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Towards a carbon neutral economy: How government should respond to market failures and market absence

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ABSTRACT

The transition towards a carbon-neutral economy is a fundamental change, it involves not only transforming the energy sector but also radical reforms across the whole economy. Managing fundamental and wholesale change across such a large economy is a massive coordination challenge requiring the simultaneous deployment of a collection of instruments and institutional change. This paper looks into the key challenges in building a carbon-neutral economy and discusses how governments and markets should work together in addressing these challenges. Due to significant failures in key markets relevant to tackling carbon emissions and to the absence of crucial markets, this paper argues that governments must play an active role in formulating and implementing effective environmental policies, regulations and design. This paper discusses major market failures and market absence, leading to suggestions on policy measures that governments should take to overcome these challenges, enabling markets to give better signals in directing resource allocation and guiding the low-carbon transition. Governments must act to facilitate a transition that enables equity in opportunities and outcomes across regions and individuals. Implementing these strategies and policies requires cohesive government structures, led from the most senior levels, to foster the necessary investment, innovation and change needed.

1. Introduction

We have been seeing devastating effects from fires, storms, and droughts as a result of the 1 °C increase in global temperature already experienced. Countries are increasingly recognizing the risks posed by unmanaged climate change. As of March 2022, 83 countries, representing 74.2% of global greenhouse gas emissions, have committed to reaching carbon neutrality,[1] recognizing that the transition to a net-zero economy will help deliver economic development and growth that is more robust, sustainable, and resilient.

In September 2020, President Xi Jinping made a vitally important pledge to the United Nations General Assembly that China, the world's largest emitter of carbon dioxide, will aim for carbon neutrality by 2060. This commitment embodies the linking by the Chinese government of the low-carbon transition to the country's sustainable development strategy and long-term prosperity. China has recognized that the old growth story, driven by fossil fuel-based energy and investment in physical capital, is not sustainable. As such, the country will transform itself again in the next 30 to 40 years as it moves toward high-income status. However, the dimensions of the goals of this transformation will not be so focused on output and income. Indicators of wellbeing, social and environmental quality, sustainability, and distribution will take center stage.

The scale of investment needed to enable this transition towards a sustainable long-term future will be huge, with the majority of the necessary capital coming from the private sector. Private investment is very sensitive to the quality of governance, and clear price signals are crucial for driving rapid changes towards growth that embodies high quality, high-tech, and sustainability. Sound policy measures should further strengthen the role of the market in the allocation of resources, particularly with regards to getting markets to give better signals, by overcoming market failures.

The purpose of this article is to describe and analyze the purposes, challenges, risks, market failures, and government policies related to

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[1] https://www.climatewatchdata.org/net-zero-tracker.

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tackling climate change and creating sustainable, resilient and inclusive economic development. The plan of the paper is as follows:

Section 2 outlines key challenges facing all countries in building a carbon neutral economy, including the immense risks and uncertainty from climate change, and urgency of action required on climate change, together with the need for a new understanding of development approaches, exploring and implementing new technologies, innovations and investments. The challenges include managing the dislocation that will inevitably be part of rapid and fundamental change during the transition.

Section 3 then discusses several major, and crucially relevant, types of market failure and cases where critical markets are entirely absent. An analysis of how markets can work or fail provides the foundation for assessments of desirable government interventions and policies to respond to climate change and promote carbon neutrality. Central to this analysis is an understanding of the role and nature of key market failures, which will allow governments to construct and implement policies that counteract these failures. The necessary policies should also take careful account of distributional issues. Some issues are raised briefly in Section 3.

I then introduce the role of government in tackling market failures and facilitating carbon neutrality in Section 4. First, I argue that governments must form a broad understanding of the key elements of an effective carbon neutrality strategy. Second, governments must work toward overcoming market limitations, such as by pricing carbon, allocating more resources to innovation and R&D, intervening to promote more effective capital markets, fostering more efficient networks, improving information for consumers and producers, and reducing pollution levels. Third, the paper examines how institutional structures and methods can be developed for measuring and tracking progress towards carbon neutrality.

Section 5 emphasizes the importance of a cohesive government structure to facilitate the realization of a carbon-neutral economy, promoting climate policy implementation across multiple government agencies to ensure a coherent approach to what is inevitably a complex and inter-related set of economic and social systems.

