frontier economics

CARBON POLICY AND ECONOMY-WIDE PRODUCTIVITY

A report for the Energy Systems Catapult

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CATAPULT Energy Systems

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EXECUTIVE SUMMARY

Rethinking Decarbonisation Incentives (RDI) is a major project led by the Energy Systems Catapult (ESC) exploring how UK policies can promote clean growth by taking a ‘whole systems’ approach to carbon policy. The ESC wants this work to promote a debate about how carbon policy can be improved to stimulate innovation and productivity. The effects of carbon policy (i.e. economic incentives relating to actions to reduce carbon emissions) on emissions are well researched. There is less explicit discussion of how carbon policy might influence economy-wide performance, economic competitiveness, innovation and productivity over time. This report looks to address this knowledge gap by exploring the links between carbon policy and productivity.

Productivity could grow now and into the future with proper carbon policies

UK greenhouse gas emissions have fallen by over 40% since 1990 while the economy has grown by about 70%. Greenhouse gas emissions are currently largely unpriced – or underpriced – in productivity measurement (which focuses on GDP per capita or per hour worked) so the benefit of those reductions (less damaging, higher quality goods and services) is not fully reflected in official statistics. On current valuations, avoided CO_2 emissions are worth about 0.4% of GDP today, with their value expected to increase to circa 1% to GDP by 2030 and arguably more into the future. Properly measuring them would provide a better measure of productivity change since 1990 and into the future.

More importantly, proper measurement would provide more accurate signals to help improve future productivity by directing money, jobs and effort into sectors more likely to grow.

Productivity (measured as GDP per hour worked) grew at around 2%-3% per year from the 1970s until the early 2000s in the UK and comparable countries like Germany, France and the USA. Since the global financial crisis a decade ago, productivity in the UK has been largely stagnant while some other countries have seen modest increases (ca. 1% year on year in the USA and Canada). Had productivity in the UK grown in line with trend over the past decade, it would be around 20% higher than it is now.

The importance of environmental and carbon policy in relation to productivity is clearly acknowledged in current policy through the Industrial Strategy, the Clean Growth Strategy and the Grand Challenges (e.g. the introduction of the Emissions Intensity Ratio to report on delivering economic growth and reduced emissions, the early funding of initiatives such as the Faraday Institution on battery technology). Given the importance of clean growth, it is notable that the Strategy is missing a clear articulation of how carbon policy links to productivity growth. Such a framework would help to guide policy.

We have developed a new analytical framework – building on well-established economic theories differentiating between immediate, medium and longer term effects – and carried out a Rapid Evidence Assessment of existing literature in order to answer four questions posed by the Energy Systems Catapult:

Question 1	Through what mechanisms do carbon policies influence productivity?
Question 2	Does the choice and design of carbon policies affect the capacity of the economy to innovate?
Question 3	Does the choice and combination of carbon policies have any particular implications for productivity over time?
Question 4	How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

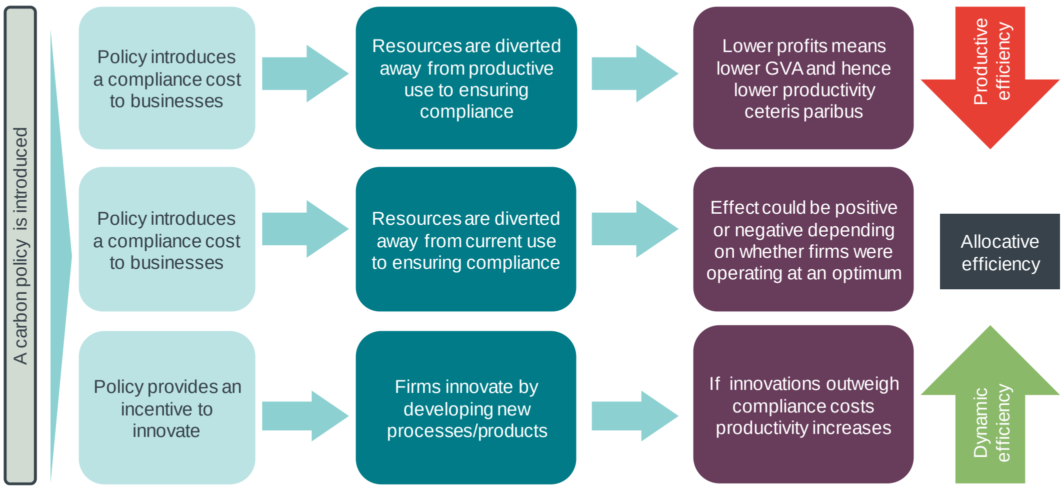
The review of existing literature suggests how we should think about incorporating carbon policy into wider economic policy

The most commonly used productivity measures are currently based on GDP (e.g. GDP per worker, GDP per hour worked) and as such do not account for the value of avoided emissions. The evidence we have reviewed uses traditional productivity measurements which don't capture the value of avoided emissions.

Question 1: Through what mechanisms do carbon policies influence productivity?

There is significant literature looking at how environmental policies in general, and carbon policy in particular, can affect productivity. The effect can be negative or positive depending on the response of firms to the policy. In the short-term the policy may represent a cost to firms and so can reduce productivity. However, for firms who are not optimising their current use of inputs then, even in the short run, carbon policy can improve productive efficiency.

Separately, there is a dynamic effect whereby carbon policy can stimulate innovation which can improve productivity if the innovation outweighs the cost of compliance with the policy – an idea first introduced by Porter (1991) and tested empirically in numerous studies. The potential effects of carbon policy on productivity are summarised in the diagram below.



Question 2: Does the choice and design of carbon pricing policy affect the capacity of the economy to innovate?

There is a considerable body of evidence about the link between carbon policy and innovation (typically measured R&D expenditures or successful patent applications). In the main this finds strong positive links between the two. The evidence is particularly strong for market based policies: recent work has found that the EU ETS has increased low-carbon patenting by almost 10% without crowding out other innovation. Other work looking at general environmental policies (typically proxied as environmental stringency) also finds positive links with innovation.

It is often thought that more flexible policy instruments (e.g. market based policies such as carbon taxes or cap and trade schemes) can achieve environmental goals and better economic outcomes than more prescriptive policies like standards. It has been argued that more prescriptive policies may fail to provide an incentive to innovate beyond the point at which a standard is met while market based instruments provide a continuous incentive to innovate. This is supported by much of the literature that was reviewed but there are also papers which do not find different effects of alternative approaches.

On balance the literature suggests that market-based policies may be more effective at promoting innovation but some research indicates that other policies (if well designed) can be potentially as effective.

Question 3: Does the choice and combination of carbon policies have any particular implications for productivity over time?

There is a long established literature looking at the links between innovation and productivity which finds that innovation drives productivity. There is less research looking to link carbon policy and productivity directly. The research we have identified broadly indicates that carbon policy can have a positive effect on productivity, albeit the measured effects to-date are relatively small.

Existing research on the productivity effects of carbon policy struggles to separate out the specific circumstances of the policy being examined from the more general impact of the policy applied in a range of settings. The results of analysis to-date are usually context-specific and provide limited general policy guidance. There are also significant gaps in the evidence base. Most notably, there are few studies examining the macro effects of these policies (i.e. impact on overall productivity or GDP growth).

Given the relatively strong evidence base suggesting a positive link between carbon policy and innovation and the well-established link between innovation and productivity, it is reasonable to conclude that carbon policy can have a positive effect on productivity. Whether or not the type of carbon policy matters for productivity is less clear from the literature.

Question 4: How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

This is an area for further work to better inform policy-makers how much focus to put on carbon policies. The transformation that would be needed to reach net zero, for example, would have widespread implications that the current empirical evidence on productivity does not address.

The research that does exist is very context specific. It examines the effects of a specific policy over a specific time period applied to a specific set of firms. As such it is difficult to generalise and extrapolate what the findings may mean for the economy as a whole. Our interpretation of the available evidence is that carbon policy may contribute a small boost to productivity growth (up to a maximum of 4% per year for a limited period), although the literature suggests that this is temporary and the effect is likely to be close to zero in the long run. It should also be noted that this estimate is a judgement and highly uncertain given the relative lack of evidence looking at the economy wide effects of carbon policy.

However, the aforementioned transformation to reach net zero would imply impacts of carbon policy on much larger drivers of productivity. For example, research by NIESR[1] suggests that improvements in skills account for around 20% of labour productivity growth in the UK in recent decades. Shifting to net zero would imply considerable changes in skills (and other drivers of productivity) that could ultimately feed through in material ways to measured productivity growth.

UK national, regional and local governments should consider reflecting carbon in productivity measurement and implement policies that recognise the link between carbon policy and changing economic activity, innovation and future productivity growth

Our findings lend themselves to three conclusions for policy.

First, policy needs to be informed by more complete measurement of productivity. Traditional productivity measurement does not account for the positive value of output produced with lower emissions. In effect a cleaner economy is also a more productive economy both today and, more significantly, into the future. The importance of clean growth within the overall Industrial Strategy suggests that **the Industrial Strategy Council should consider how its interpretation of productivity and future productivity growth is affected by proper measurement and valuation of carbon abatement**.

Second, carbon pricing and environmental standards help drive innovation in the production of less environmentally damaging outputs. The appropriate policy and length of time to deliver new innovation will vary from sector-to-sector but the existing evidence suggests a strong link between the two.

Third, carbon policies need to adapt to the specific context to improve aggregate productivity. The evidence suggests that the success of carbon policies in driving traditional measures of productivity improvement is variable. The choice of specific policy (e.g. tax, standard, strategic investment) is likely to be less important than how well the chosen policy is adapted to the particular context in which it is applied.

It is seldom the case that policies are implemented in isolation. In the 1970s many environmental policies relied on direct regulation but since the 1980s policymakers have considered and often selected market based instruments. Often these have

[1] NIESR (2015), “UK Skills and Productivity in an International Context”, BIS Research Paper Number 262

been introduced alongside direct regulation as well as strategic investments by government: for example, the combination of market reforms that led to contracts for difference (CfD) in the power sector (guaranteeing demand for low carbon technologies) combined with significant strategic investment in offshore wind development.

It appears that how a policy is designed and how it is implemented matter more for its success as the initial choice of policy instrument. Factors such as the credibility and stability of a policy are likely to be as important as the type of policy (market based vs. technical standards vs strategic investment).

The integration of policy linked to growth, productivity and the low carbon transition would be helped by better understanding the most appropriate ways in which the **carbon externality can be factored into productivity measurement** and by having better quantitative estimates of how low carbon policy measures feed through to future growth and productivity. The size of such effects could be modelled using a **scenario-based micro simulation model**. that would provide firm-level, sectoral and economy-wide estimates of the links between low carbon policy, growth and productivity.

These conclusions bring policy design, and proper measurement, to the forefront of the debate about how to ensure carbon policy supports and enhances productivity growth.

