Similarly, innovation scholarship, which studies structural change due to technological and behavioural change, tends to omit systemic financial aspects; recent exceptions are Callegari (2018) and Geddes and Schmidt (2018). Even students of 'financing innovation' tend to adopt a microeconomic perspective on how market failures prevent a small set of innovative firms from getting enough funding (Hall & Lerner, 2010), but neglect innovation's interaction with financial stability. If anything, research in this area considers the opposite direction of causation, i.e. how the 2007-08 financial crisis and subsequent stimuli have affected innovation (Giebel & Kraft, 2019; Mundaca & Richter, 2015).

Multisectoral theories of technological change lie in the small intersection of both fields. Perhaps the oldest such programme of continued relevance is to be found in Marxist crisis theories (Basu, 2018), building on Karl Marx's unique attention to technology as explaining social change (Rosenberg, 1982). Marx's differentiation of the economy into sectors producing capital and consumption goods (departments 1 and 2) allows for both underconsumption (Sweezy, 1970) or over-investment (Brenner, 2006) to generate a crisis. But existing Marxist literature tends to disregard industries *within* departments: both low-carbon and high-carbon industries are subsumed in each department.

More recent real business cycle theory explains (negative) shocks through technological change also in multi-sectoral settings (Davis, 1987). But technology shocks are typically random, not linked to secularly declining or rising industries (Azariadis & Kaas, 2016). Moreover, integrating a meaningful financial sector into these models would require major changes to the theoretical framework (Stiglitz, 2014). The only theoretical framework placing the interaction of finance and structural change front and centre appears to be the Schumpeterian one.[2]

2.2 The Schumpeterian perspective

In the Schumpeterian theory of the business cycle, innovative agents (entrepreneurs) create new clusters of vastly more productive technologies, collectively cause socio-technical transitions, and generate structural change through 'creative destruction' of less competitive products and industries.[3]

[2] Hayek (1931), like Marxist authors, only distinguishes consumption and capital goods sectors.
[3] Reinert (2002) and Hagemann (2003) discuss important theoretical influences on Schumpeter's thinking.

Examples where this theory applies include railway transport and steam shipping, based on steam engine diffusion, replacing canal and sailing ship transport in the second half of the 19th century; the internal combustion engine based on oil displacing steam-powered transport in the early 20th century (Freeman & Perez, 1988); or more recently electronics revolutionizing data processing (Mowery & Rosenberg, 1998).

The financial sector and specifically banks play a crucial role in enabling entrepreneurs to finance their new enterprises by creating credit (Schumpeter, 1939). Only with the support of financial institutions can entrepreneurs acquire the resources for executing their innovative plans and creating sunrise industries. While the credit creation function of banks is key to innovation and leads to output expansion in a 'primary wave', the increasingly profitable sunrise industries become objects of financial speculation. This 'secondary wave' of the business cycle carries the risk of overestimating sunrise industries' growth potential (Schumpeter 1939, p. 147). Over-indebtedness and defaults can result from the exhaustion of an innovation cluster, and generate a financial crisis. One instance that this theory can explain is the 1929 financial crisis, which involved a bubble in radio, electricity, airplanes, automobile and petrochemical industries (Freeman & Louca, 2001). Similarly, the investment booms for the expansion of railways in the 19th century were at the root of financial crises in several countries in the mid-1800s (Vague, 2019), and the 2001 'dotcom' bubble burst even carries a sunrise industry's name. In practice, the distinction between speculative and conventional investment may be partly artificial, the key being a miscalculation of risk that is only revealed retrospectively. Nevertheless, these examples illustrate the link between structural change and transition risks for the financial sector.

In Schumpeter's theory the origin of these risks lies in sunrise industries. Uncertainty about what technological design will ultimately prevail and about the scale at which the growing industry saturates, creates the potential for speculation and over-investment that have been characterized as 'manias' (Kindleberger, 1978) and 'irrational exuberance' (Shiller, 2001). Once the bubble bursts, and the financial crisis starts, it can be exacerbated by the failure of financially unstable sunset firms. However, the theory largely ignores the contribution of sunset industries to the *onset* of financial instability, and Schumpeter explicitly states that the negative effects of bankruptcy and decline in the sunset industries is overcompensated by the growth in the new industries (Schumpeter 1939, p. 134-5). In other words, as long as a strong sunrise sector exists, systemic economic and financial stability are not compromised by a failing sunset sector, even though sunset capital owners lose out and periods of 'structural crises of adjustment' spell unemployment and decline in living standards for a significant share of the population (Freeman & Louca, 2001). A recent example that is also relevant to the low-carbon transition is the layoffs and declines in living-standards in coal-mining communities catalysing demands for a 'just transition' (Rosemberg, 2010).

Subsequent work by Schumpeterian scholars emphasises the important role of government policy and social change in the assimilation of new technologies, which was assumed to happen automatically by Schumpeter (Freeman & Louca, 2001; Perez, 1983). The role of finance in these technological revolutions that change the 'techno-economic paradigm' is developed by Carlota Perez (2002). Her work highlights how the aftermath of the financial collapse that marks the end of the initial speculation with sunrise industry reveals the social problems resulting from the changes and generates anger, revolt and populism. A new set of regulations and institutions are needed at this turning point to establish a direction for innovation and investment, spreading the new technologies in socially beneficial ways.[4] An important take-home message from this literature is the role of government in regulating and managing economic instability arising from structural change.

Technology-based financial instability can also be seen as a case of Hyman Minsky's (1975, 1986) financial instability hypothesis, which describes how the financial sector continuously drives itself towards financial crises through the creation of increasingly complex financial structures, the accumulation of debt and financial innovation (recent discussions include Nikolaidi & Stockhammer, 2017; Taylor, 2012). Although innovation and technological change are exogenous in Minsky, his understanding of the relation of profit opportunities and financial speculation adds important insights to transition risks stemming from the fast development of rising industries.