The last section concludes.

2. Key elements of the challenges for the world in reaching carbon neutrality

In tackling climate change, promoting sustainable development and building a carbon neutral economy, the world must understand and act on five major areas of challenge. Though diverse, they all stem from the immense risks of climate change and the overall tasks of changing global systems rapidly.

The first challenge comes from the huge risks and uncertainties associated with climate change. Combatting climate change involves managing risks of enormous magnitude and multiple dimensions (temperature, rainfall, humidity, wind speed, sea-level rise and storm surges, and so on), which could destroy lives and livelihoods across the world, displace billions, and lead to widespread, prolonged, and severe conflict. Moreover, the relationship between average temperature change and those extreme events can be highly non-linear. A slight shift in the probability distribution of temperatures can increase the incidence of extreme events, and thus the economic costs, significantly. Further, some physical and biological systems may be unstable, with risks of runaway effects and destabilizing feedbacks.

In determining the pace and magnitude of climate change, tipping points such as the thawing of the permafrost and the resulting release of methane, the collapse of the Amazon Rainforest, or the melting of West Antarctica's ice sheets, embody huge risks. Such phenomena could unleash unstable processes, greatly accelerating the possibility and magnitude of devastation. The fact that we do not fully understand the highly non-linear processes associated with these tipping points—including the extent of climate change it will take to trigger them - is just one aspect of the uncertainties associated with climate change. Therefore, we need economic analyses with methodologies that take account of extreme risks, including possible large-scale unforeseen consequences whose nature may be difficult to describe, and where it may be difficult or impossible to define probabilities. And we must recognize that such risks could involve destruction of lives and livelihoods across the world, with hundreds of millions of lives at risk.

The second challenge is the sense of urgency. To understand that urgency, we must understand the potential consequences of the temperature increases that are now possible and the actions necessary in the coming years if the probabilities of such temperatures are to be radically reduced. The world has not seen an increase of 3 °C for around 3 million years, at a time when sea levels were 10–20 m higher than they are now (Dumitru et al., 2019). Many areas would become extremely difficult for habitation and hundreds of millions, perhaps billions would have to move, with great risks of prolonged conflict. Those that could not move would be in extreme danger. The IPCC 2018 Special Report showed that risks associated with a rise of 2 °C are far higher than those associated with an increase of 1.5 °C (IPCC, 2018). The risks of 4- and 5- °C increases, which are possible in 100 years or so if we fail to act, could bring still more devastating effects. Although the world has set the goal of reaching net-zero carbon emissions within 30–40 years, the path towards net zero is of critical importance, as it is the sum total of carbon emissions over time that is of the essence. Indeed, to keep the target of 1.5 °C within reach, world emissions should fall by over 40% in this decade. Action at scale is urgently required. The world's stock of infrastructure will double in the next 15 or 20 years, and the decisions shaping this infrastructure will be made in the next few years. This decade will be decisive and it is essential to avoid lock-in of dirty forms of physical capital. We must also invest strongly in natural capital, both for the achievement of net zero - it can give negative emissions - and to protect biodiversity.

The third challenge is the need for a different understanding of development approaches. A number of economists have argued for a new growth model focusing on four central types of capital, including physical, human, natural, and social capital (Stern, 2015; Hamilton and Hepburn, 2017; Managi and Kumar, 2018; Lange et al., 2018). This is very different from the traditional economic model with a narrow focus on an output objective, where output is a function of physical capital and human capital. This new approach also sees objectives much more widely, including a focus on wellbeing. When combined with an understanding of the potential of new discoveries in technologies, this approach does not imply a tradeoff between the environment and material living standards. On the contrary, we can and must advance both together. This new approach to growth sees the drive to net zero as a key part of the growth story of this century; growth which is sustainable, resilient and inclusive.

The fourth challenge concerns technology. Though many new technologies are coming down the track, we cannot have a full and precise understanding of how they will function. Innovation and R&D are necessary to foster and deploy the necessary technological progress. Just as important as the sense of urgency for this decade, is the need to look forward to determine appropriate paths of investment and innovation for the next two to three decades.

