Investing in Climate, Investing in Growth

Chapter 4

Growth implications of climate action

The current global economic environment provides governments with an opportunity to boost economic growth while also addressing the challenges of climate change. Ensuring that growth is low-emission, resilient and inclusive can help to meet the Paris Agreement goals while also delivering on the Sustainable Development Goals. While the synergies between climate and growth policies are substantial, capitalising on them requires fiscal initiatives to scale up public and private investment in the right technologies and infrastructure, combined with a well-designed structural reform package. This chapter shows how these pro-growth reform policies can support ambitious policy action on climate change to create a "decisive transition" to a low-emission, high-growth future. It presents model simulations that combine climate action with pro-growth policies including the impacts of delaying action.

The current global macroeconomic environment, including low interest rates in most countries, provides governments with an opportunity to create conditions for high-quality economic growth that is low-emission, resilient and inclusive. The synergies between climate and growth policies are substantial, but capitalising on them requires scaling up public and private investment in the right technologies and infrastructure, combined with an effective structural reform package. Growth and climate agendas can be integrated as their effectiveness depends partly on the same factors: developing and diffusing new technologies to attract investment, and reallocating resources towards high-productivity economic activities.

This chapter shows how these pro-growth reform policies can support ambitious policy action on climate change to create a "decisive transition" to a low-emission, high-growth future. Based on macro-economic model simulations, the chapter explores the potential impacts on growth and employment of scenarios that combine climate action with pro-growth policies. The chapter starts by providing context on the current global macro-economic conditions and the potential for fiscal and structural policy levers to promote growth. The following sections present the results of the model simulations, and examine the implications of a delayed action scenario and the consequences of a lack of co-ordinated action. The chapter concludes by shedding light on the structural and employment changes that economies face as they move to low-emission pathways.

The macro-economic context

Many G20 countries are in a low-growth trap

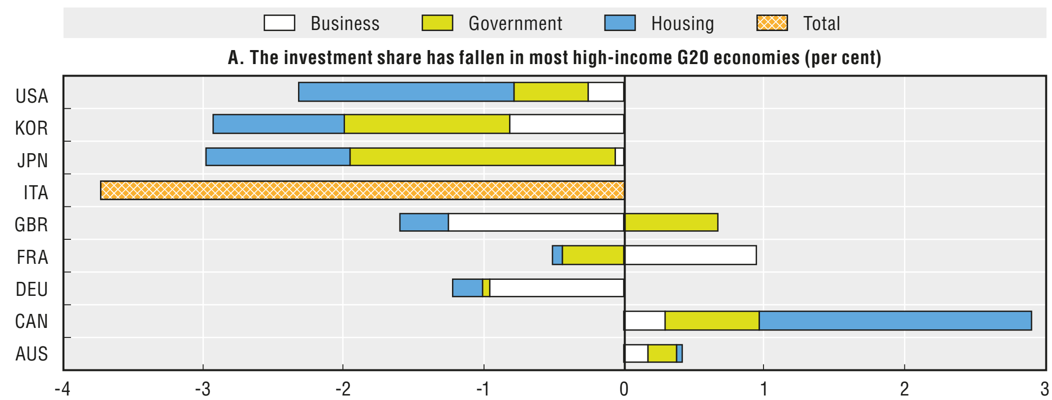
Global economic growth has hovered around 3% in the past five years, below the level needed to sustain the aspirations of citizens. In many countries, private and public investment has been weak, slowing growth in labour productivity and total factor productivity (OECD, 2015a, 2016a). In most high-income G20 countries, government, businesses and households have been investing substantially less than in the pre-crisis years (Figure 4.1).

Although overall investment as a share of GDP has increased in emerging G20 economies, its level varies significantly from country to country, and remains low in several. Yet investment is a key driver of growth, and a decisive factor enabling emerging economies to reach the levels of economic development of high-income countries. In response to these bleak economic conditions, expectations for GDP growth and investment for the next decade have been revised downwards in both advanced and major emerging economies (Figure 4.2).

As G20 governments seek to revive economic growth, the quality and inclusiveness of growth also matters. To continue to improve well-being beyond the short term, the sources of growth need to be sustainable economically, socially and environmentally. Over the longer term, the fundamentals of continued economic growth are at great risk due to the scale of potential damage from climate change described in Chapter 2. Climate change poses a major systemic risk to all economies, but particularly for societies in less-developed, less-resilient countries. Delaying action on climate change is likely to result in a more disruptive, substantially costlier transition, as high-carbon infrastructure and other assets will be made obsolete.

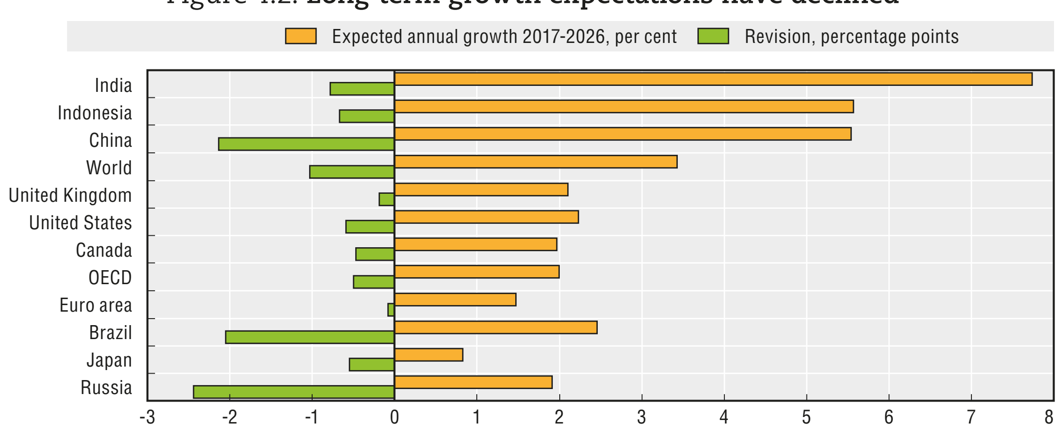
As well as supporting low-emission, climate-resilient development, new growth also needs to be inclusive. Widening inequalities and an increasing realisation that recent growth has benefited only parts of the population have made enhanced inclusiveness a key priority for governments. The benefits of low-emission, climate-resilient growth, including new economic opportunities, need to be equitably distributed across society, reducing potential opposition to climate change policies and helping to ensure existing inequalities are not compounded in the transition.

Figure 4.1. **Investment as a share of GDP in 2015 relative to the average in the pre-crisis decade***



Note: *Average of investment shares in GDP from 1996 to 2007. No breakdown available for Italy and the emerging economies
Source: OECD (2016a), Economic Outlook: Statistics and Projections (database).

Figure 4.2. **Long-term growth expectations have declined**



Note: The revision is the difference between April 2011 projections of average annual GDP growth over 2012-21 and April 2016 projections of average annual GDP growth over 2017-26. OECD and World estimates based on weighted average of available countries, using 2015 PPP shares.
Source: Consensus Forecasts; and OECD calculations.

A window of opportunity to escape the low-growth trap

To get out of the low-growth trap, collective, well-designed policy decisions are needed to support aggregate demand in the short term and provide an impulse to longer-term growth. There is little scope left for monetary policy to provide such a stimulus in most countries, so a proactive fiscal policy response is required. Such a response is feasible because interest rates are close to zero in many advanced economies, and where they are rising they are still near historic lows (OECD, 2016a). Other things being equal, lower interest rates increase the extent to which governments can borrow in the near term without losing market access or facing challenges with the sustainability of public debt. In other words, lower rates increase the "fiscal space" available to governments. Targeted government spending and taxation, wherever possible, need to be deployed to support the implementation of structural reform and improve infrastructure, helping to close the infrastructure investment gap identified in Chapter 3.