2.3 Risks associated with sunset industries

To the best of our knowledge, to date there is little theory that explains financial instability caused by sunset industries.[5] The Schumpeterian literature locates the crisis mechanism in the sunrise industries, while the contribution to financial risks from declining industries is left largely unexplored. Caiani et al. (2014) show that systemic risk from sunset industries can be shown mathematically to cause economic distress, but more theoretical effort is needed to determine under what conditions asset scrapping can trigger a financial crisis.

A theoretical literature from the 1930s and 1940s discusses the microeconomic problem of 'premature abandonment', an earlier term for asset stranding (Caplan, 1940). This literature evolved into vintage capital goods models of growth and fluctuations and the modern measurement of capital stock, but remains somewhat disconnected from structural change and in particular from financial risks (see e.g. Benhabib & Hobijn, 2003; Eisner, 1972). A neo-Schumpeterian vintage capital model allows for costly reallocation of factors of production between industries, but has not analysed under what conditions such reallocation could destabilize the financial system (Caballero & Hammour, 1996).

Institutional economic history of the secular decline of the British economy offers a different lens on the contribution of sunset industries to financial risks. It is well documented that individual industries, such as cotton or steel suffered from chronic overcapacity after 1920, and that government programmes were instituted to scrap uncompetitive machines in order to reduce capacity (Lazonick, 1984; Tolliday, 1987). Banks that had lent during the uptick of domestic demand in 1919-20 found themselves in a precarious position in the subsequently stagnating British economy. But the focus of this literature is again on the reverse causal direction, namely to investigate how the nature of the British financial system influenced British manufacturing industries' decline, not how decline conditioned financial instability (Best & Humphries, 1984; Higgins & Toms, 2003).

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[4] Note the parallels with the Marxist social structure of accumulation and regulation theories as a crisis being the turning point in the transition between two forms of capitalism (Kotz, 1990).

[5] Szostack's (1995) analysis of the Great Depression goes into detail about sunset industries but does not link to financial stability.

In summary, economic theorists and historians have identified sunrise industry speculation as the trigger of financial crises, but have not substantially investigated systemic risks originating in sunset industries, even though the latter may contribute to the severity of the crisis once it is unleashed. Our conceptual review offers an important insight for the current low-carbon transition. An industry with declining demand generates losses for its owners, unemployment for its employees, and quite possibly a default on its loans. However, theory suggests this is not enough to destabilise the economy and induce systemic financial instability. The underlying logic argues that while some companies and even financial institution go under, the financial system as a whole is diversified and profitable enough to weather this shock thanks to the dynamic sunrise industries. It is only when the sunrise industries mature, and a bubble in their financial assets pops, that theory predicts the onset of crisis.

3. LOW-CARBON TRANSITION RISKS FROM SUNSET INDUSTRIES

In contrast with what has just been reviewed, the current debate on the low-carbon transition has so far focused on financial risk from sunset industries. The simple reason is that in order to achieve the Paris agreement targets, lots of currently productive enterprises have to radically alter their production. In particular, a good share of the emissions from currently known fossil fuel reserves must be suppressed (Carbon Tracker, 2013; Meinshausen et al., 2009). The cash flow of industries supplying or using fossil fuels would be impacted. If this impact is unanticipated by investors, their assets would prematurely depreciate or 'strand' (Caldecott, 2018) and if the stranding is widespread enough, it could lead to a financial instability and crisis (Monasterolo, 2020; van der Ploeg & Rezai, 2019).

Consideration of sunrise industry risks, on the other hand, is absent from the debate. While observer bias and timing may help explain some of this neglect (for instance, before the 2007-8 crash few commentators pointed to a looming housing crisis), there is also some hard evidence to cite: Investment in low-carbon technologies has been increasing in recent decades, but they are still far away from the scale necessary to compensate for the phase-out of fossil-based technologies under a 1.5°C scenario (CPI, 2019; McCollum et al., 2018; Semieniuk & Mazzucato, 2019). Nor are the investments yet vastly more profitable – support policies have so far been required to attract private investors even in the advanced power supply sector (Mazzucato & Semieniuk, 2018; Polzin, Egli, Steffen, & Schmidt, 2019). Of course, the fast market capitalization growth in some low-carbon companies such as Ørsted, market leader in offshore wind projects, or Tesla, an electric car maker, are examples of (so-far) successful sunrise companies to point to (Financial Times, 2020a, 2020b). And there have already been instances of initially hyped low-carbon companies collapsing just as if their potential had been overestimated by Schumpeterian 'speculators', including photovoltaic cell makers Solarworld in Germany and Solyndra in the US. However, these instances hardly triggered systemic financial instability, just as the burst of the YieldCo bubble in the US in 2015 (share prices dropped 60%) did not destabilize wider stock markets (CPI, 2016). In short, at this moment, there does not yet seem to be a general 'mania' in the low-carbon sunrise industries.

The timeline and scale of structural change implied by proposed climate-change mitigation then appears to make this transition different. The aim is to correct an externality using deliberate policy intervention (Foley, 2009; Nordhaus, 2013), rather than to let a more or less evolutionary trajectory guide the transition. Past theory does caution that, if the transition is managed well and innovation in low-carbon technologies is fast, then the world might soon find itself in the 'typical' situation whereby there are fast-growing low-carbon sunrise industries, that pose the risk of a 'green bubble'.[6] However, the current debate suggests that such a sunrise industry-induced financial instability, if it materialises, may be preceded by systemic risks realised in sunset industries.

4. A MODEL AND CLASSIFICATION OF LOW-CARBON TRANSITION RISKS

So far, we have established that mechanisms causing risks for finance from new industries are fairly well understood, but the contrary is true of declining industries. To improve an understanding of possible channels whereby declining industry risks may operate, we classify them to identify the drivers, costs and impacts and their logical connection via transmission channels (summarised in Figure 1). We review evidence for each category as we describe it.