The final challenge relates to dislocation or disequilibrium during the pursuit of carbon neutrality. Rapid technical and systemic changes in the economy often result in increasing returns to scale in discovery and production, and correspondingly lead to rapid changes in (endogenously determined) beliefs and preferences. At the same time, they place potential disruption and disequilibrium at center stage. Radical change inevitably involves dislocation, with the disappearance of some activities and jobs and the emergence of others. Some relative prices will shift dramatically, with significant consequences for households and firms. For example, people currently working in coal mines may very quickly have to find new jobs because of sharply falling coal usage. Some goods and services will become more expensive in the short to medium term, including air transport, and parts of heavy industry. Dislocations will occur on both the production side and the consumption side. If people encounter major dislocations without protection, they may resist, slowing down the entire process of reaching net-zero. Thus, effectively managing such dislocations is a crucial component of maintaining equity and the pursuit of carbon neutrality.

3. Market failures, market absence, and distributional issues

Discovery, entrepreneurship, innovation and behavior will be at the heart of the transition to net zero. It is not realistic to suppose that these could be realized without markets and incentives. At the same time, as we shall examine below, there are key market failures, and market absences, which can distort decisions and impede progress.

Thus, it is crucial that both the power and failures of markets are recognized.

3.1. Market failures

The negative externality of GHG emissions is the most commonly recognized market failure associated with climate change. Pricing carbon, including through instruments such as carbon taxes and carbon markets, are all designed to combat this externality which arises because of the damage that emissions inflict on others. Standards and regulation have a role to play in the context of increasing returns to scale and basic uncertainties, circumstances in which carbon prices and taxes alone cannot overcome market failure (see, e.g., Weitzman, 1974, Stern and Stiglitz, 2022).

If the GHG externality were the only market failure (and with diminishing returns to carbon action and without uncertainty), then basic Pigouvian theory suggests that the "optimal" solution would be a "corrective" tax equal to the marginal damage caused by the externality. Such an intervention aligns social costs and benefits with marginal private costs and benefits (e.g. Sandmo, 1975). But increasing returns and uncertainty imply the need for additional tools, such as regulations with quantity constraints. And given that systemic change is central, system design (e.g., transport networks and city zoning) will be essential. There is a large literature demonstrating the desirability of interventions beyond a corrective tax, in the presence of imperfect information, incomplete markets, and limited redistributive tools (see, e.g. Atkinson and Stiglitz, 1976; Stiglitz, 2018; Weitzman, 1974). These features are strongly relevant in the context of climate change (Stern 2007, 2015; Stiglitz, 2019; Stern and Stiglitz 2022).

The second market failure relates to innovation and research and development. Ideas are extremely important public goods, but the nature of the innovation process is such that it generates large spillovers and positive externalities. Because knowledge is a public good, it must be publicly supported. Innovation is hampered when prior knowledge cannot be used efficiently as an input to research processes; an inevitable consequence of strong intellectual property regimes. On the other hand, private producers of knowledge are not able to realize the full social value of the knowledge they produce in the absence of restrictions on the use of prior knowledge. This means that the unaided market will not give sufficient incentives to idea originators. When it comes to climate change, a consequence of failing to discover, or ignoring knowledge about the returns of different research strategies (such as cheaper ways of doing things) would lead to exaggerated cost estimates, acting as a bias against action on the scale needed. Given the immense potential costs of delay and that discoveries bring down the cost of the public good of emissions reductions, these arguments acquire special importance in the context of climate change.

The third type of market failure concerns capital markets. If capital markets had no imperfections, there would be no limitations on the ability to borrow at the given market price. However, for many reasons, including around information and creditworthiness, capital market imperfections are prevalent and credit rationing is widespread. A consequence of capital market imperfections is insufficient investment, particularly in areas where price signals may not be working well and uncertainty is large, as is the case with climate change. For example, investments in solar panels or better insulation might easily pay off in a world where capital is accessible at the Treasury bill rate, or even twice that, but not at the high cost demanded in markets which take account of credit constraints (Stern and Stiglitz, 2021). Managing, sharing and reducing risks often requires special institutional structures, such as development banks, which help put together coalitions of different players capable of managing and taking different kinds of risk.

Furthermore, capital markets and firms can be shortsighted, placing excessive weight on the near term. In part, this results from deficiencies in corporate governance when the objectives of the organization are not the same as those of either society or decision-making managers.