In countries where public debt is high and where population ageing poses risks to fiscal sustainability and long-term financing challenges, these issues need to be taken into account in evaluating the size and desirability of using fiscal space. Such countries should indeed avoid substantially higher financing costs as a result of higher debt. Budget rules can also constrain the extent to which governments can use deficit-financing to fund infrastructure. In a few countries, notably Brazil, fiscal consolidation is needed to allow monetary policy to loosen and support a recovery of investment. In addition to public funding of infrastructure, governments can seek to mobilise private investment through well-designed investment policies and public-private partnerships (see Chapter 5 on investment policies and Chapter 7 on raising finance).

Independently of existing fiscal space or limiting fiscal rules, all G20 countries have considerable scope to improve their mix of public spending and revenue to boost growth and support the low-carbon transition (OECD, 2016a). This can be achieved, for example, by cutting inefficient subsidies (Chapter 5). Removing subsidies to fossil fuels, in particular, can boost growth while creating an incentive for low-emission growth. Tax reform can also support low-emission growth, by reducing taxes on income and raising taxes on greenhouse gas (GHG)-emitting and other polluting activities or immovable property (Johansson et al, 2008).

The fiscal space should be used wisely to boost production capacity with appropriate investment in hard and soft infrastructure. For countries with high debt, it is critical that such a policy initiative raises GDP sufficiently to lower the debt-to-GDP ratio. Consistency of investments with climate change goals, based on strong climate policy packages, will ensure long-term sustainability as well as avoid stranding high-carbon investment later. A productivity-enhancing fiscal initiative will yield long-term growth benefits only if the requirements of the low-carbon transition are taken into account.

Reviving growth requires stronger structural policies in G20 economies

Complementing fiscal policy with pro-growth structural reforms that support low-emission investments should be another important pillar of low-emission growth packages. Structural reforms can further strengthen aggregate demand and employment in the short term and generate gains in long-term material well-being. As recent OECD *Economic Outlooks* have argued (OECD, 2016a, 2015b), the pace of growth-enhancing reforms has slowed in high-income and emerging economies, particularly in cross-cutting policy areas with a strong influence on labour productivity, such as education and innovation (OECD, 2017). Governments have tended to concentrate reform efforts in specific policy areas, which suggests that potential gains from policy synergies and reform complementarities are being missed (OECD, 2017). Enhanced education and innovation policy is vital not only to address the persistent and widespread decline in productivity growth but also to manage the low-carbon transition successfully and to make economic growth more inclusive.

To strengthen economic growth, renewed efforts are needed across a wide range of reform areas in both advanced and emerging economies. Possible reform packages include measures to enhance entry of new firms and product market competition, particularly in services sectors with pent-up demand (Gal and Hijzen, 2016). Firm-level evidence suggests that reforms to strengthen competition, market entry and entrepreneurship can boost investment by around 4% after two years in high-income economies (Gal and Hijzen, 2016). As shown below, they would improve the response of firms to increases in energy prices and tighter environmental regulation, boosting investment, innovation and productivity.

Such reforms encourage the take-up of new technologies and more efficient use of resources; they can also hasten the development of low-carbon business models, such as new transport solutions through, for example, the development of start-ups. Reallocation-friendly banking sectors and insolvency regime reforms could ease the exit of failing firms, thereby facilitating the reallocation of resources to more productive and innovative activities, including low-carbon activities (Adalet McGowan et al., 2017). Such policies would also boost investment in knowledge-based capital, such as high-productivity technologies, research and development, management skills and worker qualifications across countries, businesses and households – for example, through education and trade – also increasing diffusion of new, lower-carbon technologies.

Steps to better match skills to jobs and to ensure that skills are used fully could also boost productivity by enabling firms and workers to adopt and use innovation and new technologies (OECD, 2016a). Reforms to housing policies and active labour market policies that combine benefits with retraining and upskilling can lower unemployment, facilitate geographic mobility and improve the matching of skills and jobs. Such policies can help workers in declining fossil fuel-intensive production find new jobs in low-carbon sectors while encouraging upward social mobility – part of ensuring a "just transition" for workers (see Chapter 6).

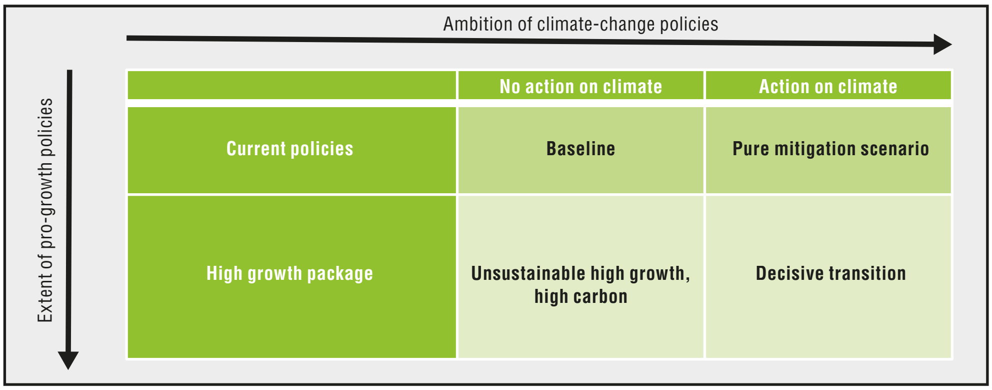
Reform efforts will only work if they are coherent. Regulatory policies need to encourage the emergence of new business models, especially in low-emission activities. Complementarities also need to be exploited to make the most of growth impacts of policy reforms. For example, relaxing labour regulations in an environment of rigid product markets may reduce employment and wages. In contrast, deregulating the business environment at the same time enhances the likelihood that businesses will compete for workers. Overall, integrating climate policies with growth policies is a policy challenge with substantial benefits. The specifics of how structural reform policies can support climate change mitigation strategies are covered in Chapter 5.

Combining economic and climate policies could both achieve the Paris climate objectives and spur economic growth

Governments have at their disposal a range of policy options to both generate economic growth and to combat climate change. How these policies are combined will influence differently both economic growth and the extent to which countries move towards low-emission and resilient pathways. The policy combinations can be stylised as choices along two dimensions: between current economic policies and pursuing a high-growth policy package on one dimension, and between no climate action and action to pursue the Paris

Agreement goals on the other dimension (Figure 4.3). If chosen appropriately, a combination of climate policy instruments, and well-aligned fiscal initiatives and structural reforms would allow G20 countries to both achieve climate goals and escape the low-growth trap.

Figure 4.3. **Identifying a pathway for the "decisive transition"**



The *baseline* scenario used in the model simulations assumes no climate policy change from the current situation, and no new policy to support growth beyond what is currently planned (top-left quadrant of Figure 4.3). In such a situation, the world would remain in a low-growth trap and miss the Paris Agreement goals.

Governments may be tempted to pursue fiscal and structural policies to provide an impulse to economic growth "at all costs", without ensuring that new investments support the low-emission transition (bottom-left quadrant). Reasons for pursuing this path could include low prices for fossil fuels, the strength of incumbent fossil fuel technologies (see Chapter 3), inaccurate or non-existent pricing of GHG emissions and other pollution externalities, and a disregard for the longer-term consequences of today's infrastructure investment decisions (see Chapter 5). There may also be a lack of "bankable" low-carbon and climate-resilience projects, due to policy misalignments and the incumbency advantage of existing technologies and business models. This "unsustainable high-carbon" pathway is not examined in this report.

Alternatively, governments may pursue policies to decarbonise economies but without taking action to provide an impulse to economic growth: a "pure mitigation" scenario (top-right quadrant). As argued below, however, this would result in higher adjustment costs, less take-up of business opportunities in the context of the low-carbon transition, and lower material well-being and employment, all of which would make the transition more difficult politically.