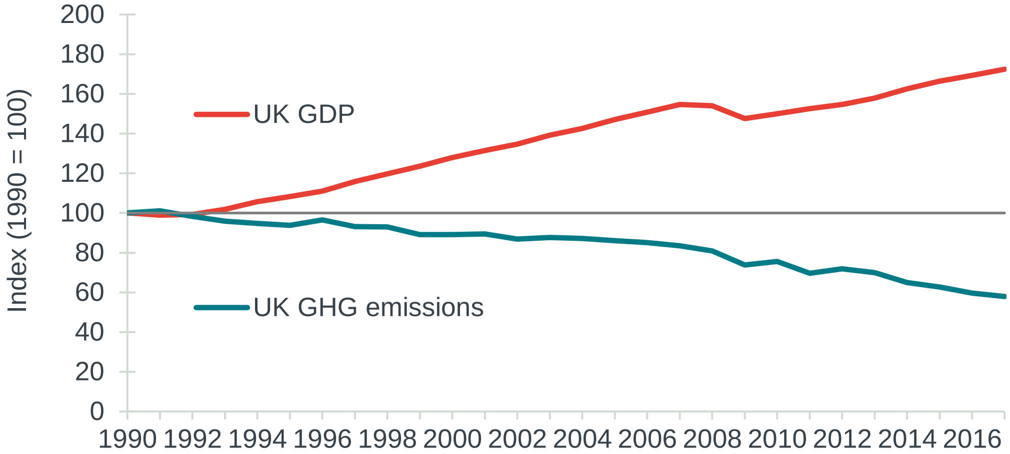
1 INTRODUCTION

1.1 Context of this report

The UK has a legally binding commitment to reduce greenhouse gas emissions by at least 80% (from their 1990 level) by 2050. It has also signed up to the Paris Agreement which foresees shifting the world to net zero emissions in the second half of the century. Such a change would involve a transformation of society and likely widespread impacts on the drivers of future growth and productivity.

Greenhouse gas emissions have already fallen by over 42% since 1990, while the economy has grown by around 72% (see Figure 1). That measurement of growth largely excludes the benefits from production with much lower greenhouse gas emissions, a fact we return to in Section 3.1 ("the measurement issue").

Figure 1 Trends in UK economic growth and greenhouse gas emissions, 1990 to 2017



Source: Frontier Economics, based on ONS GDP data and BEIS emissions statistics.

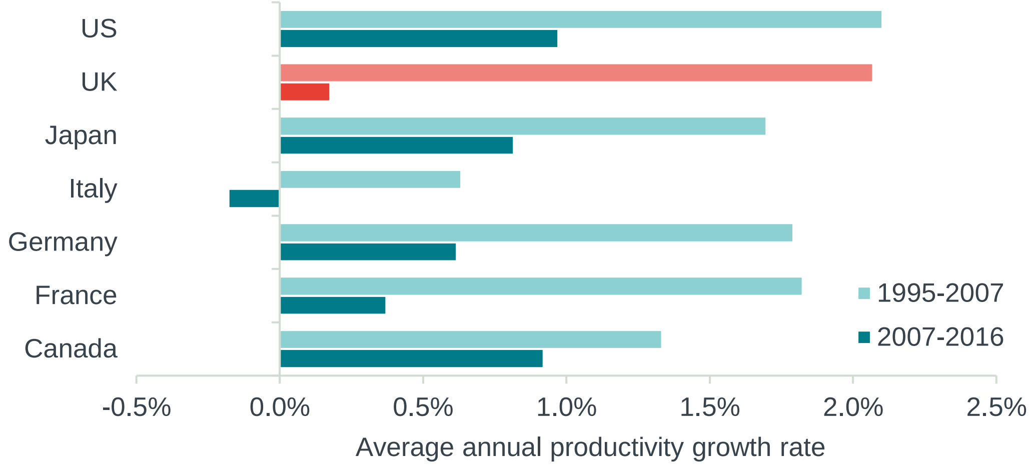
The challenge to reduce greenhouse gas emissions in the coming years remains significant. To meet the fourth and fifth carbon budgets, the UK will have to see a significant acceleration in the pace of decarbonisation, and many more changes will be needed to reach the 2050 target and ultimately net zero. The Clean Growth Strategy sets out the policies through which the required acceleration can begin. [2]

Transforming the economy to reduce its climate impacts needs to be linked to other key government objectives, notably raising living standards through, in part, higher productivity and growth. This is particularly pertinent in the context of stagnant productivity growth in the UK since the financial crisis, often termed the 'productivity puzzle' (see Figure 2). While all major industrial economies saw a hit to productivity growth after the financial crisis in 2007, it is striking that having been among the best global performers before then, the UK has since been among the worst. This measure of performance is based on trends in GDP per hour worked. And while

[2] BEIS (2018), *The Clean Growth Strategy: Leading the Way to a Low Carbon Future*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

some recent analysis by the OECD has suggested that measurement of hours might explain some of the difference between the UK and its peers,[3] it is still only a part of the explanation – much of the puzzle remains unsolved.

Figure 2 UK / G7 productivity growth before and after the financial crisis



Source: *Frontier Economics, based on analysis of ONS 'International Comparisons of Productivity' data.*

As a result, for the first time in many years, the UK Government published an Industrial Strategy.[4] The Industrial Strategy aims to boost UK productivity through a set of policies to improve innovation, skills and infrastructure.

The importance of environmental and carbon policy and the opportunities presented by clean growth are clearly acknowledged in the Industrial Strategy. Indeed, one of the priorities (or "grand challenges") is to maximise the advantages for UK industry from the global shift to clean growth "*through leading the world in the development, manufacture and use of low carbon technologies, systems and services that cost less than high carbon alternatives*" with the long term goal "*…to make clean technologies cost less than high carbon alternatives, and for UK businesses to take the lead in supplying them to global markets*".

1.2 Scope of work

The aim of this work is to help address the relative gap in knowledge about the effects of carbon policy on productivity. The work sits within wider work undertaken by the Energy Systems Catapult (ESC) 'Rethinking Decarbonisation Incentives' (RDI) project. The RDI project is exploring how UK policies can promote clean growth by taking a 'whole systems' perspective on carbon policy.

Terminology

We use "carbon policy" throughout this report as a shorthand for a wide set of policies that create economic incentives aimed at reducing all greenhouse gas

[3] Ward, A., M. Zinni and P. Marianna (2018), "International productivity gaps: Are labour input measures comparable?", OECD Statistics Working Papers, 2018/12, OECD Publishing, Paris. http://dx.doi.org/10.1787/5b43c728-en

[4] BEIS (2017), *Industrial Strategy: Building a Britain Fit for the Future*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf

emissions. Where greater specificity on particular policies is required we provide the detail in the relevant discussion.

Reducing greenhouse gas emissions and improving productivity (and hence economic growth) are two objectives which exist in parallel but there is currently little understanding of how they interact. While the effects of carbon policies on emissions are well-researched, there is less explicit discussion of how carbon policies might influence economy-wide performance, economic competitiveness, innovation and productivity over time.

Theoretically, the effect of carbon policy on productivity is ambiguous. On the one hand, carbon policies may impose additional costs on businesses which could result in reduced profits and hence productivity. On the other hand, incentives to reduce emissions may spur innovation which could result in new products or services, or more efficient methods of production, that boost the productive capacity of the economy.

The effect of carbon policy on productivity may also depend on the type or mix of carbon policies being implemented. Market-based policies, such as a cap and trade scheme or some taxes, give polluting firms flexibility in how they reduce pollution. More prescriptive policies, such as regulations or technological standards, can in effect specify in detail what technology must be used in order to achieve the required emissions reductions without giving firms much room for manoeuvre.

We were asked to examine four specific research questions shown below.

Question 1	Through what mechanisms do carbon policies influence productivity?
Question 2	Does the choice and design of carbon policies affect the capacity of the economy to innovate?
Question 3	Does the choice and combination of carbon policies have any particular implications for productivity over time?
Question 4	How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

1.3 How to link productivity and carbon policy

We explored the research brief and the four questions by developing an analytical framework that captures the static and dynamic aspects of productivity and acknowledges the different types of carbon policy that exist. It was tested through workshops and guided expert discussions. We then used a literature survey to validate it further and, where possible, add quantitative estimates for the magnitudes of the different links between carbon policies and productivity.

Productivity improvements are driven by measures to improve efficiency, of which there are three types:

- **Productive efficiency** focuses on whether goods and services are produced at least cost at a point in time. Key here is whether decision-makers in business are informed about and can respond to signals about the costs (including carbon) of production.
- **Allocative efficiency** focuses on what is produced, and whether prices of goods and services allow the relative proportion of different inputs in production to be optimal. Key here is how carbon policies may influence the allocation of (lower and higher carbon) inputs across the economy.
- **Dynamic efficiency** focuses on innovation and generating new ideas, products and processes which can improve living standards by reducing costs, improving quality and introducing new goods and services over time. Here we consider how carbon policies influence the quantity, quality and allocation of innovation inputs (such as redirecting R&D spend towards low-carbon technologies) and the ability of organisations to absorb innovative ideas to become more efficient.

The concepts of productive, allocative and dynamic efficiency are widely used in the academic literature examining the effects of environmental regulation. The traditional view of economists in the 1970s and 1980s was that environmental regulations impose compliance costs on businesses (static productive efficiency effect) which leads to reductions in profits and productivity as resources are diverted away from productive uses and into ensuring compliance. While economists have known for a long time that this is only a partial analysis, the work of Porter (1991) and Porter and Van der Linde (1995) helped to formalise why a wider analysis would be useful. They posited that environmental policies can stimulate innovation (allocative and dynamic efficiency effects) which can more than offset any (static) compliance costs imposed by the policies. Their view became crystallised into the Porter Hypothesis (PH).

The Porter Hypothesis

The Porter Hypothesis states that: *"Strict environmental regulations do not inevitably hinder competitive advantage against rivals; indeed, they often enhance it"*. Porter argued that more stringent but properly designed environmental regulations (in particular, market-based instruments such as taxes or cap-and-trade emissions allowances) can *"trigger innovation that may partially or more than fully offset the costs of complying with them"*.

The literature contains somewhat conflicting accounts of what the PH means and different versions of it have been proposed and tested. Jaffe and Palmer (1997) first distinguished between three different versions of the PH:

- **Weak version**: well-designed environmental regulation may spur innovation.
- **Strong version**: innovation induced by regulation can lead to productivity improvements which more than offset the cost of the regulation.
- **Narrow version**: flexible regulatory policies give firms greater incentives to innovate than prescriptive forms of regulation.