We should also be very clear that market decisions reflect the objectives of market players, usually acting on their perceived assessment of their own interests. The interest rates or rate of return that may emerge do not represent moral values, or valuations of overall welfare, or rights across generations.

The fourth kind of market failure is associated with networks. For example, electricity grids, public transport, and reusing and recycling all require networks that are crucial for the future of the planet. In networks the actions of one participant affect opportunities for others, hence an externality. There is an extensive need for coordination among participants in such networks, which requires "rules of the game" or public intervention, if they are to work well. Markets do not sufficiently account for the role of interdependencies between linked participants in a network and the systemic risk that networks can create (Catanzaro and Buchanan, 2013; Hendricks et al., 2006; Schweitzer et al., 2009).

Fifthly, in the processes of change involved in the transition, information, including around new products and the carbon content of products, is particularly important. Consumers will want to know carbon information around their available choices, while producers will want to know different ways of producing goods, as well as how consumers' preferences may be changing.

The sixth market failure, which is hugely important, is associated with pollution, biodiversity, and other co-benefits. Burning fossil fuels harms biodiversity and pollutes air, water and soil. Around 10 million of the world's annual 50 million deaths are closely associated with air pollution. If we move away from fossil fuels, the world will benefit enormously. Yet without public action, the market will not provide the right signals around these other co-benefits. In many cases, standards and regulation are the instruments adopted to control air pollution.

There are, in addition, key issues, beyond market failures, around structural and systemic change which are central to the transition. Indeed, the transition is in large measure about structural and systemic change. The most important of these systems are cities, land, energy, and transport. The operation of such systems depends heavily on design and governance. A strong carbon price has an important role to play in the efficient management of this process of systemic change. However, we must be clear that a carbon price alone does not re-design cities to reduce congestion and pollution. Nor does a carbon price necessarily promote circularity in the design and use of products, systems and buildings. These features will require direct public action for design and reform.

3.2. Absence of key markets

Beyond these market failures, there are also important absent markets. Such absences mean that expectations are crucial for investment. These can and should be shaped by public strategies and actions that set out direction or change over the medium and long term. The processes of investment and innovation are at the heart of the transition. And as economists from Schumpeter to Keynes to Hayek have stressed, the expectations are central to investment.

One central example of such absences concerns long-term prices of carbon, which could guide forward-looking behavior in climate change mitigation. Such markets do not exist. Managing climate change will require some new technologies, and in some cases we cannot yet be clear about what these will be. Hence markets for them do not exist.

The role of expectations in shaping innovation and investment is illustrated by the rapid technological progress generated since the Paris agreement (UNFCCC, COP21) of December 2015 (Systemiq, 2020). This did indeed change the expectations of many about the importance and likelihood of strong shifts towards low-carbon activities.

The experience of rapid changes as expectations and policies shift towards the low-carbon transition has been in the presence of only modest policy and commitment. This suggests that these processes could be strongly accelerated by stronger commitment and policies.

3.3. Distribution

The impacts of climate change are not borne equally. The poorest people are usually the ones hit earliest and hardest by climate change, as they live in more vulnerable areas, are less-well insured, and have weaker coping mechanisms. Though they are among the most adversely affected, these people are the least responsible for the emissions that cause climate change. Under most value systems, the adverse effects impacts experienced by poorer people would be weighted more heavily than those affecting richer people. Impacts within a generation vary across age, gender, location, and income. Such inequalities should be taken carefully into account by policymakers within a country. They should also influence the understanding of obligations across countries.

There are also crucial distributional issues across generations. Future generations do not have effective proxies to work with the current generation, making redistribution between the current and future generations difficult to arrange. In the case of climate change, the current generation is making decisions that will affect future generations. Any discussion on the appropriate response to climate change must, therefore, deal with deep issues of values (i.e. how we treat future generations relative to ourselves). An understanding of obligations to future generations would strongly influence the intensity of action on climate change, including the price placed on carbon. If this generation cares little about the welfare of future generations, the price of carbon would be correspondingly low.

Ineffective action to tackle climate change could generate a climate so hostile that future generations would be much worse off than we are today. As a consequence, the expenditures expected today to reduce the risks for future generations can be very high. These issues are around social discounting, but it should be clear from this argument that discounting will be critically shaped by our perception of future living conditions and these in turn depend on our actions now. For further discussion of discounting see *Why are We Waiting?* (Stern, 2015, chapters 5 and 6).