The "*decisive transition*" scenario is a high-investment, high-innovation and low-carbon transition path, combining pro-growth policies with more ambitious climate policies (bottom-right quadrant). In this scenario, countries implement a policy package that spurs growth while accelerating the transition towards long-term climate change objectives. This package comprises a fiscal initiative in support of climate objectives – for example, additional investment in infrastructure, education and R&D – and structural reforms that have been found to boost long-term growth and can be made coherent with the low-carbon transition (OECD, 2017). In the model simulation, a "typical" package is considered to combine an increase in public investment with a cut in the stringency of product-market regulations and an increase in R&D spending. In reality, the composition of this package would be country-specific, reflecting existing institutions, regulatory frameworks and preference for equity. Box 4.1 provides an overview of the underlying model assumptions while Annex 4.A2 provides further details on the models' structure and parameters.

The macro-economic impacts of the different scenarios are expected to vary over time. In particular, while decarbonisation policies are likely to create adjustment costs in the short to medium term (5 to 20 years depending on policy stringency), high-carbon pathways would mean, over the longer term, increasing damage from climate change. This would weigh negatively on output and on well-being more generally. The high-carbon pathways would also entail increasing tail risks (such as rapid sea-level rise from melting of ice sheets, and systemic effects of repeated extreme weather events) and well-being costs (such as increased mortality from air pollution). Ambitious climate mitigation action offers the benefit of decisively lower long-term costs from climate change and provides decisively more insurance against the risk of destructive extreme weather events. Conversely, it requires more investment and more stringent climate mitigation policies in the short term. Undertaking structural reforms so these adjustments occur in the context of high, inclusive growth ought to be seen as an integral part of making the economic case for climate policy action.

The macro-economic impacts of the different scenarios will also substantially differ across countries, depending on their sectoral structure and energy consumption. For example, fossil-fuel exporting countries are usually seen as incurring the highest costs in the transition. In reality the situation may be more complex, as demand for fossil fuels will continue for some time, and relative costs of extraction will determine market shares and revenues in a scenario with lower demand. Similarly, countries whose public investment is low could benefit the most from the additional increase in investment (Fournier, 2016). More flexible product and labour markets would also facilitate the transition toward a decarbonised economy (see below).

Given the importance of path dependence, the implications of delayed action are also examined, building on the IEA disjointed scenario (IEA, 2016), whereby investment to meet the goal of limiting global warming to 2°C is delayed to 2025. This implies a more abrupt path to decarbonisation from 2025 on, combining higher carbon taxes, more support to low-carbon technologies in general, and significantly larger stranding of fossil-fuel-based assets.

The model simulations in this chapter explore the implications of a decisive transition for the main macroeconomic aggregates, including GDP, employment, business investment and the ratio of public debt-to-GDP. The decisive transition scenario is compared with a baseline scenario that assumes no change from current climate policy and no new policy to support growth. The transition would involve not only undertaking mitigation policies to reduce emissions and achieve a 2°C path with a 50% probability, but also complementing these policies with a fiscal initiative (e.g. additional investment in hard and soft infrastructure) and structural reforms that would support long-term growth and reduce adjustment costs. A simulation is also run for a more ambitious climate scenario, assuming a 66% probability of keeping temperature below 2°C. The simulations build on the results from a parallel report for the German G20 Presidency on the scale and scope of energy sector investments needed to increase the chances of reaching this goal (IEA, 2017).

Box 4.1. **Key modelling assumptions**

Several assumptions underpin the decisive transition scenario:

- Governments absorb some of the incremental costs of low-carbon and climate-resilient infrastructure investments (e.g. via public investment programmes or procurement of innovative solutions). This is justified by market failures that may prevent firms from responding to more direct price-based instruments (see Chapter 5). Such public investments could trigger higher growth in business investment, at a time when it remains modest. As many climate-friendly investments involve new technology, they should also open markets for innovative firms. One important assumption underlying the simulations is that the investment undertaken is of good quality, and there is relatively strong institutions and effective public governance in place.

Box 4.1. **Key modelling assumptions** *(cont.)*

- All G20 countries take action on climate. If a leadership group of countries were to act alone, free riders would benefit from lower fossil fuel prices and substitution of carbon-intensive economic activity away from this group of countries, undermining global emission reductions (see below and Annex 4.A1 for a discussion).
- The boost in investment is assumed to be budget-neutral in the medium term and financed by better reallocating tax and spending, which would leave the public deficit unchanged. From 2017 to 2020, the measure would be financed through a higher public deficit in all the G20 countries covered in the analysis except Brazil, Japan, India and South Africa. In these four countries, assuming no change in policies, fiscal space is limited, and the initiative is expected to be budget neutral from 2017 onwards.
- In most countries, revenues from the taxation of carbon emissions are used to pay down public debt. In countries where the ratio of public debt-to-GDP is low, however, it is assumed that, in the medium term, those revenues are used to support a further increase in public consumption. A detailed discussion of the potential uses of carbon tax revenue follows in Chapter 5. Other recycling options could lead to higher growth outcomes depending on pre-existing tax levels and their distortionary effects in various economies. In most cases, the effect of the recycling is expected to vanish over time, except if revenues are used to increase good-quality productive investment.
- Interest rates set by central banks are assumed to remain at their current level for three years in the euro area and Japan, and to follow inflation and growth developments elsewhere.

Simulations were performed using Yoda, an OECD in-house semi-structural model for selected G20 economies. This model encompasses international spill-overs and delayed labour-market response to policy (hysteresis effects). To assess the robustness of simulation outcomes and complement the analysis, some simulations were also performed using the macro-economic Oxford model which has detailed trade and financial inter-linkages, but can be simulated only up to 2045 (see Annex 4.A2). Like all empirical tools, these models have several limitations. In particular, they are a stylised representation of the economy. Political decisions, social acceptance and institutional factors, for example will also play a major role in the real world, but are not taken into account in the simulations.

The quantitative analysis covers most G20 countries (representing 88% of the total of G20 economies excluding the European Union), based on data availability and the geographic scope of modelling tools.[1] With a view to identifying categories of countries that would respond differently to mitigation and pro-growth policies, four types of stylised economies are presented depending on their reliance on fossil fuels (net importers or exporters) and their level of development (advanced or emerging economies).

A "pure mitigation" scenario, without supporting growth policies, would have overall limited growth effects

Achieving the goal of limiting global warming to 2°C with 50% probability will clearly require ambitious climate policies. This includes strengthening the use of carbon pricing instruments in order to direct private investment and technological change into low-emission activities in a cost-effective way. In the model simulations, the move is achieved through higher carbon taxes and a range of energy efficiency and technology support policies (IEA, 2016, 2017). Without specific additional measures to boost growth, the impact of decarbonisation is estimated to be small in the medium term on average for G20 countries. For each country, the effects of such a "pure mitigation" scenario would depend on whether it is a net exporter or importer of fossil fuels, with a more pronounced negative effect on net fossil-fuel exporters.