As well as different types of efficiency and productivity, there are also different types of carbon policy. Grubb (2014) distinguished three types of carbon policies.[5] Grubb argues that these 'pillars' or 'domains' of carbon policy need to be combined in order to achieve a sustainable, low-carbon transition. The three policy pillars are:

- **Pillar I: Standards and engagement.** This involves direct regulation where government or regulators set particular technical standards or limits which specify the parameters of what standards firms are required to meet (e.g. Energy Efficiency Directive which introduced legally binding measures to encourage efforts to use energy more efficiently in all stages and sectors of the supply chain);
- **Pillar II: Markets and pricing.** This includes market based instruments such as an implicit or explicit carbon price which aim to internalise (ensure that polluters pay for the right to pollute) the cost of the emissions produced by the polluting firms (e.g. EU Emissions Trading Scheme which allows the trading of carbon permits thus introducing a carbon price); and
- **Pillar III: Strategic investment.** This involves government supported investments to drive growth in particular sectors by, for example, developing required infrastructure which would not normally be attractive to private investors or not at the level/speed required (e.g. the establishment of the Catapults network, electric vehicle charging).

We developed an analytical framework for addressing the research questions which combines the theories that were crystallised by Porter, the categorisation of policy initiatives as defined by Grubb and the more recent literature on innovation and economic growth. This generated a 'matrix' (see below) which allowed us to structure an evidence-gathering process.

Figure 3 Analytical framework linking productivity and carbon policies

	Type of economic carbon signal (Grubb's policy pillars)		
	Standards and engagement	Markets and pricing	Strategic investment
Productive			
Allocative			
Dynamic			

Source: Frontier Economics based on Grubb, Porter and others (see bibliography)

The framework is designed to allow a clear and consistent discussion about the trade-offs between different types of policies. For example, standards and engagement which directly influence firm behaviour by mandating what is allowed are likely to lead to relatively fast results in terms of emission reductions. This direct approach can influence productivity by helping firms exploit existing technologies

[5] Grubb, M. (2014), *Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development*, Routledge Publishing.

by overcoming knowledge and behavioural barriers to improvement. On the other hand, the approach may be less suitable for encouraging innovation since, by their nature, standards are prescriptive and would at least partially limit the responses that firms can take.

Market based instruments (such as cap and trade) do not dictate the responses firms should take. They may give more room for businesses to innovate and lead to more dynamic efficiency improvements. They can act to align upfront investment costs and long-term payback savings providing incentives for firms to make investments which would otherwise be uneconomic. On the other hand, there is a risk with market based instruments that firms see them as less stable (since taxes can be increased/decreased or even removed often more easily than standards or committed public investment).

Strategic investments may be seen as particularly important to stimulate responses (dynamic efficiency) since they can be seen as serious signals of government commitment over the longer term. As such they are less likely to influence static efficiency but may result in more investment in research and development that would over the longer term lead to productivity improving innovations.

We carried out a Rapid Evidence Assessment (REA) of the literature linking carbon policy and productivity to test and populate this framework and to better understand the importance of these effects. We sought to distinguish between static and dynamic effects and the impact of the choice of policy.

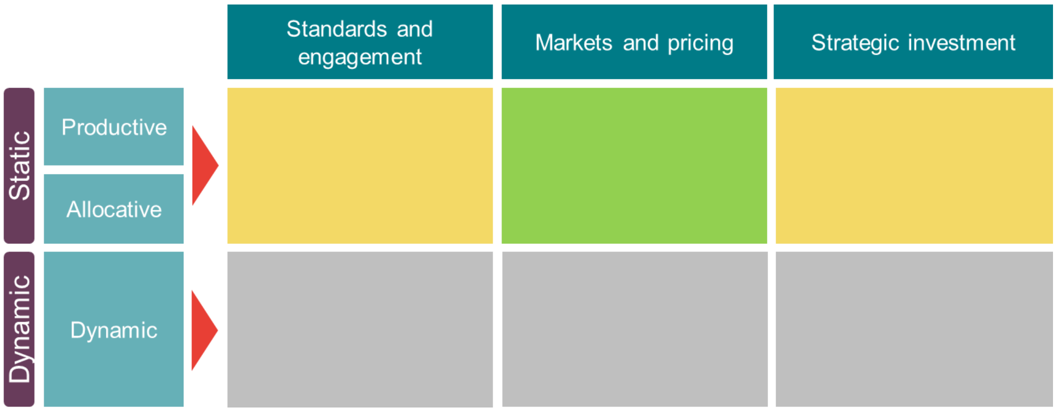
Details of the individual studies captured by this REA, that are used to inform the analysis in this report, are contained in a separate online annex to this report.

Broadly, while our REA uncovered a relatively large literature which had explored the relationships between carbon policy and aspects of productivity, we also identified that some ‘cells’ of our analytical framework were better-evidenced than others. In particular:

- The literature seldom distinguishes between productive and allocative efficiency concepts. More often these are grouped into ‘static’ efficiency, while dynamic efficiency is explored separately.
- Much of the evidence does not unpick the specific effects of a particular type of carbon policy, but instead creates composite indices of carbon policy intensity that combine aspects of the different Grubb pillars.
- The evidence base is stronger for static efficiency impacts than dynamic.

The figure below therefore shows a revised structure of the analytical framework and highlights where there are larger amounts of robust evidence (green boxes), more moderate amounts (amber boxes) or little amounts (grey boxes). The rest of this report unpacks the evidence in more depth.

Figure 4 Overall quality of evidence base supporting revised analytical framework



Source: Frontier Economics

Note: Green boxes signify larger volumes of robust evidence, amber more moderate volumes and grey where there is limited or no evidence.

1.4 Structure of the report

The rest of this report is structured as follows:

- Chapter 2 discusses the productivity challenge faced by the UK and the main policy responses from government to-date;
- Chapter 3 discusses the existing evidence on the strengths of the relationship between carbon policy and productivity; and
- Chapter 4 concludes.

2 THE PRODUCTIVITY CHALLENGE

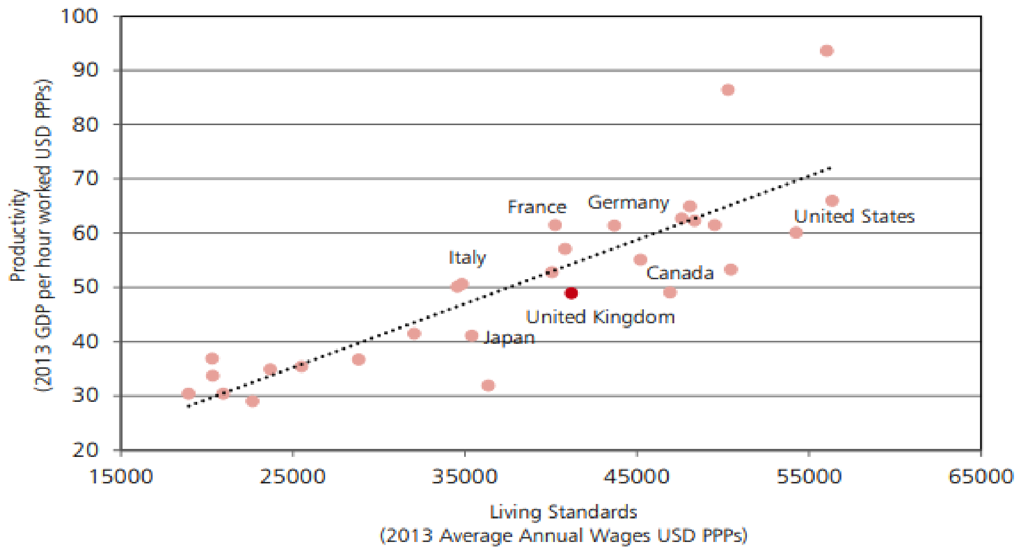
2.1 What is productivity and why does it matter?

Productivity represents the degree to which new wealth is generated. It is measured as the ratio of outputs to inputs: the more output generated for a given set of inputs the wealthier society. There are several productivity measures but the most widely used ones are:

- **Labour Productivity**: this is usually measured as the value of output or Gross Domestic Product (GDP) per worker or per hour worked. The latter is usually preferred to the former as it better captures the use of labour inputs.
- **Total Factor Productivity (TFP)**: TFP (sometimes called multi-factor productivity, MFP) is derived as the residual growth in output that cannot be explained by the rate of change in inputs of labour, capital and intermediate outputs. It is often interpreted as the contribution to economic growth made by factors such as technical and organisational innovation.

Improvements in productivity and living standards are closely correlated (see Figure 5). This is because an increase in productivity translates into an increase in output (quantity and/or quality) without a commensurate increase in input (labour and materials).[6]

Figure 5 Correlation between productivity and financial living standards



Source: OECD Dataset: Averages annual wages; OECD Dataset: Level of GDP per capita and productivity.

Source: *HMT Productivity Plan 2015 "Fixing the foundations: creating a more prosperous nation"*

[6] Living standards are often proxied by measures such as average wages or incomes. We recognise the wider debate about wellbeing and overall quality of life, and the potential for the correlation between these measures and productivity growth to be somewhat weaker. The focus of this study is on financial living standards.

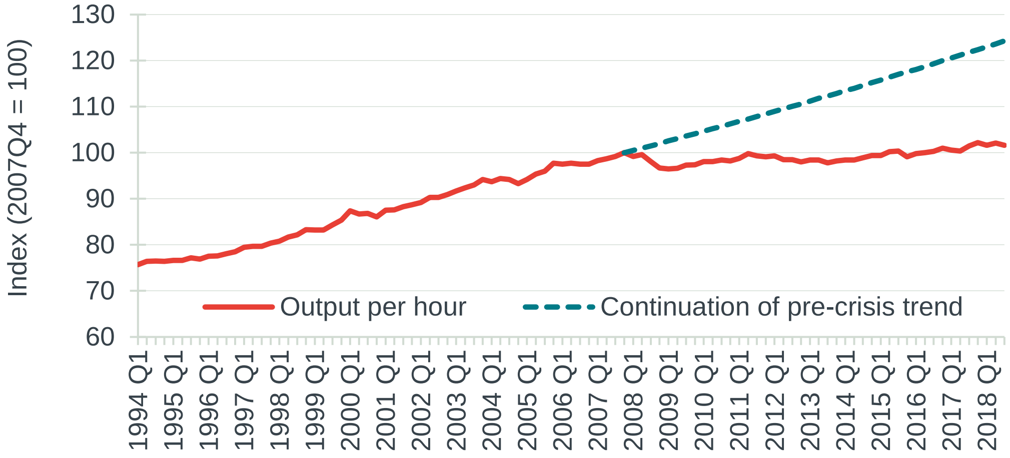
Productivity is widely regarded as the key driver of workers' incomes and hence prosperity. Improving productivity is a key target for policy makers around the world. As the famous US economist Paul Krugman once put it:

> *"Productivity isn't everything, but, in the long run, it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker."*[7]

2.2 Recent trends in UK productivity – the 'puzzle'

Productivity in the developed world and the UK had been on an upward trajectory for the past 50 years or so. On average, productivity (measured as GDP per hour worked) has been growing at around 2%-3% per year since the 1970s in the UK and comparable countries like Germany, France and the USA. Since the global financial crisis a decade ago, however, productivity in the UK has been largely stagnant, and the UK appears to have seen a more marked slowdown in productivity growth than other comparable rich countries (see Figure 2). Estimates suggest that, had UK productivity continued to grow at its historical rate after the crisis, it would now be around 20% higher than it is now (see Figure 6).