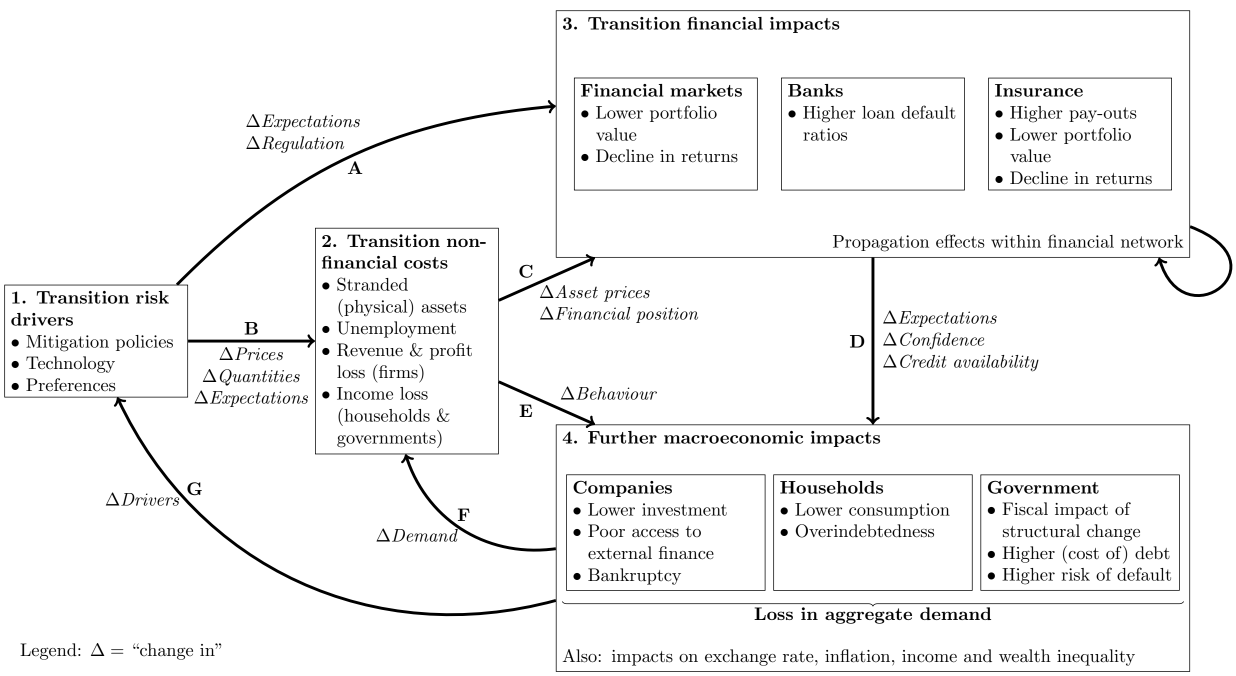

Figure 1: Schematic view of chain of causation from risk drivers to impacts (boxes) via transmission channels (arrows).

4.1 Transition risk drivers

[6] Discussions of green bubbles have to date taken place mainly outside academia, e.g. in central banking circles (DNB, 2017). If anything, academic research has considered the reverse direction of causation, how the recent financial crisis has slowed the progress of the green transition (Falcone, Morone, & Sica, 2018; Geels, 2013).

Transition risk drivers (Figure 1, box 1) can be conceptualised as changing relative prices or market demand/supply in favour of low-carbon goods and services, either immediately or over time. In the latter case, expectations about future changes may still create risks in the present (van der Ploeg & Rezai, 2020). Hence, Figure 1 can be read both as the potential unfolding of actual transition impacts and as a mental map of expected future impacts of transition drivers. Key drivers are climate change mitigation policy, technological change and changes in consumer taste (PRA, 2015). These are reviewed in turn below.

4.1.1 Climate change mitigation policies

Policy seeking to internalise the carbon externality is a key driver of risks. The central plank of most climate change mitigation strategies consists of incentive-based regulation that generates a carbon price either via taxes or cap-and-trade schemes. The suite of scenarios limiting global warming to 1.5°C in the recent IPCC report reports a median global carbon price of \$91/tCO_2 (metric ton of CO2) in 2025 and \$179/tCO_2 in 2030, with the interquartile range reaching up to \$175/tCO_2 and \$361/tCO_2 respectively (calculations based on Huppmann et al., 2018). In April 2019, only 20% of global greenhouse gas emissions were priced at all, and less than 5% of these were in line with Paris Agreement compatible levels (World Bank, 2019). Effective mitigation policies could therefore drastically increase industry and consumer prices for high-carbon products in the near future. Regulation may also directly limit the sale of high-carbon products. Ten countries have recently set specific times for bans on new internal combustion engine cars, some as soon as 2030 (Meckling & Nahm, 2019).

In addition, public subsidies, regulations and investments help lower prices of low-carbon products. Comprehensive policy approaches for 'green growth' such as China's 13th 5-year plan (National Development and Reform Commission, 2016) or Europe's Green Deal (European Commission, 2019), include mandating, subsidising or directly carrying out investments into low-carbon products and installing enabling infrastructure. This makes low-carbon products more competitive by creating markets, financing and helping innovation proceed at pace or simply altering prices directly (Block & Keller, 2011; Mazzucato & Semieniuk, 2017). Some policies can also directly affect the financial system such as differentiated prudential requirements, lending quotas or targeted refinancing lines by the central bank, indicated by arrow A in Figure 1, or alter the financial sector's expectations (Volz, 2017; Campiglio *et al.*, 2018). It is important not to confuse the policy here seeking to accelerate the transition (mitigation policy) with policy aimed at stabilizing the financial system, which we review in the next section.