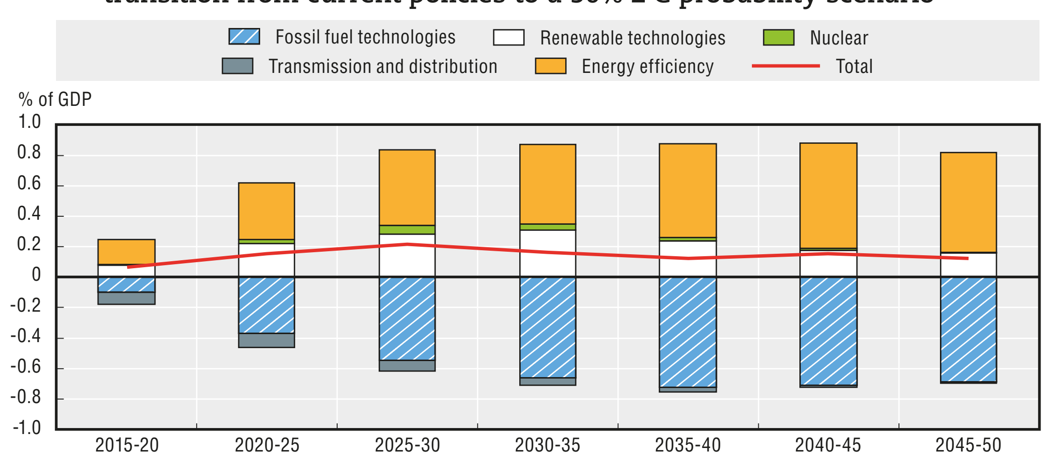
Long-term effects of mitigation policies on output in a pure mitigation scenario would be more pronounced, though still relatively small given the time horizon involved. Net fossil-fuel exporters in OECD member countries and emerging economies would experience significant losses in the long term, reflecting to a large extent massive disinvestment in high-carbon industries and lower fossil-fuel export prices. In countries where the level of public debt is low, however, recycling of carbon-tax revenues through additional spending could mitigate those losses. By contrast, net fossil-fuel importers would benefit in the long term from the increase in net investment and, to a lesser extent, the decline in international commodity prices from lower global demand. Overall, the GDP impact of mitigation policies would be small in net fossil-fuel importer economies in the long term.

Examining these results in more detail, the move to a low-emission pathway implies reducing high-carbon investment, and using the freed resources to fund part of the increase in low-carbon investment spurred by mitigation policies. According to IEA (2016, 2017) estimates, the energy sector requires net investment of around 0.2% of GDP in order to reduce emissions to a level that keeps warming at or below 2°C (Figure 4.4). This includes investment in renewable energy technologies, nuclear power and energy efficiency, and the lower investment in fossil-fuel supply and power transmission and distribution, due to lower electricity demand. This estimate is based on the assumption that world GDP would grow around 2% between now and 2045-50. This scenario assumes an orderly transition to a low-carbon economy and is contingent on the deployment of energy technologies that deliver net negative emissions.

The investment data used in the scenario is restricted to the energy sector. Agriculture, forestry and land use are likely to play an important role in achieving a 2°C objective, especially in countries such as Brazil and Indonesia, but the majority of infrastructure investment needs relates to energy supply and use (see Chapters 2 and 3) (OECD, 2015b; OECD, 2016b). In addition, there are limited up-to-date data for land-use investment, making their inclusion in macro-economic estimates difficult.

Further, investment in total urban and non-urban transportation infrastructure could add the equivalent of 0.2-0.3% of world GDP on average per year, according to estimates from the IEA Energy Technology Perspectives and data from the International Transport Forum. This information could not be included in the simulation exercise, however, because detailed data are not available for all scenarios and individual countries. Adding this infrastructure investment would have increased the positive GDP impact of investment in this scenario, though to a limited extent.[3]

Figure 4.4. **World net additional energy-related investments implied by a transition from current policies to a 50% 2°C probability scenario**



Note: based on Current Policy Scenario and 50% 2°C Scenario.
Source: IEA 2016.

Studies based on integrated assessment models have concluded that mitigation policies will have a negative impact in the long term (IPCC, 2014). Once economies adjust to new policies, however, the cost in terms of lower material living standards is low (OECD, 2015c). Other studies have suggested that limiting global warming to 2˚C with 50% probability would entail global consumption losses of 2-6% by 2050; this would amount to a small fraction of the consumption gains in the context of continued economic growth (IPCC, 2014). The magnitude of the impact depends crucially on assumptions about availability and costs of low-emission technologies, the degree of market flexibility and the options for recycling carbon tax revenues.

Box 4.2. **Modelling exercises for growth and climate policy analysis**

A range of modelling approaches has been used to assess the effects of climate mitigation policies on economic growth (see Clarke et al., 2014). Differences in results arise, among other things, from the choice of modelling approach. Computable general equilibrium models such as ENV-Linkages have been used for instance in OECD (2009). Other studies have used macro-economic models accounting for short-term market failures, such as E3me used in IRENA (2017) to estimate GDP and employment effects of a low-carbon scenario based on extensive deployment of renewable energy and energy efficiency. Other differences arise from key parameter assumptions (e.g. the cost of low-carbon technologies, endogenous or exogenous technical change, the degree of crowding out of investment); and the choice of policy instruments (carbon pricing alone or in combination with low-carbon technology support, energy efficiency measures, etc.).

Most economic analyses to date have focused primarily on climate policy. The “decisive transition” scenario in this report is driven by the need to consider climate policy in the current macro-economic context of low-growth, low productivity growth, under-investment and low interest rates. It also broadens the policy tool-kit to include dedicated fiscal initiatives (beyond the carbon tax, used for mitigation purposes) and structural reforms that are aligned with both the growth imperative and the requirements of the transition to low-emission, climate-resilient economies.

A decisive transition would spur growth while limiting climate change

Complementing climate change policies with a combination of a fiscal initiative and structural reforms would help achieve both climate and growth objectives. The fiscal initiative comprises spending or tax measures that will foster productivity in the medium to long term. Measures should be chosen according to each country’s most pressing needs and could include not only raising spending on soft and hard infrastructure or education, but also reducing taxes that are most likely to lower economic growth, such as income tax. Measures should also be closely aligned with the general objectives of the transition to a low-carbon, climate-resilient global economy.

In all countries, there is scope to design these policies to ensure the benefits of higher growth are shared by all, including low-income households. Such measures include decreasing labour taxes at the lower end of the wage distribution, and improving access to education, health, low-cost quality housing and public transport. Priorities will differ depending on individual countries (OECD, 2016a, 2017). Spending on adaptation policies that would improve the resilience of economies could also be part of this package.

To illustrate the impact of a decisive transition on the economy, the model simulation presented below assumes that in addition to mitigation policies, countries put in place a pro-environment, pro-growth policy package that combines fiscal and structural measures.

This approach differs from previous work on the issue in that it places climate policy actions within the current macro-economic context of low-growth, low productivity growth, under-investment and low interest rates, and broadens the policy tool-kit to include dedicated fiscal initiatives (beyond the carbon tax, used for mitigation purposes) and structural reforms that can support the low-carbon transition. The policy package used in the simulations includes:

- A fiscal initiative that corresponds to an increase in public investment of 0.5% of GDP. This represents a larger increase than in the pure mitigation scenario in countries that are net fossil fuel importers, as there is a need to invest more to compensate for the disinvestment triggered by decarbonisation policies. In many countries, such a package could be deficit-financed for a few years, before turning budget-neutral. OECD analysis suggests that thanks to low real interest rates, OECD member countries could afford to finance a fiscal initiative equivalent to 0.5% of GDP per year for about three to four years, on average (Mourougane et al., 2016). After this period, reallocating spending and taxation to the most growth-friendly and equity-enhancing measures would help to free up resources (see Fournier and Johansson (2016) for examples). Assuming it takes the form of an increase of good-quality public investment, such an initiative would leave the public debt-to-GDP ratio unchanged in the long term. These measures are also to be aligned with low-emission and climate-resilience objectives.
- Changes in R&D spending that would be needed at the world level to achieve a 50% 2˚C scenario. Estimates have been derived from Marangoni and Tavoni (2014), assuming all countries act collectively. The impact of R&D spending on total factor productivity draws on recent OECD analysis (Egert and Gal, 2016).
- Reforms to make product-market regulation more conducive to competition and market entry, essential to facilitate the transition. The impact of product-market reforms on long-term output is based on new OECD analysis on the impact of selected structural reforms for both OECD member countries and emerging economies (Egert, forthcoming ; Egert and Gal, 2016). The measure is calibrated using past observations of reform changes. In practice, the reform is assumed to be more ambitious in emerging economies than in OECD member countries, explaining why the resulting output impact is larger for emerging economies. A more flexible regulatory environment, for example as measured by the OECD product-market regulation (PMR) indicators, reduces the cost of the transition to a low-carbon economy. In particular, new results show it can reduce the negative effects from higher fossil fuel prices on business investment. In countries with most flexible product markets, the effect of higher end-user fossil-fuel prices on investment seems neutral or could even be positive (Box 4.3).