Figure 6 UK labour productivity trends (whole economy), 1994 to 2018



Source: Office for National Statistics Labour Productivity Bulletin

It is not unprecedented for productivity slumps to occur. The UK experienced stagnant productivity in the 1970s and 1980s. What is unusual about the current period is the duration of the slowdown (over a decade). The prolonged slowdown has been termed the *productivity puzzle* and the issue has attracted a great deal of attention from analysts and policy makers.

There are different explanations offered as to what has caused the productivity slowdown including reduced business investment, low interest rates sustaining relatively unproductive companies and even broader welfare and labour market reforms leading to more people being in work but doing less productive jobs. Measurement issues too may play a significant role in this – Bank of England

[7] Paul Krugman, The Age of Diminishing Expectations (1994)

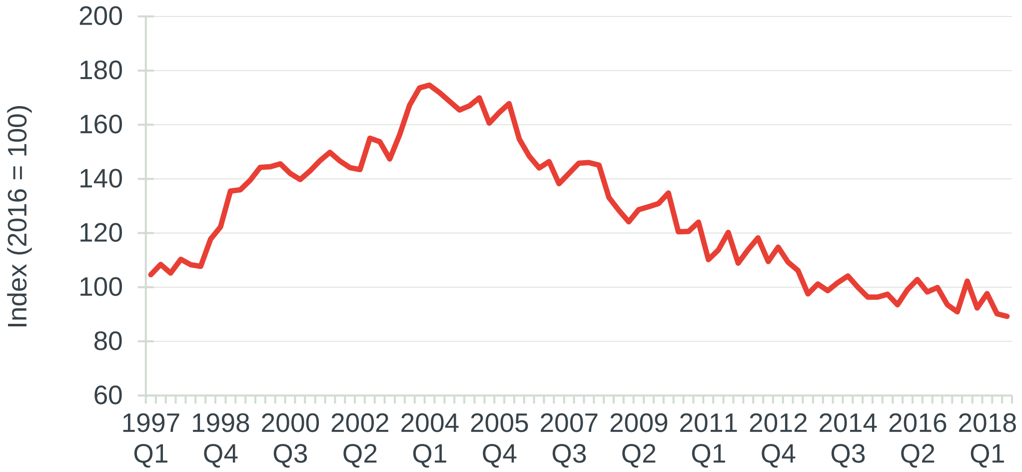
analysis suggests that as much as a quarter of the productivity slowdown may have been explained by measurement issues.[8]

Productivity within the energy sector

The ONS publishes a number of sectoral analyses of productivity trends. While there is no single definition of 'the energy sector' that can be mapped to the ONS data, the closest (based on Standard Industrial Classification codes) is 'Electricity, Gas, Steam and Air Conditioning Supply' (SIC35) which includes electric power generation, transmission and distribution.

Analysis of ONS estimates of output per hour worked in this sector is shown below. In contrast to the economy-wide trends, productivity growth was very rapid up to 2004 and then began a sharp decline. Measured labour productivity grew at an average rate of more than 7.5% per year between 1997Q1 and 2004Q1, but then declined at an average rate of 4.1% per year between 2004Q1 and 2018Q1.

Figure 7 Output per hour in the energy sector (SIC35), 1997Q1 to 2018Q3



Source: Office for National Statistics Labour Productivity Bulletin Q3 2018

It is not clear what may be behind this trend (e.g. how far it is driven by changes within the more detailed industry codes within SIC35, or how far it may relate to challenges in measuring sector output) but it is clear that the productivity challenge is also one facing the energy sector.

2.3 The policy response

The productivity slowdown has been a key issue for successive UK governments and there have been considerable efforts to address it.

In 2015, HM Treasury published its Productivity Plan which set out fifteen points aimed to boost productivity and living standards.[9] These were grouped into eight themes under two broad headings, and is summarised below. Note that energy

[8] https://www.bankofengland.co.uk/-/media/boe/files/quarterly-bulletin/2014/the-uk-productivity-puzzle

[9] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/443898/Productivity_Plan_web.pdf

features as a driver of 'long-term investment', both in terms of being low carbon and in terms of being reliable.

Figure 8 HM Treasury's 2015 framework for raising productivity

Long-term investment	A dynamic economy
Business investing for the long-term ▪ Competitive tax system ▪ Rewards for saving and investment	**Flexible, fair markets** ▪ Planning freedoms, more houses ▪ Higher pay, lower welfare ▪ More people able to work and progress
Skills and human capital ▪ Highly skilled workforce ▪ World-leading universities	**Productive finance** ▪ Financial services leading the world in investing for growth
Economic infrastructure ▪ Modern transport system ▪ **Reliable, low-carbon energy** ▪ World-class digital infrastructure	**Openness and competition** ▪ Competitive markets and less regulation ▪ An open trading nation
Ideas and knowledge ▪ High quality science and innovation	**Resurgent cities** ▪ A rebalanced economy

Source: Based on HMT Productivity Plan (2015) "Fixing the foundations: creating a more prosperous nation"

Productivity is also at the heart of the Industrial Strategy: the roadmap towards building a more productive, wealth-creating economy.[10] The Industrial Strategy recognises the productivity challenges facing the UK and notes the discrepancies in performance between different regions of the country as well as between firms: the UK still has some of the most innovative and productive businesses in the world but is also characterised by a long tail of laggards. The Strategy also acknowledges the importance of the 'first mover advantage' and how the earliest nations to adopt new technologies are able to reap the greatest rewards in terms of additional jobs and increased revenue.

The Industrial Strategy identifies five foundations of productivity:

- **Ideas** where the ambition of government is to transform the UK into the most innovative economy in the world. The Industrial Strategy envisages a target to increase R&D expenditure to 2.7% of GDP (in line with peers like Germany and Japan) which policy would encourage through increased R&D tax credits and more money (£725m) available to support innovation through the Industrial Strategy Challenge Fund.
- **People** where the technical education system is transformed to rival academic education and additional funding is provided to address shortfalls in skills in key areas such as science, technology, engineering and maths (STEM).

[10] BEIS (2017), *Industrial Strategy: Building a Britain Fit for the Future*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf

- **Infrastructure** where additional investments are made to support specific sectors (£1bn investment in digital infrastructure and £400m support for electric car charging infrastructure) as well as increasing the National Productivity Investment Fund (supporting investments in transport, housing and digital infrastructure) to £31bn.
- **Places** where Local Industrial Strategies are agreed building on the strengths of local areas and a new £1.7bn Transforming Cities fund is set up to support intra-city transport.
- **Business environment** where Sector Deals between government and industry are launched to address specific productivity challenges as well as support investment in businesses with high growth potential through the establishment of a £2.5 billion Investment Fund incubated through the British Business Bank.

The importance of environment and carbon policy in relation to productivity is clearly acknowledged. One of the Grand Challenges (aimed to position the UK at the forefront of the industries of the future) is to "*maximise the advantages to the UK from the global shift towards clean growth through leading the world in the development, manufacture and use of low carbon technologies, systems and services that cost less than high carbon alternatives*". The initiatives include support for innovation and collaboration with international initiatives for clean energy research, encouraging the development of smart energy systems, encouraging efficiency improvements in the construction industry, more efficient and sustainable farming and extending the UK's leadership in green finance.

The initiatives in the Industrial Strategy are supplemented with the more detailed Clean Growth Strategy which sets out the goals of the government to continue reducing harmful emissions through the 2020s and beyond, while also capitalising on the opportunities to be a global leader in the area of clean growth.[11]

[11] BEIS (2018), *The Clean Growth Strategy: Leading the Way to a Low Carbon Future*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

3 LINKING CARBON POLICY AND PRODUCTIVITY

The objectives set out in the 2008 Climate Change Act and in the Paris Agreement require a transformation of the economy. Achieving net zero emissions – the commitment under the Paris Agreement – in the second half of the century will involve considerable changes to activities that will drive future productivity.

The UK faces a number of long-term societal challenges: for example, dealing with the public health costs of looking after an increasingly ageing population, or the potential erosion of parts of the existing tax base. But climate change is somewhat unique among these: having explicit objectives over emissions over a decades-long horizon enshrined in the UK's international commitments and domestic law is clearly a highly unusual situation. Sitting alongside what will inevitably be a long-term process for the Industrial Strategy to succeed, understanding the links between carbon policy and productivity will be an important component of implementing the Industrial Strategy effectively.

We discuss those links in this section. It is divided into two main sections:

- First, we discuss the consequences of the failure to fully capture the costs and benefits of reducing greenhouse gases in our measurement of productivity.
- Second, setting aside measurement issues, we discuss the existing evidence about the links between carbon policy and productivity.

3.1 The measurement issue

Measures of output should in principle be adjusted to take account of externalities (positive or negative). If such an adjustment is not made, there is a risk that measures of economic output are biased downwards and ignore the value of reducing negative externalities such as pollution, or indeed the costs of increasing them. Measures of productivity growth that ignore wider impacts overstate the "social benefits" of production (Ball et al. 2002a, 2002b, 2002c).

One manifestation of this trend is the focus in the "25 Year Plan to Improve the Environment"[12] on properly measuring natural capital: if natural capital is depleted as part of the production process that needs to be included in the cost of production. That ensures only production that adds value takes place, as intended in a market economy.

Similarly, accurate measurement of growth and GDP should include the external costs of greenhouse gas emissions. In practice, these externalities are largely unaccounted for in productivity measurement. This could lead to tensions between policies which appear to be 'productivity-maximising' if they also generate additional emissions that are not accounted for in any cost-benefit assessment. It

[12] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

also means that emissions reductions achieved to-date are not reflected positively in measured productivity growth.

This leads to an important policy point: **appraisal and evaluation of policies which aim to enhance productivity need to assess whether there are resulting carbon-related or other environmental externalities** and ensure that these are taken into account.

DOES THE FAILURE TO ACCOUNT FOR CARBON EXTERNALITIES HAVE A MATERIAL EFFECT ON HOW WE MIGHT ACCOUNT FOR RECENT PRODUCTIVITY TRENDS IN THE UK?

The amount of emissions that are avoided in the UK each year through actions to-date can be multiplied by a carbon price to understand their value. The precise magnitude of the estimate depends on the carbon price used. Absent any abatement since 1990 the UK would have emitted an additional 215.6 million tonnes of CO_2 in 2016. If we multiply this by the carbon values currently used in government appraisals (£4.20 for traded and £66 for non-traded)[13] we obtain a total value of avoided emissions of £7.5bn or 0.4% of GDP, assuming half of the reduction came from the traded sector.