4.1.2 Technological change

Cost-saving technological innovations, possibly incentivised by earlier climate policies, further lower the prices of low-carbon technologies (Kavlak, McNerney, & Trancik, 2018; Nemet, 2019). This is a non-linear process often approximated by s-curves of adoption. (Rogers, 2003). The cheaper a new technology becomes, the more widely it is used, and through scale and learning effects becomes even cheaper, until it emerges as the 'new normal' (Arthur, 1989), altering the technological paradigm (Dosi, 1982). Structural change between technologies and the change in the ratio of relative demand can thus accelerate over time, which has led to underestimating the rate of adoption of low-carbon technologies (Creutzig et al., 2017). Since technology diffusion self-reinforces and evolves endogenously, once set in train, it can contribute substantially to price changes even without any new policy changes. As a new socio-technical regime gradually establishes itself, it requires decreasing amounts of external support to diffuse further (Geels, 2002).

4.1.3 Preference change

Buyers' preferences and the public's support for particular products and policies can drive demand and prices. Preferences are endogenous to institutions and their changes (Bowles, 1998) and the more people use a technology, network externalities may accelerate further adoption (McShane, Bradlow, & Berger, 2012; Pettifor, Wilson, Axsen, Abrahamse, & Anable, 2017). Through their demand-pull effect, preferences can also affect the pace and direction of technological change, which can interact with government procurement policies (Boon & Edler, 2018). Lastly, preference changes can stir political movements, putting broader pressure on policy making and changing what is politically feasible.[7] The public mobilisation against nuclear fission provides a cautionary story for other technologies (Boudet, 2019). Therefore, changes in preferences can lead both to price changes and quantity restrictions.

4.2. Transition costs

Transition drivers translate into transition costs (Figure 1, box 2) via two transmission channels (Figure 1, arrow B). Price and quantity changes lead to adjustments in all sectors, affecting revenues of producers, the real income of households, and state tax revenue. Although prices of high-carbon production may rise, market price behaviour may be more complex (see Sidebar 1). But the drivers also transmit via expectations about future revenue streams, especially if policy and preference changes are credible and long-lasting (Helm, Hepburn, & Mash, 2003). For example, some of the car bans discussed above lack credible enforcement mechanisms (Plötz, Axsen, Funke, & Gnann, 2019), and current Nationally Determined Contributions under the Paris agreement, are subject to implementation (den Elzen et al., 2019; Pauw, Castro, Pickering, & Bhasin, 2019). But if expectations do change, they can do so quickly and across the board due to herd effects, also directly affecting the financial sector (arrow A). [8] This leads to asset stranding.

Sidebar 1: The effect of a carbon price on fossil fuel prices

Carbon taxes are likely to have two opposite effects on fossil fuel prices. In the short run, consumer prices will rise as firms pass costs on to consumers, lowering demand, while producers earn less revenue per unit sold, a typical consequence of a tax increase in a partial equilibrium setting. In the long run, profit opportunities from cheaper low-carbon substitutes could induce an accelerated structural change away from fossil fuels, which could lower prices due to lack of demand and oversupply. If fossil fuel

[7] Of course, this blade cuts both ways. While 'Fridays for Future' and 'Extinction Rebellion' protests of 2019 may make stringent policy more feasible (Horton, 2019), protests may also constrain the rollout of climate policy (Jewell & Cherp, 2020).

[8] In a rational expectations framework, stranded assets occur under policy time-inconsistency (Kalkuhl, Steckel, & Edenhofer, 2019).

producers expect demand not to recover in the long run, but to decline further, they might decide to flood the market in the short-run in a race to the bottom, to sell whatever they can, the 'green paradox' (Jensen, Mohlin, Pittel, & Sterner, 2015). This accelerates the price decline as the lowest-cost producers capture what is left of the declining market (Mercure et al., 2018).

4.2.1 Physical asset stranding

A growing literature analyses high-carbon physical assets at risk of stranding. The risk that excess reserves of fossil-fuel companies poses for their valuation was briefly reviewed in Section 3. The inconsistency that arises between the valuation of these resources by fossil-fuel companies, and the valuation consistent with climate-change mitigation is discussed by Bebbington *et al*. (2019).[9] Davis *et al*. (2010) calculate that existing fossil-fuel sector assets in 2009 would emit about 500 Gt of CO_2, or about half the carbon budget then remaining. These assessments have since been refined for fossil electricity assets and show an increasingly slim opportunity for new-build non-stranded assets (Davis & Socolow, 2014; Johnson et al., 2015; Pfeiffer, Hepburn, Vogt-Schilb, & Caldecott, 2018). Yet, uncertainty remains: Rozenberg *et al*. (2015) calculate that for a 2°C warming scenario any fossil fuel asset built after 2017 cannot start operating if existing assets are prioritised and the carbon budget is to be respected. Meanwhile, Smith et al. (2019) find that current fossil fuel infrastructure does not yet commit the world to warming beyond 1.5°C. Part of this range arises from the uncertainty about the size of the carbon budget itself (Rogelj, Forster, Kriegler, Smith, & Séférian, 2019).

Asset stranding can spill out of the fossil energy sector. Considering the relevance of fossil fuels as inputs in mining and manufacturing processes, which then provide crucial intermediate inputs to downstream sectors, stranding of physical assets could take place virtually anywhere in the economy. Cahen-Fourot *et al*. (2019) show how moving away from fossil fuels as input factors could create significant 'cascades' of asset stranding across the production network of European economies. In the building sector (including residential housing), retrofitting costs may exceed private returns (Fowlie, Greenstone, & Wolfram, 2018; Muldoon-Smith & Greenhalgh, 2019), and IRENA (2017) projects the building sector to hold the most stranded assets. Unruh (2000) coined the term 'carbon lock-in'. In short, both land and produced capital inputs can become stranded.