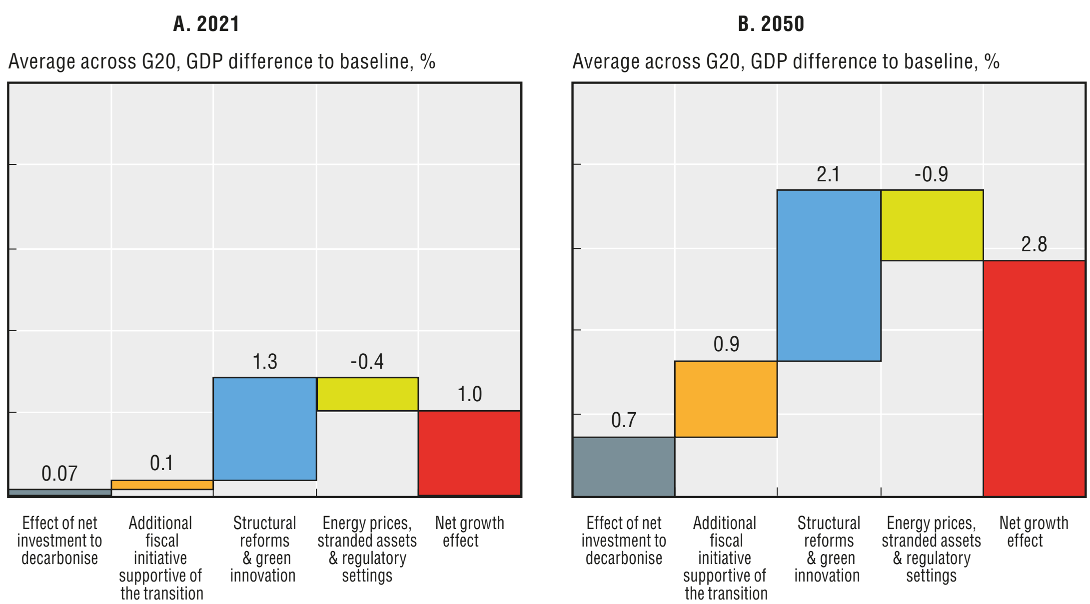
The simulations indicate that selected pro-growth policies can offset the negative impact of mitigation policies aimed at limiting global warming to 2°C with 50% probability, showing that combined climate and growth policies can be, on average across countries, good for growth, in both the long term and the short term. After five years, average gains in output for G20 economies would amount to around 1%, thanks to well-aligned pro-growth policies (Figures 4.5 and 4.6). Estimates suggest that those effects could raise long-run output by up to 1-4% in most of the large advanced economies and emerging economies by 2050. Those gains would be just below 3% by 2050 for G20 countries. The detailed results for the country types are provided in Table 4.1.

An important part of the output effect is an overall boost in investment, including in low-emission infrastructure, by 0.5% of GDP, increasing long-term output by up to 2% in advanced economies and emerging economies by 2050. Medium-term gains would amount to 0.2-0.5 % in most countries.

The countries that would experience the highest gains are those where the initial stock of public capital is lowest, and those where long-term unemployment is high. Net fossil-fuel exporters would benefit the most from the initiative, which is supposed to offset the negative impact of the disinvestment caused by mitigation policies. In a few economies that are heavily reliant on fossil fuels, a typical pro-growth package may not be sufficient to fully compensate for mitigation cost in the short term. Designing the policy package that would best fit each country's needs, however, would have a stronger counterbalancing effect.

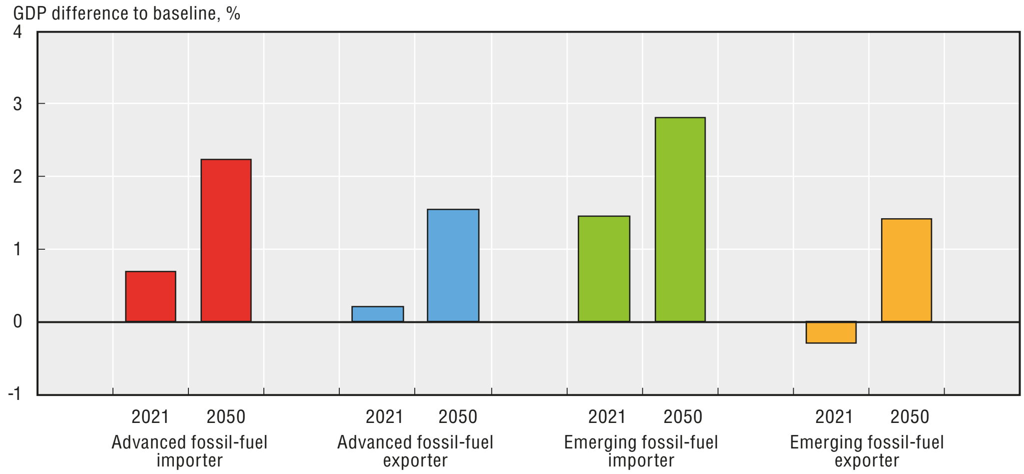
Adding reforms that favour innovation and growth (such as basic public R&D and structural reforms) to the fiscal initiative would increase the output gains. Indeed, implementing structural reforms can enhance output and lower the public-finance impact of an increase in public investment, through their gradual effect on total factor productivity and potential output. In particular, reforms aimed at removing barriers that hold back demand for investment, such as improving the design of regulations to reduce unnecessary burdens on entrepreneurship, can markedly boost output in the long term through their effect on total factor productivity.

Figure 4.5. **Contribution of selected pro-growth and mitigation policies in the G20**
(50% probability of achieving 2°C)



Note: The average G20 is a weighted average of selected G20 economies, representing 88% of the G20 countries (i.e. excluding the European Union). Energy prices and stranded assets are based on the IEA scenario and correspond to a move to a 2°C climate objective with a 50% probability. Regulatory setting captures the reduced costs of the transition in a more flexible regulatory environment, based on firm level investment regression that interacts energy price inflation with product-market regulation settings. Fiscal initiative corresponds to an increase in public investment that complements the net investment from decarbonisation so that in total, investment would increase by 0.5% of GDP. This means that net fossil fuel exporters who experience disinvestment from mitigation policies are assumed to invest more to compensate for this disinvestment. The structural reform considered here is a lowering in barriers to investment by 0.35 point for the OECD member countries and by 0.85 point for emerging economies, which correspond to the average change in this measure in the past. The impact has been calculated using estimation of business regulation on income per capita by Égert (forthcoming) and Égert and Gal (2016). Innovation corresponds to the increase in R&D spending necessary to reach a 2°C scenario using estimates from Marangoni and Tavoni (2014). It is assumed that the stylised fossil fuel exporters recycle their carbon tax revenues into higher public consumption in the medium term, given their initial low level of public debt. No recycling is assumed for the net importers.

Figure 4.6. **Net growth effect of selected pro-growth and mitigation policies in stylised economies**



Note: See the Note for Figure 4.5.