There will also be important distributional issues in managing the transition to a carbon-neutral economy. For example, coal mining will be phased out. Thus, those who earned their living there are likely to require help in finding new activities or income support. There will be those who suffer, particularly from higher prices for high carbon products. These are challenges of managing a "just transition".

4. The role of government in overcoming market failures, fostering systemic change, and facilitating carbon neutrality

The market failures and the absence of key markets described in the previous section provide an analytical foundation for formulating the right kind of government policy. These issues should be combined with those of systemic transformation and questions of distribution.

4.1. Agenda for governments to correct market failures and inefficiencies

For markets to play a constructive and effective role in guiding investment and innovation toward a low-carbon future, governments must analyze and act on market failures. Appropriate interventions involve standards, regulation and design as well as setting prices, taxes, subsidies and market structures (Hepburn, 2010). We begin with the discussion of prices for carbon.

Broadly speaking there are two ways of thinking about the price of carbon. One is in terms of the net present value of the incremental damage to all future people and activities arising from an extra unit of carbon emitted today. A second is the marginal cost of reducing the emissions of carbon by one unit. The former is often labelled the SCC or social cost of carbon and the latter the MAC or marginal abatement cost. In a perfect economy, with all markets present and perfect, with convex preferences and production possibilities, including increasing marginal abatement costs or diminishing returns to carbon action, with limited risk and uncertainty, and with the availability of lump-sum transfers, the SCC and MAC would be equal, at an "optimum" which maximized a social welfare function of a particular structure. However, we clearly do not live in a world which can plausibly be described by such assumptions. Thus, the SCC and MAC may differ, even when policy is set carefully and well. In the literature on public economics or social-cost benefit analysis we can build systems based on consumer prices (here SCC) or producer prices (here MAC).

For example, after reinstating the US to the Paris Agreement, President Biden issued an executive order establishing an Interagency Working Group on the Social Cost of Greenhouse gasses (also referred to as the social cost of carbon, SCC). SCCs can be used as a shadow price in government cost-benefit analysis. They can also inform internal prices by private firms and calculations of possible carbon taxes. This wide range of uses means that it is important to approach attempts to calibrate the SCC with great care.

4.1.1. Estimates of the price of carbon

Stern and Stiglitz (2021 and 2022) suggest that the most suitable approach to carbon pricing is to look at the prices that could guide the economy toward trajectories that would limit the increase in temperature to 1.5 to 2 °C. We advise that because the world has come together to suggest such a goal and because this approach to prices is much more robust in the sense that it is less sensitive to the specific assumptions around models, functional forms and parameters. Calculations of the SCC are highly sensitive to such assumptions as we illustrate below.

SCCs are usually calculated from Integrated Assessment Models (IAMs). We sketch the logic briefly in what follows. The standard IAMs sees society as if there were a representative agent who has infinite life and an objective of maximizing intertemporal utility **W**, constrained by resources. They use dynamic equations to describe the co-evolution of capital accumulation and the economy. A time-separable utility function ***U*** is used to describe intertemporal welfare, and it can be written as ***U*** (**C, E**) when assuming a single aggregate consumption variable (C) and an environmental variable (E). In order to align private incentives with public decision-making, it is crucial to determine the appropriate price of carbon. And how much we are willing to spend on the improvement of the environment today can be measured by the marginal social cost (MSC), as

$$(1)\ \mathrm{MSC} = (\partial W/\partial \mathrm{E})/U'(C_0),$$ [2]

where C_0 represents the current consumption. Thus, the optimal carbon and capital accumulation trajectory can be calculated by setting the marginal carbon abatement cost equal to the marginal social cost of carbon, and carrying out corresponding optimizing calculations, including for paths of capital accumulation, along the whole time trajectory.

[2] See more details in section 2.1 of Stern and Stiglitz (2022).

Ignore risk for now, the Hamiltonian can be written as[3]

$$(1)\quad H \equiv U(C) + P_E \psi + P_K \Omega + \gamma \Gamma,$$

where P_K represents the shadow price of capital, P_E represents the shadow price of carbon, ψ= dE/dt and Ω = dK/dt, and Γ are constraints on government mitigation policies and costs of government actions to reduce carbon. We assume that the set of controls {C(t), e(t)} $\equiv$ a are constrained to a set which for simplicity we express[4] through Γ (a) = 0; where e is the flow of carbon corresponding to the stock E.