Higher carbon values are expected in Phase III of the EU ETS. If we use the predicted carbon values (even holding emissions reductions constant at their 2016 level) for 2025 (£41.90) there is a more significant effect on GDP (close to 0.6%). Carbon values are expected to rise further by 2030 which could increase the impact on GDP to close to 1%.

Appropriately accounting for the value of avoided carbon emissions could increase productivity by a small but not insignificant amount. Furthermore, this captures only one aspect of how carbon policy affects productivity – the direct impact of reduced emissions. Other, larger, drivers of productivity growth (e.g. skills) would also be affected by comprehensive carbon policies.

Productivity measurements quoted today exclude the additional benefit from meeting the carbon budgets to-date. There would be additional value in productivity measures trying to take more explicit account of carbon externalities, not least in helping provide a more transparent link between long-term objectives around emissions reduction and economic growth. We therefore suggest that, in reviewing its approach to monitoring and evaluating the Industrial Strategy, **the Industrial Strategy Council considers ways to present adjusted measures of productivity that account for greenhouse gas externalities**.[14]

[13] The guidance differentiates between the traded and non-traded sectors referring to those included in the EU ETS and those that are not. The traded and non-traded prices of carbon are different in the short-term but are projected to converge over time based on the assumption that there will be a global carbon market in the 2030s. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671205/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2017.pdf

[14] The Industrial Strategy Council is a body, chaired by Bank of England Chief Economist Andy Haldane, that has been set up to measure the progress and impact of the government's Industrial Strategy. The Council will develop measures of success and an approach to evaluating the overall impact of the Strategy. Details of the Council and its remit are available at https://www.gov.uk/government/news/new-industrial-strategy-council-meets-as-membership-announced.

There are of course many unpriced externalities not included in productivity measurement: road congestion, social costs associated with crime, health costs associated with many behaviours, and so on. It would probably never be feasible or cost-effective to attempt to incorporate all of them into a refined measure of output and productivity. But it feels like an important point to acknowledge given the renewed policy focus on productivity and Industrial Strategy and worth a body like the Industrial Strategy Council tasked with monitoring progress on the UK's productivity performance spending some time giving serious consideration to, building on the work already done with Natural Capital Accounting.

Starting with incorporating greenhouse gas emissions into productivity measurement would make sense because they are already clearly defined, measured and monitored, with existing valuations that have been agreed for policy purposes. As described above, the long-term and global nature of the challenge around climate change, and the fact that targets for emissions reduction are enshrined in UK law and international agreements makes the carbon externality somewhat of a special case in the more general point about unpriced externalities not featuring in productivity measurement at present.

Further work would be needed to decide on the appropriate value to assign to the reduction in emissions, how to report the alternative productivity measure and how to incorporate it into policy decisions (e.g. potentially through new Green Book guidance).

3.2 Empirical evidence on the links between carbon policy and productivity

3.2.1 Summary of evidence

The Rapid Evidence Assessment (REA) identified a range of academic papers which are summarised in this chapter. These range from purely theoretical papers setting out the channels through which carbon policy can lead to changes in productivity to quantitative empirical studies which include top-down economy-wide or sector-wide studies as well as bottom-up econometric studies examining firm level data and even case studies.

The volume and quality of evidence varied considerably for different segments of the framework and the four research questions. On the whole it was found that the majority of work does not differentiate between the different efficiency concepts (productive, allocative, dynamic). Instead, papers tend to use a single productivity measure and seldom specify whether the effects found are static or dynamic.

Further, we found that much of the empirical literature has understandably focused on policies and outcomes which are measurable. For example, we found relatively plentiful and good quality econometric evidence looking at the innovation and productivity implications of the EU ETS in the short term. On the other hand, less empirical evidence was available looking at the dynamic impacts of this or other policies.

Much of the empirical literature we identified was focused on testing different versions of the so-called Porter Hypothesis (PH) in which Porter (1991) argued that more stringent but properly designed environmental regulations (in particular, market-based instruments such as taxes or cap-and-trade emissions allowances) can “trigger innovation that may partially or more than fully offset the costs of complying with them”.

Overall, we found more empirical research looking at the direct effects of carbon abatement policies on innovation and fewer papers examining the link with productivity.

We summarise the findings from the evidence review in relation to the four research questions below and in Figure 9.

- **Through what mechanisms do carbon policies influence productivity?** There is significant literature looking at how environmental policies in general, and carbon policy in particular, can affect productivity. The effect can be negative or positive depending on the response of firms to the policy. In the short-term the policy may represent a cost to firms and so can reduce productivity. However, for firms who are not optimising their current use of inputs then, even in the short run, carbon policy can improve productive efficiency. Separately, there is a dynamic effect whereby carbon policy can stimulate innovation which can improve productivity if the innovation outweighs the cost of compliance with the policy – an idea first introduced by Porter (1991) and tested empirically in numerous studies.
- **Does the choice and design of carbon policies affect the capacity of the economy to innovate?** There is a considerable body of evidence which studies the link between carbon policy and innovation (typically measured R&D expenditures or successful patent applications). In the main this finds strong positive links between the two. The evidence is particularly strong for market based policies: recent work has found that the EU ETS has increased low-carbon patenting by almost 10% without crowding out other innovation. Other work looking at general environmental policies (typically proxied as environmental stringency) also finds a positive links with innovation.
- **Does the choice and combination of carbon policies have any particular implications for productivity over time?** There is a long established literature looking at the links between innovation and productivity in general which finds that innovation drives productivity. There is less research looking to link carbon policy and productivity directly. The research we have identified broadly indicates that carbon policy can have a positive effect on productivity, albeit the measured effects to-date are relatively small.
- **How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?** The research that does exist is very context specific. It examines the effects of a specific policy over a specific time period applied to a specific set of firms. As such it is difficult to generalise and extrapolate what the findings may mean for the economy as a whole. Our interpretation of the available evidence is that carbon policy may contribute a small boost to productivity growth (up to 4% on a temporary basis), although the effect is temporary and likely to be close to zero in the long run. It should also be noted that this estimate is a judgement and highly uncertain given the relative lack of evidence looking at the economy wide effects of carbon policy.

Figure 9 Summary of evidence reviewed for each question

Question 1	Through what mechanisms do carbon policies influence productivity?	▪ Theoretical effect is ambiguous. ▪ Compliance costs reduce productivity as resources diverted away from production. However, regulations may improve productivity if firms are not optimising. ▪ If innovation is induced, productivity could be improved.
Question 2	Does the choice and design of carbon policies affect the capacity of the economy to innovate?	▪ Strong evidence base that market-based policies are associated with increases in innovation ('narrow' Porter Hypothesis). ▪ Good evidence that strategic investment is associated with more innovation. ▪ More ambiguous effects on the impacts of standards and engagement.
Question 3	Does the choice and combination of carbon policies have any particular implications for productivity over time?	▪ Substantial literature demonstrating that increases in innovation are associated with productivity improvements. ▪ Literature linking carbon policy and productivity directly is more scarce, and very context-specific. ▪ Literature generally finds small positive effects of market-based policies and less clear results of other types of carbon policy.
Question 4	How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?	▪ Most of the literature uses micro-data linking very specific policies to firm-level outcomes. ▪ Very difficult to extrapolate to the macroeconomic effects from this, but the few studies that exist suggest small positive effect of up to 5% of productivity growth.

Source: Frontier Economics

Note: Colour coding in key messages boxes signifies availability of evidence where green indicates significant evidence base, amber signifies reasonable evidence base and red signifies limited availability of evidence.

3.2.2 Through what mechanisms do carbon policies influence productivity?

Carbon policy can influence productivity in several ways. Traditionally, environmental-related policies were seen as profit and productivity reducing: they impose a compliance cost on businesses (diverting resources away from production to pollution reduction) which, all else being equal, would lead to a reduction in profits and hence lower productivity.

Ambec et al. (2013) state that "*...the traditional view of environmental regulation, held by virtually all economists, was that requiring firms to reduce an externality like pollution necessarily restricted their options and thus by definition reduced their profits. After all, if profitable opportunities existed to reduce pollution, profit-maximizing firms would already be taking advantage of them.*"

Technological standards, environmental taxes and cap and trade schemes would force firms to allocate labour and capital to pollution reduction which, although beneficial to society at large, is unproductive from a business perspective. Early studies on the US concluded that environmental regulation caused a productivity slowdown, presumably due to a displacement of "productive" investment by environmental regulation (Gollop and Roberts,1983; Gray and Shadbegian, 1993, 2003).

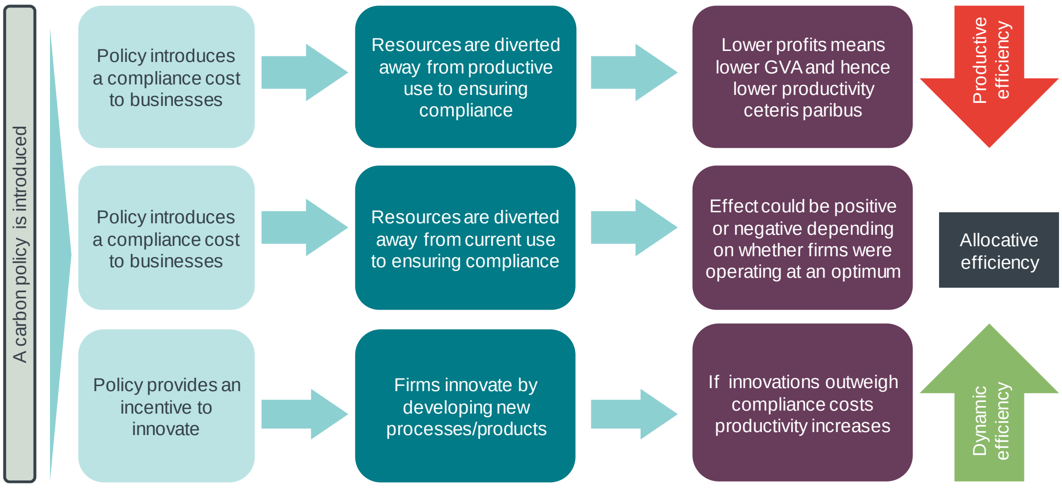
There was a long tradition of thinking that challenged this interpretation. It was best articulated by Michael Porter (1991) who described how well designed regulation can enhance firm competitiveness, not hinder it. Well-designed environmental regulation can spur on innovation which could more than offset the costs of the regulation resulting in a net productivity gain. This is known as the Porter Hypothesis (PH).

The literature contains somewhat conflicting accounts of what the PH means and different versions of it have been proposed and tested. Jaffe and Palmer (1997) first distinguished between different versions of the PH:

- Weak version: properly designed environmental regulation may spur innovation;
- Strong version: the regulation induced innovation can lead to productivity improvements which more than offset the cost of the regulation;
- Narrow version: flexible regulatory policies give firms greater incentives to innovate than prescriptive forms of regulation.

We illustrate the potential static and dynamic efficiency effects of carbon policy in Figure 10.