Table 4.1**. Contribution of selected pro-growth and mitigation policies in stylised economies and the G20**

GDP difference to baseline, %

Policy component	Advanced fossil-fuel importer		Advanced fossil-fuel exporter		Emerging fossil-fuel importer		Emerging fossil-fuel exporter		G20 average	
	2021	2050	2021	2050	2021	2050	2021	2050	2021	2050
Effect of net investment to decarbonise & additional fiscal initiative supportive of the transition	0.4	1.5	0.3	1.1	0.0	0.7	0.2	1.6	0.2	1.6
Structural reforms & green innovation	0.7	1.3	0.6	1.4	1.7	2.6	1.9	5.1	1.3	2.1
Energy prices, stranded assets & regulatory settings	-0.3	-0.6	-0.7	-0.9	-0.3	-0.5	-2.4	-5.3	-0.4	-0.9
Net growth effect	**0.7**	**2.2**	**0.2**	**1.6**	**1.5**	**2.8**	**-0.3**	**1.4**	**1.0**	**2.8**

Note: See the note for Figure 4.5

Box 4.3. **A regulatory environment that encourages competition and firm entry improves firms' investment and innovation response to climate change mitigation action**

Climate change mitigation action requires flexibility: old technologies and infrastructure need to be replaced by new ones. New OECD research undertaken for this project shows that governments need to provide a flexible regulatory environment – which does not restrict firm creation, market entry or competition – to encourage private investment and innovation and thus make the most out of the low-carbon transition (Annex 4.A4). Previous research has already shown that such a flexible regulatory environment can boost productivity, investment and employment across the income spectrum.

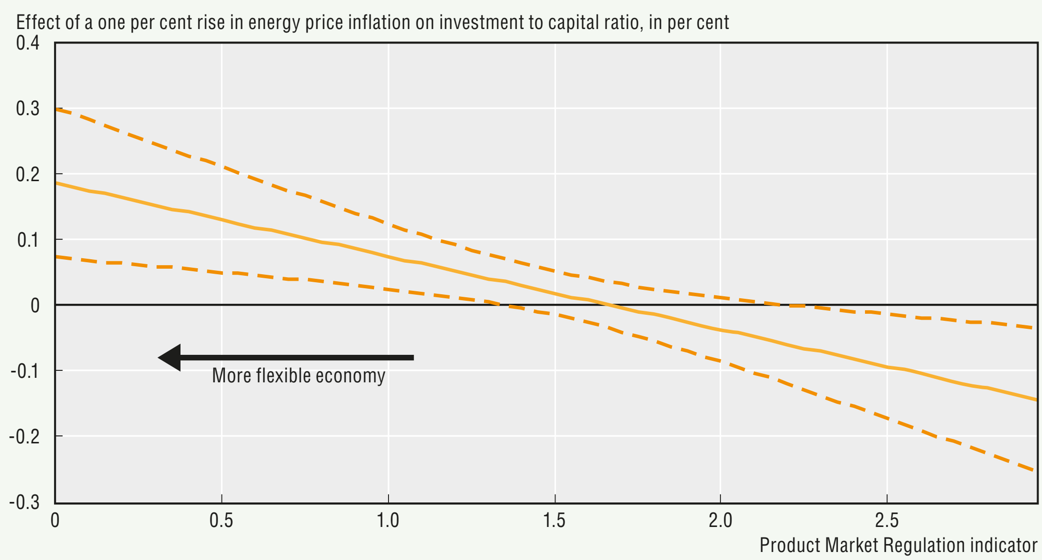
The new OECD research undertaken for this project has econometrically estimated the response of firms' investment to higher energy prices, taking into account the regulatory environment in which firms operate, as measured by the OECD's Product Market Regulation (PMR) indicator. Pricing carbon emissions in energy use is a key element of policies to lower CO_2 emissions. Carbon pricing results in higher energy prices. The new research shows that the effect of higher energy prices on manufacturing investment tends to be neutral

Box 4.3. **A regulatory environment that encourages competition and firm entry improves firms' investment and innovation response to climate change mitigation action** *(cont.)*

or even significantly positive if product market regulations are not restrictive. By contrast, the effect is significantly negative if product market regulations restrict competition and entry of new firms. The research can be seen as providing tentative support to the claim that environmental regulations may induce firms to innovate and improve efficiency, thus boosting productivity – the "Porter hypothesis" (Porter, 1991; Porter and van der Linde, 1995) – provided the regulatory framework encourages competition and entry of firms.

The estimated effect of an increase in the energy price index on manufacturing investment depends on the restrictiveness of product market regulation (Figure 4.7). If regulatory restrictiveness is low (PMR indicator below about 1.5), a rise in energy prices has a significant and positive effect on investment: firms adapt to higher prices by boosting investment. By contrast, if regulatory restrictiveness is high (PMR above about 2.3), a rise in energy prices has a significant and negative effect on investment. For example, in a country with restrictive regulation (PMR of 2.5), a typical firm's investment would diminish by about 1% in response to an increase of energy prices of 10%. In a country with competition-friendly regulation (PMR of 1), a typical firm's investment would rise by about 1%. The OECD has recorded PMR values of 2.5 or higher for several emerging economies among the G20. A PMR value of about 1 has been recorded for the United Kingdom.

Figure 4.7. **The effect of energy price inflation on investment depends on product market regulations**

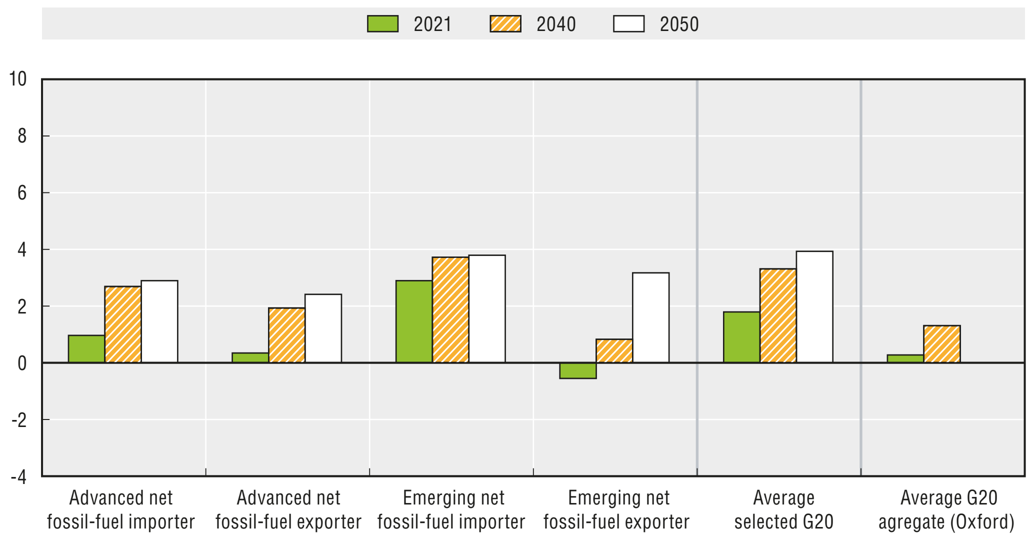


Note: The econometric model described in Annex 4.A4 is built on a baseline used in Dlugosch and Koźluk (2017). It includes country-year, industry-year and firm-fixed effects, a measure for stringency in labour market index, a measure of access to finance, sales over total capital, lagged out gap and lagged real interest rates as further controls. Energy price inflation is the three-year moving average of changes in the energy price index. Time sample: 1999-2011. The dashed line indicates the 95% confidence interval, using firm clustered standard errors.