To take into consideration the immense risks from climate change, one solution is to add an additional constraint to the Hamiltonian, which is that the temperature – represented as a function of the state variables of the environment in the model – never reach 2 °C above pre-industrial levels. The logic for this kind of constraint in the presence of extreme risk is examined in Stern and Stiglitz (2022).

With this additional constraint in place, we can calculate, in terms of marginal damages, the social cost of carbon along a path where temperature is constrained below 2 °C.[5] The social cost of carbon calculated in this way corresponds more closely to, but is not the same as, that provided by the Stern-Stiglitz Commission (2017). The Commission examined the prices of carbon that lead, over time, with markets *as they exist, modified by government climate interventions, to* achieve the goals of the Paris Agreement, which includes holding temperature increases to well-below 2 °C.

The above calculations, even with the 2 °C constraint, continues to focus on "consumer prices" rather than "producer prices", whereas the Stern-Stiglitz Commission (2017) took the latter approach.

As the 2017 Stern-Stiglitz report of the international carbon pricing commission that we co-chaired emphasized, the producer prices that can lead to the satisfaction of the temperature constraint should be accompanied by other government interventions which should be shaped alongside the prices. The report suggested a price of $50 - $100 per ton of CO_2 for 2030. Since then, the Paris Agreement target has been set at 1.5 °C rather than "well below 2 °C" as ambitions strengthened, and carbon emissions have continued to increase, implying that the top of the price range indicated in 2017 (i.e., $100 per ton of CO_2) would be more appropriate.

4.1.2. R&D and innovation policies

Even with an appropriate carbon price, private sector allocations that influence the level and direction of R&D innovation may not be socially desirable because ideas are public goods. Without public action, private entrepreneurs will not be able to capture the full value of their discoveries. This is of special importance here because the use of the ideas to reduce carbon itself promotes a public good, and further that there are severe social costs to delay.

Market failures in R&D and innovation imply a need for government intervention, such as promoting R&D and innovation through carefully managing the intellectual property framework. In addition, a range of other tools are available, including providing subsidies for publicly funded research and, in some cases, for publicly produced research, which tends to trigger private research (Eurostat, 2020).

The impact on private R&D investment over time must be taken into account when evaluating pricing and regulatory policies. Regulations are able to raise the shadow price of carbon, and this can be done in ways that may help focus attention during the innovation process. In a world where markets, contracts and regulatory norms (as a function of the state of nature) are incomplete, regulating quantities is better than setting prices. In the context of innovation, there could be even greater advantages of quantity regulation because in this case researchers would focus more on meeting a specific goal, rather than analyzing ways to reduce production costs. When it is likely that the costs of not achieving a particular goal are extremely high (nonlinear damage function), it makes sense to encourage researchers to focus on achieving the goal.

Therefore, governments should work with the private sector to allocate more resources toward transforming technologies and discovering new ways of doing things. For example, it is possible to make steel without using fossil fuels, which is happening now through the use of hydrogen. However, this is still a topic that requires a great deal of further research and development, particularly around cost reduction. The digital management of systems is another area with tremendous potential that also requires further R&D.

Increased attention on climate change has resulted in soared innovation. This indicates that there are numerous possibilities. For instance, there are a variety of low-emission technologies that have become available and even competitive with fossil-fuel-based technologies in the absence of targeted subsidies or carbon pricing. This is already the case for renewable generation in many parts of the world and can be true of electric vehicle technologies in the near future. A majority of these significant changes were not predicted or reflected in the standard model. As argued by Systemiq (2021), about a quarter of emissions are coming from sectors where low-emission technologies are already cheaper than their fossil-fuel-based counterparts. This proportion could grow to three-quarters over the next decade, should there be relevant supporting policies in place.

4.1.3. Policies to correct other market inefficiencies

On the remaining market inefficiencies identified in Section 3, we consider first those of the capital market. There are problems associated with the ability of different agents to convey risk and there are limits to the ability of any agent to carry risk. There are important issues around information about counterparties and the nature of the risk itself.