Research has been conducted on systematically valuing the loss of assets due to stranding. Mercure *et al*. (2018) estimate losses of $1tn-$4tn in the fossil in the fossil fuel sector in the period 2016-2035 under various scenarios including the current trajectory of low-carbon technology without additional policy measures, while $0.957tn of power sector asset stranding until 2050 was found in a bottom up assessment by Saygin *et al*. (2019). One of the most cited works in this area is in the grey literature: for the IEA's Below 2 Degree scenario, Carbon Tracker and PRI estimate one third of business as usual investments into oil and gas, or $1.6tn, would be stranded in the period 2018-2025 (Carbon Tracker & UNPRI, 2018). IRENA (2017) calculates an economy-wide $10tn stranded over the period 2015-50, which increases to $20tn in a scenario of delayed transition policies. Dietz *et al*. (2016) calculate *value at risk*

[9] Research supported by the fossil fuel producer Shell suggests the deployment of carbon capture and storage could allow significantly more reserves being exploited while respecting the carbon budget (Budinis, Krevor, Dowell, Brandon, & Hawkes, 2018).

from the transition to be 0.4% of global financial assets, or $0.6tn. Recent analytical models show how, depending on the type and stringency of the policy implemented, some asset stranding in the form of underutilisation of installed capital is not only likely, but also optimal from a social perspective (Coulomb, Lecuyer, & Vogt-Schilb, 2019; Rozenberg, Vogt-Schilb, & Hallegatte, 2018) . None of these studies model the impact of asset stranding on the financial sector.

4.2.2 Other transition costs

Along with asset stranding, workers could also become 'stranded'. Although net aggregate job changes in a rapid transition could be positive even in large-scale fossil fuel producing countries, high-carbon sectors are likely to suffer from significant unemployment (Bastidas & Mc Isaac, 2019; Pollin, 2015). Without stabilising government policy, high-cost fossil fuel producers could even lose up to 3% (USA) and 8% (Canada) of employment (Mercure *et al*. 2018), when including multiplier and knock-on effects of income and spending changes across the economy. As reviewed in Section 2, transitional unemployment is well documented for structural change. A fast-growing policy literature considers prospects and costs for retraining workers to ensure a 'just transition' (ILO, 2015; Oei *et al*., 2020; Pollin, 2019).

Governments could also lose tax and other revenue from plunging sales and incomes of their domestic industries (not to be confused with carbon price revenue reviewed in section 5), especially, but not exclusively for fossil fuel exporters. For instance, Malova and van der Ploeg (2017) calculate that low oil and gas demand, in line with a 2°C scenario, would require the Russian government to divert an additional 0.9% of GDP a year towards investments outside the fossil energy sector in order to keep the fiscal stance sustainable. Regulations, such as production quotas or standards, may also restrict revenue.

Real incomes of households could shrink due to rising prices, in addition to loss of employment, declining return on investments. These costs apply unequally. As poor households spend a larger fraction of their incomes on high-carbon products, a carbon tax would be regressive without countervailing redistribution. For the US, Fremstad & Paul (2019) estimate that households in the poorest deciles incur 50% more additional costs as a fraction of their expenditure than households in the highest decile. Strict low-carbon building and appliance regulations, while not 'stranding', may affect the value of residential housing unequally, and disproportionately impact the financial position of households struggling to raise the capital for retrofitting existing houses (Brown, Sorrell, & Kivimaa, 2019; Cabrera Serrenho, Drewniok, Dunant, & Allwood, 2019; Schleich, 2019). Since poorer households are at a higher risk of defaulting on loans, such regressive impacts can create further risks for the financial sector.

4.3 Financial impacts

Transition costs impact the financial system (Figure 1, box 3) via two transmission channels: credit and market risks (Figure 1, arrow C). First, the loss of assets and income increases the likelihood of default on debt; therefore, banks could see their share of non-performing loans grow. Higher ratios of non-performing loans could in turn reduce the profitability of the lending bank, affect its market valuation and, if the phenomenon is significant enough, lead to its default (Dafermos & Nikolaidi, 2019b). The significance of this effect depends on how exposed the banking system is to industries that will have to decline as part of the low-carbon transition (see Vermeulen *et al*. (2019) and Giuzio *et al*. (2019) for data concerning Dutch and eurozone banks).

Second, institutional investors and other institutions holding financial assets could suffer negative portfolio effects due to the revaluation of assets triggered by the transition process (Campiglio, Monnin, & von Jagow, 2019). The transition costs reviewed above, or expectations about their realisation, could induce financial analysts to revise the expected discounted cashflow that carbon-intensive firms will offer in the future, thus leading to a reduction in the current value of financial assets.[10] The revaluation could also take place 'endogenously', as a result of the application of new valuation models by financial analysts. Whoever holds the devalued financial assets will see their wealth diminished. Economic theory is gradually incorporating transition-related risks into both growth and asset pricing theory (van der Ploeg & Rezai, 2020), and precise numerical estimates for specific investors are being estimated (e.g. Monasterolo, Zheng, & Battiston, 2018).

The impact of the transition on private financial markets could go well beyond the direct exposure of investors to carbon-intensive sectors, due to second-round effects. Financial systems have featured deeply connected networks throughout history (Graeber, 2011), and international financial liberalisation since the 1970s has only reinforced this interconnectedness (Christophers, 2013). Financial institutions tend to be heavily exposed to each other (Battiston, Puliga, Kaushik, Tasca, & Caldarelli, 2012). In particular, many financial assets are used as collateral in short-term repurchase agreements (repos), so any decline in asset prices can cause liquidity problems. This means that a financial institution could be strongly negatively affected by the low-carbon transition even if not directly exposed to carbon-intensive sectors by 'second-round effects' (Battiston, Mandel, Monasterolo, Schütze, & Visentin, 2017). A further decline of asset prices could occur due to fire sales; episodes in which too many companies simultaneously sell off assets to try to pay off excessive debt and avoid bankruptcy. This could prompt a vicious cycle of asset price falls and sell-outs, known as debt-deflation (Fisher, 1932).