The fiscal initiative in the decisive transition would also trigger an increase in business investment, especially in countries where investment needs are the highest (Figure 4.8). Business investment in the average of selected G20 economies could rise by almost 4% by 2050, according to the Yoda model. Simulations from the Oxford model would point to smaller increases on average in G20 economies. One condition underlying those positive outcomes is that governance and framework conditions are good enough to mobilise business investment. Policies to achieve this outcome are discussed in Chapter 5.

Figure 4.8. **Business investment impact of a decisive transition to decarbonisation**

Difference to baseline, per cent



Note: The average G20 is a weighted average of the G20 economies covered in the analysis, which represent 88% of the G20 countries (i.e. excluding the EU).

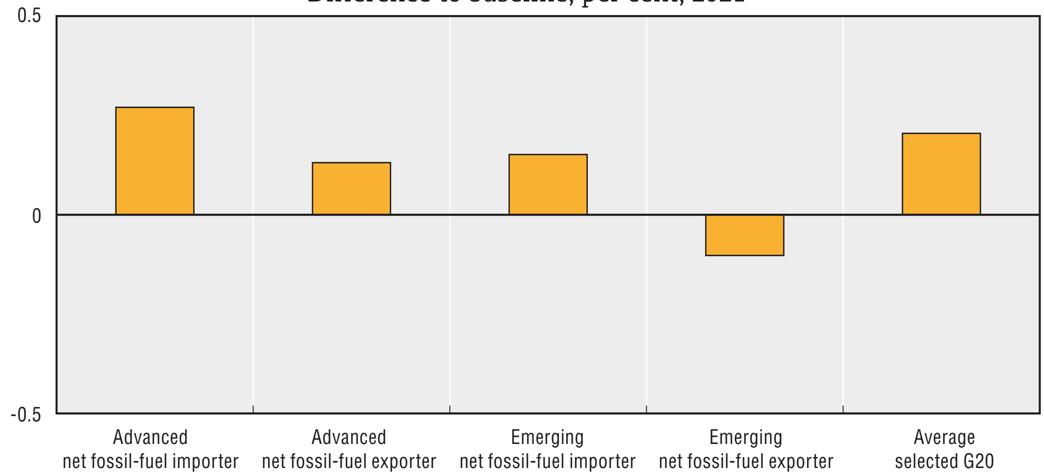
Consistent with growth and real wages developments, countries are expected to experience sizeable gains in employment (Figure 4.9). Gains would amount to 0.2% in the average of G20 countries after five years. Those gains would mostly come from the additional investment and structural reforms. Long-term developments in employment and gross employment reallocation effects from those policies are examined in more detail later in this chapter.

Finally, the likely impact of a decisive transition on public finances is expected to be small, assuming investment needs will be financed by the deficit for three years and be budget-neutral thereafter (Figure 4.10). Over the medium term, the ratio of public debt-to-GDP would fall compared with a no-policy-change scenario in net fossil-fuel importers, reflecting mostly gains in carbon tax revenues. In some countries, output gains more than finance the initial fiscal impulse. The ratio of public debt-to-GDP could fall by 5-7 percentage points compared with the baseline scenario in the average of selected G20 economies after five years, and by up to 20 percentage points by 2040.

Overall, these estimates rely on very specific assumptions and should be interpreted with care. A crucial assumption is that governments invest in good-quality projects and that the fundamental framework conditions are in place to get the most out of these investments (see Chapter 5 for a discussion of policies). Furthermore, a typical policy package has been simulated in all countries, for practical reasons. On the one hand, choosing the composition of this package in light of each country's institutional and regulatory frameworks, as well as its social preferences, would certainly be the most effective way of maximising the impact on output. On the other hand, poor choice of policy settings and ineffective implementation and governance of reforms would lower the output impact of the policy package. In addition, the simulations presented in the chapter do not account for the political economy of reforms and any difficulties in ensuring reform acceptance (see Chapter 6).

Figure 4.9. **Impact of a decisive transition on employment**

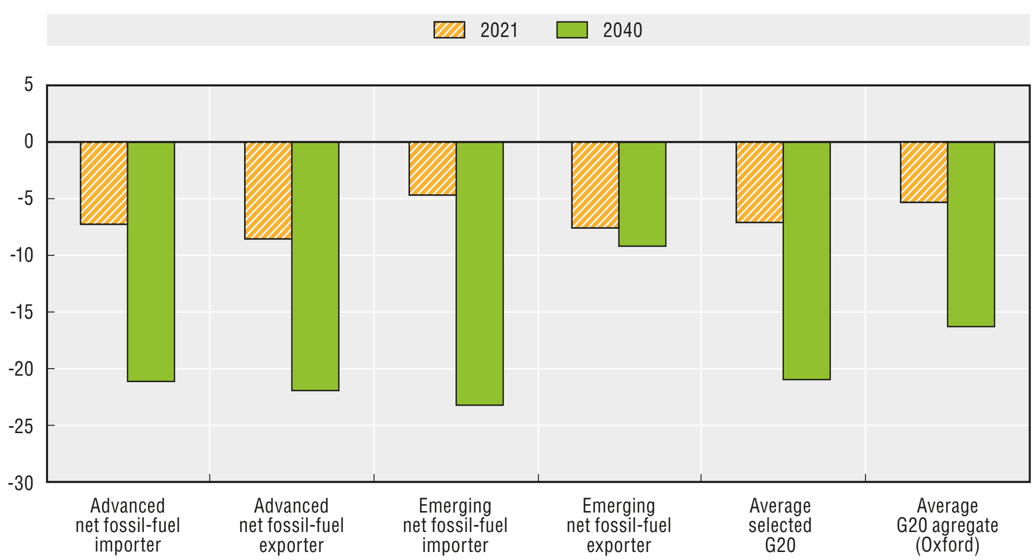
Difference to baseline, per cent, 2021



Note: see Figure 4.8.

Figure 4.10. **Impact of a decisive transition to decarbonisation on the debt-to-GDP ratio**

Difference to baseline, percentage points



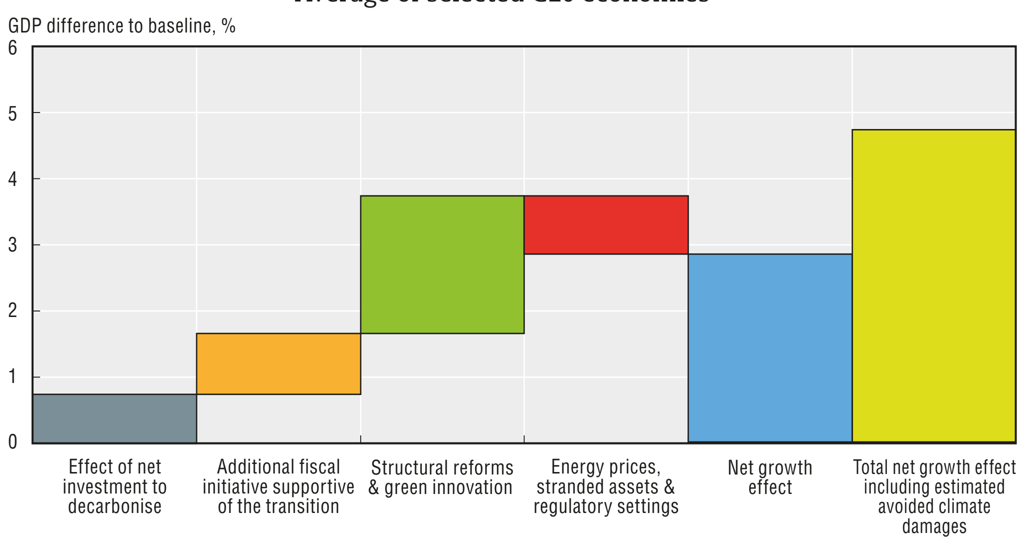
Note: The average G20 is a weighted average of the G20 economies covered in the analysis, which represent 88% of the G20 countries (i.e. excluding the EU).The net fossil fuel exporter takes the example of a country where public debt is low and carbon tax revenues are recycled into additional public consumption in the medium term. No recycling is assumed in the other stylised economies.