There are different methods for managing risks within imperfect capital markets, one of which is development banks. For example, development banks can take early-stage risks and provide equity in infrastructure projects. Beyond market players, governments can also help in reducing, managing, and sharing risks through, for example, feed-in tariffs or contracts for difference in electricity supply or speeding up provisions of necessary permits. Furthermore, private capital markets are not sufficiently sensitive to the macroeconomic externalities arising from sectoral reallocations, for example they can together make large quantities of sub-prime loans in housing which together can destabilize the economy.

The second in the group of additional market failures are those related to networks. Here, governments can also play a crucial role in facilitating the development of reliable and efficient networks such as electricity grids, public transportation, and reusing and recycling via the circular economy. In many countries around the world, electricity grid limitations are a major disincentive against low-carbon development. The UK has developed quite an advanced capacity for offshore wind and grid functioning. However, this process requires bringing the electricity to the shore, building stations on the shore to manage that electricity, and then transmitting the electricity across the country, often with high-voltage DC cables. Managing the politics and economics of such grids can be quite complicated and difficult.

In China, the grid structure has been historically tilted toward fossil fuels and against renewables, but the country has become a world leader in renewables despite the obstacles presented by its grid structure. In France, Électricité de France running generation and RTE running transmission are powerful state owned near-monopolies. There is a lot of sunshine in southern Europe, particularly in Spain, where land has little value. This would be a tremendous place to expand solar power, but grids are required to export electricity northwest through Europe. The capacities of the grid system in France act as an obstacle preventing the export of electricity from Spain into France. In these three examples, enhancement and reform of the functioning of the grid structures in the

[3] See more details in section 2.2 of Stern and Stiglitz (2022).

[4] Given {K,E}, specifying {C, e} implies a particular level of investment.

[5] See Dietz and Venmans (2019).

UK, China, and Europe are crucial in the process of expanding renewable energy.

The third of the additional market failures concerns information. Governments can act strongly when it comes to labeling requirements on certain products. Many consumers now want to understand the origin and carbon content of the things they buy, which is information that governments can insist companies provide. There can be technology hubs too, for example around universities, to help share knowledge on new technologies.

Finally, it is essential for governments to act strongly when it comes to pollution. Relevant policies should include standards and regulations on air pollution and emissions from vehicles. Examples where this is combined with pricing concern ultra-low emission zones, such as in London where higher polluting vehicles pay much more to enter.

Government policies play a critical role in tackling market failures in each of these cases. It is surely clear that in the world we live in, with multiple market failures, we cannot rely on just one instrument such as carbon pricing. However, we should emphasize that carbon pricing is top of our list of instruments and should play a central role.

We should also emphasize that tackling the market failures we have described, vitally important though it is, would not be sufficient to guide the radical change in each of the core systems of the economy—energy, land, cities, and transportation – that will be necessary. Such change requires a level of complex coordination that goes far beyond standard pricing, especially in the presence of multiple market failures. Markets alone do not typically manage these sorts of changes well. For example, within cities, we can see that transport, residences, and workplaces interact very powerfully. Government interventions to manage congestion and building efficiency will necessarily involve design, zoning, regulation policy, and so on (Coalition for Urban Transitions, 2019).

As emphasized in Section 3, the radical transformations involved in the transition will require policies that can help manage the inevitable dislocations. Continuous investment in people and places affected will be critical, to drive forward the transition from old activities to new, and ensure adequate social safety nets. This is a major policy challenge, that of a "just transition", but we do not go into this in detail here.

4.2. Measurements of carbon neutrality

In order to incentivize and mobilize agencies across government to work toward carbon neutrality, we should design metrics and indices against which actions of every government agency will be measured and assessed. For example, a carbon neutrality index or carbon neutrality indicator applicable across different actors and agencies would be valuable. There is also great value in an agency to chart, examine and assess progress in the economy as a whole. Careful consideration should be given to the institutional structures that could deliver these two functions. For the latter, in the UK, we have the Climate Change Committee.