Figure 10 Illustrative links between carbon policy and productivity



Source: Frontier Economics

Note: Illustrative example

It is worth noting that within the simple framework presented above there are a number of complicating factors which also reflect that the productivity effects of a carbon policy will depend on the type of policy implemented (as discussed previously, we have used Grubb's three policy pillars for the purposes of this work).

For example, if 'carbon policy' is limited to a pure carbon tax, then in principle there is no immediate impact on productivity since the carbon tax simply acts as a transfer from businesses and households to the government. Measured output for productivity purposes is gross of tax (profit is measured before tax) and as such there is no mechanical link between a tax and productivity in the very short term. Over time, of course, one would expect behavioural responses to the tax (such as increased innovation) which would affect profitability and productivity as described in Figure 10.

Wider carbon policies such as regulations may impose additional costs on business which reduce measured profitability and therefore reduce productivity (reduced productive efficiency). Alternatively, regulatory policies and standards designed to address specific market failures may actually boost productivity even in the short run. Where businesses do not take up 'self-financing' cost-reducing measures, a policy could generate improvements even in measured productive efficiency. There is evidence that interventions with net negative abatement costs (such as insulation retrofit) are not made by some businesses.[15] A growing literature is exploring the application of behavioural economics to decision-making *within firms* which might explain why these kinds of decisions happen, even if they are not profit-maximising as traditionally assumed in economic analysis of business behaviour.[16] This literature in particular highlights that decision-making in firms is often complex, decentralised and governed by rules-of-thumb and group behaviours that can generate 'sub-optimal' outcomes.

However it still needs to be considered whether these measures can be well-designed (to tackle the right behavioural failures) and targeted in such a way that they reduce costs and increase productivity overall.

Strategic public investments in low-carbon technology may be needed to help test and demonstrate new technologies at sufficient scale to bring them to commercial reality at costs which can begin to compete with existing technology and overcome any 'lock-in' effects (e.g. lack of electric vehicle charging infrastructure locks-in the use of internal combustion engines). This can promote dynamic efficiency, though any displacement effects (if public investment is diverted from other uses) would need to be considered.

3.2.3 Does the choice and design of carbon policies affect the capacity of the economy to innovate?

There is a considerable body of literature looking to establish an empirical link between carbon policy and innovation (see Jaffe and Palmer 1997). In this

[15] See for example McKinsey (2009), *Pathways to a Low Carbon Economy* (https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/sustainability/cost%20curve%20pdfs/pathways_lowcarbon_economy_version2.ashx)

[16] See for example Armstrong, M. and S. Huck (2010), 'Behavioral Economics as Applied to Firms: A Primer', CESifo Working Paper 2937, http://www.cesifo-group.de/DocDL/cesifo1_wp2937.pdf

literature innovation is typically measured as R&D expenditures or successful patent applications. There are different measures for carbon policy used. Some studies look at very specific policies (e.g. the EU ETS) while others use proxies for the stringency of carbon policies such as Pollution Abatement and Control Expenditures (PACE)[17] or the Environmental Policy Stringency index (EPS).[18]

Most of the evidence we have reviewed suggests a positive link between carbon policies and innovation. Further, there is evidence to suggest that market based policies may be better at stimulating innovation compared with more prescriptive command and control approaches.

General evidence on the links between carbon policy and innovation

Studies using general measures of carbon policy (not distinguishing between policy types) generally find a positive link with innovation. Some of the empirical studies correlate abatement costs incurred (e.g. PACE) with innovation while others look at the overall stringency of carbon policy and how that influences innovation.

An early study by Jaffe and Palmer (1997) looks at the relationship between total R&D expenditures (or number of total successful patent applications) and pollution abatement costs (as a proxy for stringency of carbon policy). The authors find a positive relationship: an increase of pollution abatement costs by 1% is associated with a 0.15% increase in R&D expenditures.

Later studies produce similar findings. Lanoie et al. (2007), for example, look at how carbon policy stringency affects the probability of having a specific R&D budget devoted to environmental issues and find a positive effect: higher carbon policy stringency leads to a higher probability of having a dedicated R&D budget.

A recent econometric study by Rubashkina et al. (2015) use a cross-country sector level approach with data from 17 European countries between 1997 and 2009. The authors use PACE data as the carbon policy indicator and use a similar specification as Jaffe and Palmer (1997) finding a positive and significant effect of PACE on patent applications: a 10% increase in PACE is associated with a 0.3%-0.9% increase in patent applications.

Standards and engagements

Evidence from studies focussing on prescriptive regulations such as technology or performance standards, inspections, reporting requirements and similar measures suggests that there is a positive impact of these regulations on innovation. The type of regulation also has been found to make a difference in the strength of the impact reported.

[17] The Pollution Abatement Costs and Expenditures (PACE) survey is an annual survey of manufacturing establishment's operating costs and capital investment expenditures for pollution abatement purposes.

[18] See for example the OECD's Environmental Policy Stringency (EPS) Index available at: https://stats.oecd.org/Index.aspx?DataSetCode=EPS. This is a country-specific and internationally-comparable measure of the stringency of environmental policy. Stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour. The index is based on the degree of stringency of 14 environmental policy instruments, primarily related to climate and air pollution.

Hamamoto (2006) estimates an econometric model using data from Japanese manufacturing industries which were heavy purchasers of pollution abatement capital in the 1960s and 1970s. It is based on the Jaffe–Palmer model of the relationship between the stringency of environmental regulations and R&D expenditures. The results suggest that the environmental regulations based on command and control approach had a positive and significant impact on the R&D activity in the industries.

Lanoie et al. (2007) also find that performance-based standards have a strong positive impact on the probability of putting in a specific R&D budget for pollution control, unlike technological-based standards.

Testa et al. (2011) surveyed 78 European firms operating in the building and construction sector in Italy, the Netherlands and France. They found strong evidence supporting the 'weak' version of the PH: a more stringent regulatory environmental policy affects investments in environmental technologies for the building and construction sector in the investigated regions. Specifically, the higher the number of environmental inspections, the higher the probability that an organisation increases its investments into technical innovations. They also find a high impact of technology-based standards on a firm's investments in technical innovations.

Markets and pricing

Market-based environmental regulations include instruments which influence firms' behaviour by changing their economic incentive structure. These policies work by attaching a cost to the environmental impact of a certain action (the externality).

Studies find evidence of a positive link between market-based instruments and innovation. The literature also suggests that market-based policies are better at encouraging innovation than more prescriptive regulations such as technical standards.

Recent studies have focused their efforts on measuring the impact of targeted mechanisms such as emissions trading systems and carbon taxes, along with the more traditional environmental taxes such as excise duties on energy products, vehicle taxes etc.

A recent important paper by Calel and Dechezleprêtre (2016) conducted the first comprehensive investigation of the impact of the European Union Emissions Trading System (EU ETS) on low carbon technological change in the first five years of its existence. They compared 'regulated' firms (those operating large installations) and 'unregulated' firms (those operating small installations) and used robust quasi-experimental methods to estimate a causal relationship.[19] The EU ETS may be expected to encourage innovation for regulated and unregulated firms to different extents. The authors find that the EU ETS has increased low carbon patenting without crowding out patenting for other technologies. Taking into

[19] Quasi-experimental methods are those which are designed in a way to be as close to a randomised controlled trial (RCT) as possible. Typically this involves comparing outcomes over time for a treatment and control group where the control group is verified to be as good a proxy as possible for what would have happened to the treatment group without a particular intervention (e.g. a particular carbon policy) affecting them.

account the whole sample, the EU ETS would account for a 9.1% increase in low-carbon patenting.

Previous work has tried to estimate how switching from prescriptive environmental regulations to more market-based policies affects innovation levels for the affected firms. Burtraw (2000) provided evidence that the switch from a command-and-control approach to a more flexible emissions trading program[20] enhanced innovation and fostered organisational change and competition in the upstream input market. That is, the program gave firms the flexibility to select the best strategy for reducing emissions, including a switch to coal with lower sulphur content.

Similar findings are reported by Isaksson (2005) who examined the impact of Sweden's decision in 1992 to impose a charge on nitrogen oxides (NOx) emissions. Looking at the impact on the abatement cost functions of combustion plants, the author found that extensive emissions reductions occurred at zero or very low cost, primarily due to learning and technological developments that occurred during the period analysed.

Testa et al. (2011) on the other hand, did not find any significant relation between 'Pigouvian taxes' (taxes on externalities such as carbon emissions) and investment in innovation in their model although they argue that this may be due to the particular design of the tax rather than the policy per se. They focused on data from firms in Italy, the Netherlands and France in the building and construction sectors.

Strategic investments

Apart from the above policies, strategic investments may be required to facilitate the deployment of low-carbon technologies or to stimulate innovation. For example, in order to promote new, less mature technologies, direct investments might be needed to encourage adoption which a carbon tax cannot achieve on its own (or not in the timescales required). Strategic investments may also be needed to avoid the lock-in of conventional technologies (e.g. electric vehicle charging infrastructure is needed to overcome the lock-in to conventional engines).

The literature review identified studies which attempt to test the above by looking at the links between direct investments and low carbon technological innovations. In general, the evidence suggests that there is positive relationship between them.

Hanson and Laitner (2006) used numerical simulations from a general equilibrium model to show that a 'moderate energy policy'[21] supported by a technology-led investment[22] strategy can spur innovation and secure substantial domestic reductions of carbon emissions in the US.

Nemet and Kammen (2006) used multiple measures of patenting activity from the US energy sector to reveal widespread declines in innovative activity that were

[20] The context is a switch in US environmental regulations for SO_2 emissions in the 1990s from a technological standard with emissions caps to an allowance trading programme.

[21] A ''Moderate Energy Policy'' is defined as one in which cost effective technology investments are made that increase the nation's overall energy efficiency, and that reduce the carbon intensity with respect to the nation's energy supply technologies

[22] Investments in energy-efficient and renewable energy technologies by the year 2050. Such investments are the result of a moderate set of programs and policies designed to overcome the many institutional and organisational barriers that slow the adoption of energy-efficient, low-carbon technologies.

correlated with declines in R&D investment—notably in the environmentally significant wind and solar areas.

Bointner (2014) reviewed the literature on innovation drivers and barriers in the energy sector of 14 IEA countries. Results show that appropriate public R&D funding for research and development associated with a subsequent promotion of the market diffusion of a niche technology may lead to a breakthrough of the respective technology.

3.2.4 Does the choice and combination of carbon policies have any particular implications for productivity over time?

A few studies try to test whether well-designed carbon policies lead to increased competitiveness of firms, not just to new innovations. The evidence in this regard is comparatively more scarce and ambiguous than that for the link between environmental policies and innovation.