The overall effect of such revaluations of financial assets remains unclear, but is being addressed by a nascent research literature published mostly outside of, or in collaboration with, academia (e.g. HSBC, 2019; Mercer, 2019; UNEP FI, 2019). Two types of analytical approaches are employed (Campiglio *et al*., 2019). First, studies looking at the long term usually project transition scenarios to the future, derive sectoral economic gains/costs, and transform them into changes in financial asset prices. This approach is implicitly based on the representation of the low-carbon transition as a relatively smooth process of reallocation of resources from certain sectors to others, with financial investors placidly following. However, financial sector dynamics are often characterised by sudden changes of 'sentiments' leading to unexpected volatility of prices. PRA (2018) calls the eventuality of fluctuations of the sentiments of

[10] The extent of current mis-valuation is contested. Byrd and Cooperman (2018) argue coal asset stranding is already priced into investors' expectations, while Silver (2017) avers that stranded asset risk is invisible to institutional investors. Griffin et al. (2015) discuss reasons for the lack of response of investors to news about impending stranded assets, and Sen & von Schickfus (2020) suggest high-carbon firms expect compensation for anticipated stranding. Christophers (2019) reports and analyses investors' views.

investors concerning the likelihood of future transition scenarios a 'climate Minsky moment'.[11] In order to grasp these effects, a second research approach uses the 'stress testing' conceptual framework to analyse the reaction of asset prices to certain types of shocks (e.g. a change in consumer preferences) and the effect of these changes on the portfolios of financial institutions (Vermeulen *et al*., 2019).

Table 1 summarises outputs from the few academic and a selected number of central bank studies that report exposure of banks to high-carbon sectors (rows 1,2), and stress tests in the sense that 2nd round effects are traced (3) and feedback to the economy is considered (4). The last two rows show value at risk, and a scenario study for *physical risks*, i.e. from climate change itself. The studies cannot be directly compared, as they use various system boundaries. But it is clear that only looking at direct exposure (1,2) gives much lower values than when tracing second-round effects (3,4).

Table 1: Estimates of potential maximal financial exposure to transition risks, and comparison with physical impact estimates

#	Region & Channel	Channel	Scenario (with value in parentheses as a share of regional GDP)
1	Giuzio *et al*. (2019)	1st round exposure of 40 European banks	Exposure to 20 largest emitting firms amounts to 1.8% of 40 banks' assets (---)
2	Nieto (2019)	Outstanding syndicated loans in China, Europe, Japan, Switzerland, USA to high environmental risk	Outstanding loans amount to 1.6 trillion 2014 USD (3.1% of GDP of selected countries)
3	Battiston *et al*. (2017)	1st & 2nd round exposure of top 50 EU banks to high-carbon assets	100% loss of fossil fuel & utility sector portfolio wipes out 13.5% of top 50 banks' equity (32.7% of European Union GDP)
4	Vermeulen *et al*. (2018)	1st & 2nd round impacts on portfolios of 80 Dutch financial institutions	Loss of up to 0.16 trillion 2018 EUR when combining technology and policy shocks (up to 18% of Dutch GDP)
Physical risk studies for comparison:			
5	Dietz *et al*. (2016)	Global assets at risk under DICE BAU vs mitigation scenario	99th percentile of total assets at risk amounts to 24.2 trillion 2013 USD (31.5% of global GDP)

[11] The timing of the change in expectations is contingent on the drivers, but the 2020s were highlighted as the most likely period in which the carbon bubble may burst and carbon risks materialise (UNPRI, 2019; Bond, 2019). Scenarios charting pathways to meet the Paris targets also see global fossil fuel demand peaking in the 2020s (Rogelj et al., 2018).

6	Lamperti *et al*. (2019)	Global bank failures from physical risks	Additional government expenditure needed to rescue banks (5-15% of global GDP)

Note: Where possible, the comparison with GDP was calculated by using regional GDP figures in current national currency or USD from the IMF.

4.4 Further macroeconomic impacts

Transition costs and financial impacts could each trigger further macroeconomic impacts (Figure 1, box 4, and arrows D and E); in particular aggregate demand may fall. This could in turn amplify transition costs and financial impacts, sending the economy into a downward spiral of negative real-financial interactions with negative macroeconomic multipliers amplifying initial losses. We highlight some of the possible channels for demand reductions as follows.

Banking channel. The increase in non-performing loans could lead to credit rationing by commercial banks. Even if the origin of the shock lies in carbon-intensive sectors, credit rationing could affect all sectors irrespective of their carbon intensity. This might translate into higher interest rates, or a quantitative rationing of credit, which would in turn lead to a drop in investment levels of both firms (new capital assets), households (new real estate) and governments (new public infrastructure). Lower investment would reduce aggregate demand, affecting in turn expenditure in all sectors.

Investment channel. In addition to having limited access to credit, firms might have less appetite for investments if the transition has led to a drop in their market valuation depressing confidence and expectations. Behind this lies 'Tobin's q' theory, which suggests that a low market capitalisation to book value ratio lowers investments.[12] If the crisis affects the entire economy, these effects may also reduce investment in low-carbon sectors.

Consumption channel. Reduced income and wealth levels could reduce household consumption levels. Widening income and wealth inequality in combination with stronger credit rationing may additionally impact consumption expenditure negatively, due to higher propensities to consume and inability to smooth consumption of poorer households (Amromin, De Nardi, & Schulze, 2018; Fisher, Johnson, Latner, & Smeeding, 2018).

Public debt channel. Government expenditure is likely to initially react counter-cyclically to the reduction in other expenditure categories due to automatic stabilisers, public support to failing industries, and not least through the bail-out of failing financial institutions. However, higher public debt could translate into a lower capacity to spend in the future, especially in countries highly dependent on international

[12] The original theory is subject to qualifications (Altissimo et al., 2005; Jovanovic & Rousseau, 2014).

credit markets.[13] A worsening of sovereign credit ratings would also raise the corporate cost of capital, as the two tend to be related (Kling, Lo, Murinde, & Volz, 2018; Kling, Volz, Murinde, & Ayas, 2020).