From a bottom-up perspective, companies are also declaring that they want to work toward net-zero emissions. Again it will be of value to form a deeper, shared understanding of companies' strategies and how to measure the success of their implementation. The actions of individual companies will also drastically affect their supply chains, so the system of carbon footprint measurement and strategies for reaching net-zero will have far-reaching consequences. Again, institutional structures matter and we have seen a valuable initiative in the Task Force on Climate-Related Financial Disclosure (TCFD). This requires financial institutions to reveal their "climate exposure". It will soon become compulsory in the UK.

Measurement and management will be of special importance in transport and power ministries, as their measurements will be crucial in revealing how the emissions in those sectors are changing over time in the context of long-term goals. Systems of measurement should be based on broad principles in terms of carbon content, carbon trajectory, and supply chains. From these broad principles, we must craft specific measures relevant to each major area of activity. Measurement and management of land systems will also play a key role.

Around 70% of global emissions come from cities and measurement and management will be vital here too. Effective progress toward carbon neutrality will require a broad set of principles around different kinds of emissions, including short-term, current, and future footprints in cities. Clear principles applicable to all sectors of the economy to standardize reporting, increase the availability of information, and bring clarity to plans for the future can help drive action forward and to manage effectively and efficiently.

5. Government structure on the path to carbon neutrality

The transition is about fostering rapid and far-reaching structural change. Thus, it is crucial to act coherently right across the whole economy, across all parts of government, and across geographies and levels of government. Therefore, the structure or organization of government is of great importance on the road to net-zero carbon emissions.

Emissions arise from almost all aspects of society and the economy. Therefore, it does not make sense to separate environment and ecological issues from investment by line ministries. For example, China placed the challenge of climate issues in the hands of the Ministry of Ecology and Environment (MEE) a few years ago. The MEE has played a kind of supervisory role, monitoring and limiting certain activities. However, the drive to net zero is about "making things happen" and generating entrepreneurial ideas and solutions. To reach net-zero from a whole economy perspective, it is reasonable to have an institutional structure, led from the most senior levels, to foster the right kind of investment, innovation and change across the whole economy. Responsibilities should be focused in institutions that look across the whole economy and the entirety of investment procedures. China's National Development and Reform Commission (NDRC) should surely have a central role. The Ministry of Finance and the central bank are also significant players in such a strategy.

Beyond China, a more broadly applicable approach is to embed a carbon neutrality strategy into every ministry, making each ministry responsible to the prime minister or the president for what they're doing in the area of carbon emissions. A whole "system of government" approach is needed to reach the world's ambitious climate goals.

The UK has the Climate Change Committee, which sets targets for 15 years in the future that it believes will be necessary in order to follow an effective and efficient path toward net-zero. This committee is beginning to closely monitor what is happening in different parts of the economy so that it can raise alerts to early problems and challenges. This is a valuable example of how an independent institutional arrangement can contribute to clarity on both strategy and delivery, even though it is not itself an arm of government or delivery.

6. Conclusion

This paper first discusses fundamental challenges facing the world in building a carbon neutral future. Discussion must be anchored in a recognition of the immense potential risks associated with poorly managed climate change. That recognition leads us quickly to an understanding of the great urgency. All countries must act strongly starting now. As we examine the nature of necessary action, we can see that we have in our hands a new approach to our model of economic development. It is a far more attractive approach than the dirty and destructive models of the past. And we must recognize that the process of reaching carbon neutrality will require rapid, fundamental changes, which will inevitably lead to dislocation and disequilibrium across the economy.

Whilst markets and entrepreneurship will be at the heart of this new approach to growth and development, markets alone are not equipped for solving all the challenges, for three main reasons. First, many markets vital for addressing climate change have exhibited critically important failures. The standard methodological approaches in the economics of climate change have largely focused on the GHG externality, the most commonly discussed market failure. While other types of market failures, such as those associated with R&D and innovation, capital markets, networks, and co-benefits of limiting climate change, are also important elements of market inefficiency. Second, there are also important absent markets, such as those to take into account future carbon prices and new technologies. The absence of key markets places expectations at center stage and here there is much the government can do to help set these in directions that can encourage investment. Third, so much of what is necessary involves system change and prices alone cannot manage such complexities.

There is so much that economic analysis can contribute to the formulation of government policy to guide and incentivize the fundamental change we need and to realize this new approach to growth as we manage climate change and foster sustainable, resilient and inclusive growth. It will need the coordination of the full range of our subject and the development of some new economics. That has been the central argument of this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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