Apart from empirical studies, there has been evidence put forward through numerical simulations of macroeconomic models to look at economy-wide effects of regulations on productivity. These exercises suggest that the impact on competitiveness tends to be low. For example, the impact assessment[23] of the 2050 Roadmaps[24] towards a low carbon economy by the European Commission used this approach to conclude that their impacts on GDP are generally projected to be positive but low in under scenarios that were modelled (e.g. those with explicit energy efficiency policies).

General evidence on the links between carbon policy and productivity

Studies that investigate the link between carbon policy and growth without distinguishing the type of policy find that the link between is ambiguous.

Lanoie et al (2008) find that stricter carbon policies lead to modest long-term gains in productivity in a sample of 17 Quebec manufacturing sectors. They find that productivity is reduced after one year, but then increases in subsequent years with a net positive gain in productivity after four years. Similarly, Albrizio et al (2014) use the OECD EPS to explore the impact of carbon policies on productivity in Italy. They find, at the aggregate level, a negative effect on productivity growth is found one year before the policy change. This negative 'announcement effect' is offset by positive impacts within three years of the policy implementation.

On the other hand, Rubashkina et al (2015) find no significant links between PACE and productivity in their study of 17 EU countries using a robust econometric approach.

[23] In order to assess quantitatively the impacts of the policy options for targets and ambition level, a series of scenarios have been developed, reflecting a comprehensive and consistent set of combinations of options. Their impacts are compared to the Reference scenario, in order to get a clear and consistent presentation of their costs and benefits.

[24] The Low Carbon Economy Roadmap; The Energy Roadmap 2050; and the Transport White Paper.

Standards and engagement

Our evidence review suggests that the link between prescriptive carbon policies based on standards and engagement and productivity tends to be negative, although there are exceptions. This resonates with the view that policies that are inflexible (which describes most command-and-control approaches) limit the options for firms to operate and make adjustments, leading to a negative effect on their competitiveness.

Early studies such as Gollop and Roberts (1983) estimated that SO_2 regulations in the form of emission constraints slowed down productivity growth in the United States in the 1970s by 43%. Similar findings were reported in later studies such as Rassier and Earnhart (2010) who looked at 73 US chemical firms between 1995 and 2001 and found that tighter regulations in the form of permitted wastewater discharge limits lowered profitability of the firms.

Shi and Xu (2018) conducted a firm-level study in China and found that high pollution targets for firms in more pollution-intensive industries were less likely to export and, if they did export, they exported less. This implied a negative link between environmental targets imposed and their productivity.

On the other hand, Berman and Bui (2001) report that refineries located in the Los Angeles area enjoyed a significantly higher productivity than other U.S. refineries, despite a more stringent air pollution regulation standard in this area.

One explanation for the conflicting empirical results here is that firm, industry, or environmental characteristics may affect the extent to which innovation offsets and productivity, or competitiveness enhancements occur. Lankoski (2010) provides a summary of the issues in comparing across studies covering different time periods and industries, and points out a range of measurement and methodological issues that could render comparisons problematic.

Markets and pricing

Recent studies have tried to use data from market-based instruments within the carbon policy mix to look at their impact on competitiveness. Evidence suggests that there exists a weak but positive link between them.

The EC's *Roadmap for Moving to a Competitive Low Carbon Economy* (2011) projects that the effects on GDP in 2020 of putting the EU on a long-term decarbonisation pathway would be limited. They use comprehensive global and EU macro-modelling and scenario analysis modelling to show that if access to international carbon credits is allowed, GDP growth is projected to reduce by around 0.2% to 0.5% compared to Business As Usual. The report argues that using revenues from market-based instruments to reduce other taxes could lead to higher GDP. The model results find that if the EU uses additional revenues from auctioning CO_2 emissions allowances in the EU ETS sectors and raises tax revenues from the non-ETS sectors, reductions in labour costs (brought about by distortionary taxes on labour) would lead to a net increase of GDP by 2020 of 0.4% to 0.6%.

Another recent study by Marin et al. (2018) employed a similar methodology and found that the ETS had not affected firm performance negatively. This work suggests that firms have reacted to the EU ETS by passing-through costs to their customers on the one hand and improving labour productivity on the other hand.

Strategic investments

We found relatively few empirical studies that investigate the impact of strategic investments in low-carbon technology on productivity. Further research could seek to explore this.

In one of the few papers uncovered by our review, Hanson and Laitner (2006) found that a technology-led investment strategy and a moderate energy policy resulting in substantial domestic reductions of carbon emissions had a small but net positive impact on the US economy.

3.2.5 How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

The majority of studies on the productivity effect of carbon policies are conducted at the firm and industry-level, with only few papers adopting a macroeconomic view. The robustness of studies has improved in recent years with researchers using quasi-experimental techniques to try and estimate causal impacts, whereas earlier work had more often relied on correlations.

The research that does exist is very context-driven: studying the effects of a specific policy (e.g. Phase II of the EU ETS) over a specific time period and over a specific set of firms or industries (often manufacturing). Finally, the majority of research we have reviewed does not account for the value of avoided carbon in the calculations – i.e. traditional measures of productivity are used. As such it is difficult to generalise and extrapolate what the findings may mean for the economy as a whole.

On the whole, the evidence we have reviewed shows that:

- There are relatively strong links between carbon abatement incentives and innovation which is expected to drive productivity improvements over time. The positive link holds in studies looking at firm outcomes but also more macroeconomic research – several cross-country level studies show that tighter environmental regulation increases environmental innovation (Lanjouw and Mody, 1996; Popp, 2006; DeVries and Withagen, 2005).[25]
- There is less empirical evidence to directly quantify the link from low-carbon investment through to productivity. The effects that are detected are much more dependent on the specific policy studied and time period in question. Overall, it is reasonable to suggest that the effect on productivity may be positive but small in magnitude. The micro studies looking at firm outcomes indicate small productivity effects. Albrizio et al (2014) suggest that the overall effect at the economy level may be positive but small. Specifically, they find that a tightening of the stringency of carbon policy is associated with an increase in productivity

[25] The relationships described in these go beyond simple cross sectional associations – for example, studies look at both variation between countries as well as across time.

growth in the following three years of around 0.05 percentage points (from 1.17% to 1.22%) corresponding to a temporary productivity boost of around 4% for each of the three years. It should be noted, however, that the positive effect is preceded by a negative announcement effect (a reduction in productivity growth by around 0.08 percentage points in the year before the policy tightening) which reduces the positive effect to close to zero. For the most technologically advanced firms, the authors find an increase in TFP of up to 1.5 percentage points while the effect on less advanced firms is zero or even negative.

Our interpretation of the available evidence is that carbon policy may contribute a small boost to productivity growth but quantifying this precisely is very challenging. The limited evidence we have identified suggests a temporary boost to productivity growth of up to 4% (which is close to zero in the long run due to its temporary nature and preceding negative productivity effect) although it should be noted that this estimate is a judgement given the relative lack of evidence looking at the economy-wide effects of carbon policy.

The literature we have reviewed does not always explicitly test how far the effects that are found depend on the type of policy (e.g. market based instrument vs. standards). As noted earlier, it is often thought that more flexible policy instruments (e.g. market based policies such as carbon taxes or a carbon price) can achieve environmental goals and better economic outcomes than more prescriptive policies like standards. More prescriptive policies fail to provide an incentive to innovate beyond the point at which a standard is met, while market based instruments provide a continuous incentive to innovate (De Serres et al., 2011). Much of the literature appears to support this view (see for example Burtraw, 2000 or Isaksson, 2005 discussed previously). Johnstone et al. (2010b) find some evidence of perceived flexibility of environmental policies increasing patenting behaviour. De Santis and Lasinio (2015) also find that market-based measures are best suited to promoting innovation and productivity. The literature is not, though, unanimous on this point: Arimura et al. (2007), for example, do not find any different effects of voluntary approaches relative to command-and-control measures.

IMPLICATIONS FOR POLICY

The fact that different types of policy instruments are effective for stimulating innovation activity in different sectors might also explain apparently contradictory results in the literature. In the renewable energy sector, for example, broad policies such as tradable energy certificates are more effective when applied to more mature technologies, while more targeted subsidies, such as feed-in tariffs are more effective in case of early stage technologies (Johnstone et al., 2010a). Hamamoto (2006) claims that in Japan in the 1960s and 1970s command-and-control policies did trigger higher overall R&D activity but that a SOx charge, which was introduced later, did not.

On balance the literature suggests that market based policies may be more effective at promoting innovation but this finding is not universally accepted. However, given the mixed results in the empirical literature, it is prudent to conclude the design of the policy and the context in which it is applied are likely to be just as important as the type the policy used.

For a policy to gain traction it needs to be well received and supported by the sectors it is seeking to influence. Factors which are likely to influence this include:[26]

- **The credibility of the policy signal:** defined as the likelihood that policy makers will keep their implementation promises. This includes having a suitable set of policies and legislation, sound and transparent decision-making processes (including for enforcing and monitoring policy) and a supportive socioeconomic environment, in terms of public opinion and the private sector.
- **The stability of the policy signal:** this includes a solid track record of policy consistency (e.g. refraining from sudden policy reversal) and of meeting targets and/or significant fluctuations in the carbon signals.
- **The acceptability of the policy signal:** this refers to the extent to which industry and the public at large are likely to receive a policy. Evidence (e.g. Blassi et al. 2017) suggests that public opposition to carbon policy (e.g. taxes) stems from concerns that the personal costs would be too high, that carbon taxes may be regressive and that they may be less effective than subsidies. The public may also be suspicious of governments' motives, and may assume that carbon taxes are introduced only to raise revenues rather than reduce emissions. This suggests that policy success depends crucially on how a policy is communicated and designed to address the most widely held concerns.

These conclusions bring policy design, and proper measurement to the forefront of the debate, rather than technical design choices of the type of policy.

3.3 Gaps in the evidence base

The evidence from the literature reviewed shows that there has been substantial effort to understand if and how environmental regulations impact investments in low carbon technological innovations as well as productivity. Seminal papers like

[26] See Bassi et al. (2017) Credible, Effective and Publicly Acceptable Politics to Decarbonise the European Union. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2017/12/Credible-effective-and-publicly-acceptable-policies-to-decarbonise-the-European-Union-Final-report-2.pdf

Porter (1995) went on to redefine the fundamental thinking about these links. Many researchers have then attempted to use various research methods to theoretically and/or empirically support/refute the Porter Hypothesis. Many of those studies focus on the existence of a link rather than the magnitude or strength of that link.

Due to the time periods of their implementation- tradable emission permits began at scale with the EU ETS in 2005 whereas environmental (Pigouvian) taxes have been around much longer - there are fewer studies that examine the impact of many recent environmental policies. The studies are constrained by the number of years of data as well as different countries implementing them.

Another factor limiting our ability to draw sweeping conclusions is the changing nature of the robustness of the methods used and the quality of data. There have been significant improvements in estimation methodologies over time with recent studies able to estimate effects using more advanced econometric study designs but making it difficult to compare them with older studies.