Other macroeconomic effects. The low-carbon transition, especially if implemented in an uncoordinated way at the global level, could lead to changes in inflation, trade balances and exchange rates, which in turn could generate dynamics to re-assess existing international economic agreements (such as on trade). These impacts are, at the moment, very hard to adequately quantify.

The combined effect of these impacts most likely decreases aggregate demand, which in turn could further exacerbate transition costs (arrow F), financial impacts. A negative feedback loop from asset stranding in sunset industries could lead to a full-blown credit crunch, which could make it hard for sunrise industry firms to finance investment in the short run and in turn affect transition drivers (arrow G). The only study that currently attempts to connect transition financial impacts with macroeconomic impacts is Vermeulen *et al.* (2018), highlighting the absence of possible financial cost in integrated climate change scenarios, both with and without mitigation (Farmer, Hepburn, Mealy, & Teytelboym, 2015). However, many of the channels from finance to the real economy and vice versa are explored widely in the macroeconomic literature, so any future modelling efforts can use these as benchmarks.

5. POLICY RESPONSES TO MITIGATE TRANSITION RISKS

While some policies drive the transition, others seek to mitigate systemic financial impacts. Following the 2008 financial crisis, central banks and financial supervisors have intensified efforts to strengthen financial regulation and identify systemic financial risks in order to mitigate these. Central banks in particular were subject to an intensive discourse on their role in safeguarding financial stability, and their mandate more broadly (e.g. Dikau & Volz, 2020; e.g. G30, 2015; Volz, 2017). Building on early academic contributions on the role of financial governance in addressing climate-related financial risks (Campiglio, 2016; Volz, 2017), monetary and financial authorities have started to include climate change among these systemic risks and consider adequate policy responses to mitigate them.[14] Most attention has been devoted to the risk of abrupt changes in asset valuations due to stranded assets. Hence, much of the discussion on policy responses has centred around ways to mitigate sunset sector risk. Growing attention is now also being paid to impacts on sovereign risks – stemming both from physical and transition risks – and how these can be mitigated (Battiston & Monasterolo, 2019; Buhr et al., 2018; Kling et al., 2018; Volz et al., 2020). There has also been a discussion on the role of financial policies in scaling up investment in green activities, such as green supporting factors in financial regulation or green asset purchases by central banks (e.g. Vaze, Meng, & Giuliani, 2019). This discourse has largely ignored potential risks from rising industries.

[13] The problem of crowding-out would seem less relevant as a crisis-ridden and transforming economy is likely to be far from full capacity (Deleidi, Mazzucato, & Semieniuk, 2020; Heim & Mirowski, 1987).
[14] See, for instance, Batten *et al*. (2016), ESRB (2016), Finansinspektionen (2016), Regelink *et al*. (2017), PRA (PRA, 2018) and NGFS (2019).

Regulatory responses are mainly preventive in that they aim at providing information and incentivising the move away from high-carbon assets, so that any future transition driver has less impact. They include suggestions for enhancing transparency through taxonomies of 'green' and 'brown' assets and a (mandatory) disclosure of risks (Thomä, Dupré, & Hayne, 2018; Volz et al., 2015), climate-related stress testing at both micro and macro prudential level (Battiston *et al*., 2017), and climate calibrated capital rules or collateral frameworks.[15] Initially, the focus was on a disclosure of financial risks from climate change, which would help firms to manage, and financial markets to price in these risks and thus avoid rapid revaluation. In January 2016, the Financial Stability Board established a Task Force on Climate-related Financial Disclosures (TCFD). In its report in 2017, the TCFD makes recommendations on disclosures at the firm level (TCFD, 2017). Risks that are thus disclosed can then be assessed under different scenarios of the future, and firms can use these for risk management (Berg, Clapp, Lannoo, & Peters, 2018; TCFD, 2016). The financial sector is to use the disclosures for adequate pricing. There have also been proposals for introducing risk differentials in financial regulation, i.e. high-carbon penalising or low-carbon supporting factors (Dafermos & Nikolaidi, 2019a).

The current thinking of policy makers is captured in the work of the Central Banks and Supervisors Network for Greening the Financial System (NGFS), a group of more than 50 central banks and supervisors, established at the Paris One Planet Summit in December 2017. In April 2019, the NGFS (2019) put forward a high-level framework for the integration of climate-related factors into prudential supervision, comprising five elements. According to this framework, the first step is to raise awareness of climate-related risks and build capacity amongst firms to analyse their exposure. The second step is the assessment of climate risks at both the micro and macro prudential level, i.e. at the level of individual financial institutions and the financial system as a whole. Examples include the assessment of financial institutions' exposure to high-carbon sectors, or possible impacts of tightening energy efficiency regulation on the valuation of energy inefficient homes. Climate-related stress tests could be conducted at the level of financial institutions and of the system at large. The third step suggested by the NGFS is to provide guidance to regulated firms on appropriate approaches to governance, strategy and risk management to mitigate climate-related risks. Step four is about climate-related disclosures to enhance transparency and promote market discipline. This may include an integration of climate-related disclosure requirements in line with the TCFD recommendations into Pillar 3 of the Basel III banking regulations. The fifth and final step is to consider additional capital charges related to climate risks. This could include an integration of climate-related capital surcharges into the minimum capital requirements under Pillar 1 of the Basel III regulatory framework, or special capital requirements for firms that exhibit higher risk concentration in their balance sheet or that do not comply with supervisory expectations under Pillar 2. The NGFS (2019, p. 6) emphasises that climate change-related financial risks "are best mitigated through an early and orderly transition."