Overall, we found more empirical research looking at the direct effects of carbon abatement policies on innovation and fewer papers examining the link with productivity. Further, the majority of empirical studies focus on contemporaneous effects and the dynamic links are less well explored. Given the nature of innovation is more long term and that the dynamic benefits of carbon policies may take a number of years to fully materialise, future research which examines these issues over a longer time horizon would add significant value.

Finally, as indicated in the previous section, much of the evidence we have discovered is testing specific policies in a specific time period and context. It is also predominantly at the micro level (firms) and as such the findings tend to be specific rather than general. This makes it very difficult to extrapolate from these findings to make conclusions about the aggregate productivity impacts of carbon abatement incentives. Extrapolating from firm level analysis to the macroeconomy is problematic because of:

- Displacement effects: where a policy is found to increase levels of innovation (and productivity), it is not always clear if this may be at the expense of reduced innovation elsewhere in the economy – in other words, it is possible that carbon policy encourages firms to innovate in the low carbon space at the expense of another area (e.g. ICT). Only one study we examined tackled this question directly, and found additional innovative activity (Calel and Dechezleprêtre, 2016).
- Spillover effects: a policy encouraging innovation in one sector may lead to the development of general purpose technologies and as such the productivity impacts could be far greater than those estimated by just looking at the sector at which the policy is aimed (see for example Medhurst et al. 2014).
- Non domestic effects: Environmental policies can also promote foreign innovation (Dechezleprêtre and Glachant, 2014) and technology transfer (e.g. in the automobile sector, Dechezleprêtre et al., 2013) – effects which are not normally captured by the existing literature.

4 CONCLUSIONS AND POLICY IMPLICATIONS

Summary of findings

The main aim of this work was to examine the links between carbon policy and productivity. Within that we were asked to address four specific research questions summarised in the figure below.

Question 1	Through what mechanisms do carbon policies influence productivity?
Question 2	Does the choice and design of carbon policies affect the capacity of the economy to innovate?
Question 3	Does the choice and combination of carbon policies have any particular implications for productivity over time?
Question 4	How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

We sought to address the research questions by gathering and interpreting available published evidence. Our main findings in relation to the research questions are:

Question 1: Through what mechanisms do carbon policies influence productivity?

There is significant literature looking at how environmental policies in general, and carbon policy in particular, can affect productivity. The effect can be negative or positive depending on the response of firms to the policy. In the short-term the policy may represent a cost to firms and so can reduce productivity. However, for firms who are not optimising their current use of inputs then, even in the short run, carbon policy can improve productive efficiency. Separately, there is a dynamic effect whereby carbon policy can stimulate innovation which can improve productivity if the innovation outweighs the cost of compliance with the policy – an idea first introduced by Porter (1991) and tested empirically in numerous studies.

Question 2: Does the choice and design of carbon pricing policy affect the capacity of the economy to innovate?

There is a considerable body of evidence which studies the link between carbon policy and innovation (typically measured R&D expenditures or successful patent applications). In the main this finds strong positive links between the two. The evidence is particularly strong for market based policies: recent work has found that the EU ETS has increased low-carbon patenting by almost 10% without crowding out other innovation. Other work looking at general environmental policies (typically proxied as environmental stringency) also finds positive links with innovation.

It is often thought that more flexible policy instruments (e.g. market based policies such as carbon taxes or cap and trade schemes) can achieve environmental goals and better economic outcomes than more prescriptive policies like standards. It has been argued that more prescriptive policies may fail to provide an incentive to innovate beyond the point at which a standard is met while market based instruments provide a continuous incentive to innovate. This is supported by much of the literature that was reviewed but there are also papers which do not find different effects of alternative approaches.

On balance the literature suggests that market-based policies may be more effective at promoting innovation but this finding is not universally accepted as there is also research indicating that other policies (if well designed) can be potentially as effective.

Question 3: Does the choice and combination of carbon policies have any particular implications for productivity over time?

There is a long established literature looking at the links between innovation and productivity in general which finds that innovation drives productivity. There is less research looking to link carbon policy and productivity directly. The research we have identified broadly indicates that carbon policy can have a positive effect on productivity, albeit the measured effects to-date are relatively small.

Existing research on the productivity effects of carbon policy struggles to separate out the specific circumstances of the policy being examined from the more general impact of the policy applied in a range of settings. The results of analysis to-date are usually context-specific and provide limited general policy guidance. There are also significant gaps in the evidence base. Most notably, there are few studies examining the macro effects of these policies (i.e. impact on overall productivity or GDP growth).

Given the relatively strong evidence base suggesting a positive link between carbon policy and innovation and the well-established link between innovation and productivity, it is reasonable to conclude that carbon policy can have a positive effect on productivity. Whether or not the type of carbon policy matters for productivity is less clear from the literature.

Question 4: How important, in productivity terms, is it to have a coherent set of economic carbon abatement drivers and how could this be measured or quantified?

This is clearly an area for further work, in order to better inform policy-makers how much focus to put on carbon policies. The transformation that would be needed to reach net zero, for example, would have widespread implications that the current empirical evidence on productivity does not address.

The research that does exist is very context specific. It examines the effects of a specific policy over a specific time period applied to a specific set of firms. As such it is difficult to generalise and extrapolate what the findings may mean for the economy as a whole. Our interpretation of the available evidence is that carbon policy may contribute a small boost to productivity growth (up to a maximum of 4% per year for a limited period), although the literature suggests that this is temporary and the effect is likely to be close to zero in the long run. It should also be noted that this estimate is a judgement and highly uncertain given the relative lack of evidence looking at the economy wide effects of carbon policy.

The aforementioned transformation to reach net zero would imply impacts of carbon policy on much larger drivers of productivity. For example, research by NIESR[27] suggests that improvements in skills account for around 20% of labour productivity growth in the UK in recent decades. Shifting to net zero would imply considerable changes in skills (and other drivers of productivity) that could ultimately feed through in material ways to measured productivity growth.

There are also significant gaps in the evidence base, notably:

- There are few studies looking at the dynamic efficiency impacts of carbon abatement incentives;
- There are few studies examining the macro effects of these policies; and
- There are more studies looking at the innovation effects of environmental policies than there are papers looking at the direct links with productivity.

Finally, it is important to note that productivity measures are currently based on GDP (GDP per worker, GDP per hour worked) and as such do not account for the value of avoided emissions (the “measurement issue” discussed in Section 3.1).

Policy implications

Our findings lend themselves to three conclusions for policy.

First, policy needs to be informed by more complete measurement of productivity. Traditional productivity measurement does not account for the positive value of harmful emissions that have been avoided as a result of environmental policy. In effect a cleaner economy is also a more productive economy both today and, more significantly, into the future. The importance of clean growth within the overall Industrial Strategy suggests that **the Industrial Strategy Council should consider how its interpretation of productivity and future productivity growth is affected by proper measurement and valuation of carbon abatement**.

Second, carbon pricing and environmental standards help drive innovation in the production of less environmentally damaging outputs. The appropriate policy and length of time to deliver new innovation will vary from sector-to-sector but the existing evidence suggests a strong link between the two.

Third, carbon policies need to adapt to the specific context to improve aggregate productivity. The evidence suggests that the success of carbon policies in driving traditional measures of productivity improvement is variable. The choice of specific policy (e.g. tax, standard, strategic investment) is likely to be less important than how well the chosen policy is adapted to the particular context in which it is applied.

It is seldom the case that policies are implemented in isolation. In the 1970s almost all environmental policies relied on direct regulation but since the 1980s policymakers have considered and often selected market based instruments. Often

[27] NIESR (2015), “UK Skills and Productivity in an International Context”, BIS Research Paper Number 262

these have been introduced alongside direct regulation as well as strategic investments by government: for example, the auctioning of Contracts for Difference (CfD) designed to protect low-carbon electricity generators from volatile wholesale prices (by guaranteeing a flat rate for 15 years) runs alongside funding for R&D in renewable generation and the creation of the Offshore Renewable Energy Catapult which provides (among other services) open access and independent test and research facilities.

It appears that how a policy is designed and how it is implemented matter more for its success as the initial choice of policy instrument. Factors such as the credibility and stability of a policy are likely to be as important as the type of policy (market based vs. technical standards vs strategic investment).

These conclusions bring policy design, and proper measurement, to the forefront of the debate about how to ensure carbon policy supports and enhances productivity growth.

Moving forward

The integration of policy linked to growth, productivity and the low carbon transition would be helped by better understanding the most appropriate ways in which the **carbon externality can be factored into productivity measurement**. As a starting point, we would suggest a review of best practice and lessons from other countries. A list of criteria could be developed to assess the suitability and viability of alternative approaches and allow for a preferred method to be chosen.

There are existing methodologies which could offer a feasible way forward. One such approach is the adjusted growth accounting framework which adjusts traditional productivity growth by the weighted difference of bad output and input growth. In essence this involves including environmental services as an input in the production function. TFP growth is then measured as the difference between increases in output and increases in labour, capital and environmental inputs used to generate outputs.

An alternative method is the so called distance function approach in which data on inputs, traditional outputs and “bad” outputs are used to determine the technological production frontier, showing all possible (efficient) input/output combinations. For each possible input-output combination, the distance function then measures the possible efficiency gain of moving from an inefficient point to the efficient frontier.

There are specific challenges associated with both methods but exploring them and potentially others offers a practical way forward for improving productivity measurement.

In addition to proper measurement, policy would be better supported with a more accurate understanding of the benefits and costs of new actions. The work presented in this report has relied on existing empirical evidence to quantify the links between carbon policy and productivity. To understand the links more directly and allow policy-makers to assess the potential size of effects in more detail (and at different levels of aggregation) requires a **scenario-based micro simulation model**. Such a model would provide quantitative estimates of how carbon prices do (and could in the future) feed through into growth and productivity.

A model could be constructed bottom up allowing analysis at sector but also economy wide level. The model would draw on existing parameters (from the literature) and wider data to allow the user to track how different carbon policies feed through in terms of firm and sector level costs, prices, profitability and productivity and then how these translate into economy-wide effects.

Constructing such a model would require different data sources to be combined. For example firm and sector level profitability and productivity can be obtained from sources such as the Annual Business Survey (ABS) or Financial Analysis Made Easy (FAME) data which has detailed financial information (including costs and profits) at the firm level and follows a very large number of businesses (several million). Other firm level data sources which could be used to construct the required data include the Business Structure Database (which includes turnover and employment information on all businesses in the UK) while price data can be obtained from the ONS retail price indices. The core of the model would rest with how measures to reduce emissions interact with the business data. That would need to draw on the type of literature and evidence investigated in this report alongside techniques to simulate measures might feed through where existing evidence is insufficient. It would provide policy makers with a direct understanding of the links between low-carbon policy options and productivity effects.

Combined, the micro simulation modelling and work exploring how to incorporate the carbon externality into productivity measurement would enable us to better understand how carbon policy affects productivity at the firm, sector and economy-wide level.

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