Existing stabilisation policy has been criticised by academic studies as inadequate. In particular, researchers have criticised too strong a focus on disclosure and the expectation that it will lead to an "efficient market reaction to climate change risks" (Carney, 2015, p. 12). For instance, (Christophers, 2017, p. 1124) contends that "there is something fundamentally awry with expecting enhanced

[15] For an overview of policy tools available to central banks and supervisors see Dikau & Volz (2019).

disclosure to miraculously provide financial systemic safety." Ameli *et al*. (2019) argue, based on interviews with investors, that disclosure by itself is insufficient to change investment behaviour, as the argument rests on the unrealistic efficient market hypothesis (that financial markets price in all information). Monasterolo *et al*. (2017) note the difficulty of disclosing supply-chain carbon exposure. Lastly, disclosure may help re-classify fossil fuel assets as junk, but does not make their associated systemic risk disappear (Mercure, 2019). These sentiments are reflected in the IPCC's recent assessment that effective mitigation would require an evolution of the global financial system (de Coninck *et al*., 2018). Against this, some central bankers have, while acknowledging their role as financial regulators by enhancing transparency and stress testing, insisted that central banks ought to adhere to the principle of market neutrality in the conduct of monetary policy and not favour green assets over brown (e.g. Weidmann, 2019). Proposals for risk differentials in financial regulation or collateral policies, and any activist policies aimed at fostering a green transition, have been controversial (Dikau & Volz, 2019). Nevertheless, a growing number of central banks and supervisors have started to implement micro and macro prudential measures to address transition risks (D'Orazio & Popoyan, 2019; Dikau & Volz, 2020; Frisari, Gallardo, Nakano, Cárdenas, & Monnin, 2019) or are considering doing so, going beyond disclosure and stress testing.

There is also a growing awareness of low-carbon transition risks for finance among finance ministries.[16] A Coalition of Finance Ministers for Climate Action (CAPE) was established by 23 countries in April 2019 and has since grown to more than 50 members, all of which have signed the six "Helsinki Principles", committing to national climate action and incorporating climate change into financial policies. While climate-related financial risks and impacts are included in the deliberations, to date the emphasis of CAPE has been primarily on fiscal policies.[17]

Lastly, and although we cannot go into depth, it is important to mention that appropriate redistributive and industrial policy can also reduce financial risks indirectly by mitigating transition costs (box 2) . For a budget-neutral example, consider how government revenue from carbon taxes or auctioned-off emission permits could be used as a tool to mitigate transition costs for households. If part of this revenue is redistributed among citizens, and since richer households consume more carbon and thus pay a higher price in absolute terms, feebates turn carbon prices into a progressive instrument (Boyce, 2018), and just transition policies would further mitigate impacts. Government revenue could also be used to maintain minimum company solvency during the transition (Caldecott & Dericks, 2018), and industrial policy could direct (private and public) investments into sunrise industries to help reduce the amount of assets at risk of stranding. One vehicle for this is existing public development banks that have

[16] The French Ministry of Finance was among the first to address climate risk for the financial sector. Enacted in August 2015, Article 173 of the French Energy Transition Act introduced mandatory reporting requirements on climate-related financial risks and the measures adopted to mitigate them for listed companies and/or large non-listed firms, including both non-financial and financial firms (Direction Générale du Trésor, n.d.).

[17] Helsinki Principle 5 ("Mobilize private sources of climate finance by facilitating investments and the development of a financial sector which supports climate mitigation and adaptation") includes the identification of "strategies to incorporate climate risks and opportunities into investment decisions, such as supporting global efforts for transparency and disclosure of climate-related financial risks and impacts, identifying risks to financial stability posed by climate change, and considering ways to manage these risks" (CAPE, 2019, p. 3).

long experience with financing industrial policy and can strategically focus on structural change through their mandates and ability to function on lower operating margins than commercial lenders (Geddes, Schmidt, & Steffen, 2018; Griffith-Jones & Ocampo, 2018; Mazzucato & Penna, 2016). Note, however, that loss of substantial revenues from fossil-fuel royalties in major fossil-fuel producer countries could affect the ability of those nations to support the low-carbon transition through fiscal means.

6. CONCLUSION

Low-carbon transition risks for finance are likely to be generated mainly from unanticipated, stringent climate-mitigation policy, but also from technological and preference changes and their interaction with each other. The current academic research on these topics addresses either the real-economy transition costs, or the financial impact, but does little to connect the two. A comprehensive theoretical framework of sunset industry systemic risks for finance is lacking as the theoretical and historical literature has focussed on risks from sunrise industries instead. We contribute to thinking about the conceptual issues in understanding transition risks from sunset industries by developing a consistent theoretical framework of the drivers, transmission channels and impacts of the phase-out of carbon-intensive industries on the financial system. An important insight from existing Schumpeterian theory on financial risks of transition, however, is that once low-carbon industries do become more productive, as the sunrise industries in previous transitions ultimately did, the potential for financial instability begins to threaten the low-carbon sector too.

High-carbon industries could abruptly become uncompetitive due to strong climate-change mitigation policy and the resulting price changes and expectations, reinforced by fast technological change and preference changes. These transition drivers cause physical assets to lose their ability to generate revenue and become stranded. Asset stranding combines with other transition costs, notably unemployment, losses in revenue, profits and reductions in real incomes that generate significant risks for portfolio losses and debt default. Financial actors might become unable to service their own debt and obligations, creating loss propagation within the financial network. The adverse impact of credit tightening and lack of confidence as well as the direct impact of transition costs on the macroeconomy, could lead to a general economic crisis with further risks for finance. None of this suggests that financial markets would be better off without or with a limited transition: several studies have clearly demonstrated that financial sector exposure to the transition already exists, and delaying climate-change action would only necessitate an even more rapid and potentially more damaging transition in the future, while exposure to physical risks under unmitigated climate change would be drastically increased. Targeted financial stabilization policies, however, can mitigate some transition risks by direct regulation of the financial sector, as well as intervention at the transition cost stage.

What the current transition needs is a set of theoretical propositions and stylized facts about the link between fast depreciation of capital and financial impact. These could be implemented in multi-sectoral models with a financial sector and vintage capital structure. Putting together real and financial economic mechanisms would make it possible to explore the whole set of interlinked parts of transition drivers, costs and impacts to arrive at benchmarks both of systemic risk and effects of policy measures.

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