Avoided climate change damages bring additional economic gains

The simulations presented above do not account for the costs associated with climate change damages, which would weigh on long-term economic growth, through lost output as well as reduced well-being. The mitigation effort in the decisive transition would significantly reduce these long-term risks. Accounting for avoided climate damages enhances the output impact of the decisive transition, as damages affect the long-term capacity of the economy (Figure 4.11). Those damages depend heavily on countries' locations (damages are usually larger in countries close to the Equator), geographies and economic and social structures. The effects of climate damages on output are estimated to be small in the short to medium term but more marked in the long term and in some emerging economies. Evidence from the literature suggests that climate change damages could have a disastrous effect after 2050, beyond the scope of the analysis considered here (IPCC WGII, 2014; OECD, 2015d).

Figure 4.11. **Effect of including avoided damages in a decisive transition scenario in 2050 (50% probability of meeting 2˚C)**

Average of selected G20 economies



Note: See Figure 4.5.

It should be noted that the scale of climate damages is very hard to gauge with standard modelling tools (Box 4.4). It has been computed in this report using simple rules for the baseline and decisive transition scenarios. The emissions profile that is consistent with the Yoda model is used to calculate the average expected global temperature increase by 2100, using the MAGICC model (Meinshausen, Raper and Wigley, 2011). The resulting average global temperature increases from pre-industrial levels are 4.3˚C in the baseline scenario and 1.6˚C (with a 50% chance of remaining below 2˚C) in the decisive transition scenario. These estimates correspond to the upper range of the global temperature sensitivity as used in Clarke et al. (2014). Global damages associated with these temperature increases have been calculated using the climate damage function in Nordhaus (2016) and correspond to a very small subset of likely climate-change damages to the economy, excluding in particular extreme events (Box 4.4). Those global estimates are then distributed across regions and countries following OECD (2015d).

Box 4.4. **The challenge of estimating the consequences of climate impacts**

Economic analyses do not yet adequately capture the full range of climate impacts and should not be seen as providing the complete picture of the costs of climate change impacts (for a discussion see e.g. Stern, 2013). Some of the main challenges include:

- *Uncertainty:* The impacts of climate change depend upon the interactions between natural systems, socio-economic changes and the severity of temperature changes, all of which are subject to considerable uncertainties in estimating future impacts. These interactions can be complex and non-linear.
- *Modelling assumptions:* Decisions about the extent of autonomous adaptation, macroeconomic impacts and the weight to place on future losses can all significantly affect the results produced.
- *Data gaps and modelling constraints:* Some impacts, such as changes in climate extremes, are subject to very limited available data, but could be a significant source of future losses from climate change. In addition, non-market impacts (such as impacts on biodiversity) are not well captured in existing models.

Furthermore, economic models tend to struggle to capture the impacts of localised extreme climate events on global value chains, combined with a limited ability to project their frequency, severity and location. The latest climate science projects increasing incidence of episodes of high temperatures (IPCC, 2013). Extreme precipitation events are projected to increase in some regions, while rising sea levels will also increase flood risk in coastal areas. The processes governing cyclones are particularly difficult to model, but available evidence suggests that cyclone wind speeds will increase while cyclone frequency stays the same or diminishes.

Historical experience provides some indication of the potential economic impact of future extreme weather events. A single event, Hurricane Sandy, led to 43 deaths and economic losses of USD 50 billion in the United States (City of New York, 2013). In general, wealthier countries tend to suffer larger losses from climate extremes in absolute terms, due to the higher value of assets at risk, but smaller in proportional terms (Cummins and Mahul, 2009; Bosello and Dasgupta, 2015). Evidence on the longer-term impacts of disasters is mixed, reflecting both measurement challenges and the counterbalancing effects of the economic stimulus from reconstruction activities. Lis and Nickel (2010) found that natural disasters lead to median GDP being 4% lower five years later in developing countries. Disasters do not appear to have an impact on measured growth in OECD countries. Meanwhile, Cavallo et al. (2013) found that even extremely large disasters do not display a significant long-term impact on economic growth, unless they are followed by a “radical political revolution”.

The ambiguous evidence on GDP impacts should not hide the underlying issue that impacts on welfare are undoubtedly negative. First, reconstruction activities are recorded as additional value-added, although they may merely replace destroyed capital stock. Second, the poor tend to bear the brunt of climate-related disasters. Their economic losses are smaller in absolute terms but have a disproportionately negative impact on welfare (Hallegatte et al., 2017). Third, only a subset of the impacts from extreme events is included in GDP, with impacts such as deaths and injuries only being captured indirectly. These costs are predominantly borne by developing countries. For example, between 1970 and 2008, 95% of deaths from natural disasters occurred in developing countries (Handmer et al., 2012).

Avoided damages from decisive action would appear more markedly in the second half of the century, when increases in global temperature diverge between a business-as-usual scenario and the decisive transition scenario. With emissions reaching net-zero in the second half of the century, damages to GDP would hardly increase in the decisive transition scenario, at about 1% of GDP, while upper estimates without climate action show a rapid increase towards 10 to 12% annually on a global scale by 2100 (OECD; 2015d; Nordhaus, 2016; Weitzman, 2012), with much more pronounced impacts for the most vulnerable regions.

The results are subject to several caveats:

- The method does not include potential co-benefits such as reduced air pollution, which could alter the macroeconomic impact of a transition to a low-carbon path via their effect on health and productivity (see Chapter 3).
- Non-market damages are captured in a very crude manner, through a 25% increase in the estimated damages.
- Extreme events and their possible systemic effects are highly uncertain and difficult to quantify (Box 4.4).
- Uncertainties surrounding market damage estimates are large, reflecting uncertainties that occur in every stage of the process of calculating damages (Clarke et al., 2014; OECD, 2015). Results are highly dependent on assumptions (e.g. the rate of economic growth in different countries; or when certain technologies will come online). Alternative measures of climate damages, such as the social cost of carbon (the economic cost caused by an additional tonne of CO_2) are also subject to high uncertainties and depend in particular on the assumption made on the rate of time preference, as part of the discount rate (Nordhaus, 2016; Anthoff and Tol, 2013; Greenstone, Kopits and Wolverton, 2013).
- The macro-economic adjustment effects of climate change due to changing relative prices and marked differences in sectoral labour productivity are not covered. Should climate change induce structural shifts toward the less productive sectors, climate change damages would be exacerbated by the sectoral and temporal reallocation of factor inputs (Kalkuhl and Edenhofer, 2016).

Pursuing a more ambitious climate scenario: 66% probability of limiting global warming to 2˚C

Limiting warming to 2°C is not enough to satisfy the objectives of the Paris Agreement. While it is difficult to precisely define what “well below 2°C” and “efforts to limit to 1.5°C” mean, a step towards a more ambitious scenario can be described in which more stringent action raises the probability of holding warming below 2°C from 50% to 66% (see IEA, 2017, for policy and technology details). This scenario will require more investment effort at the global level, in response to more ambitious GHG emission-reduction policies than in the 50% 2˚C scenario. Simulations presented here suggest that this more ambitious scenario can still deliver positive output outcomes, provided that mitigation is accompanied by strong pro-growth reforms.

The net impact on growth will depend on the relative changes of a range of factors. More stringent environmental policies and higher stranded assets in this scenario than in the 50% 2˚C path will have a stronger dampening effect on the productive capacity of economies. Estimates suggest that mitigation costs could be about three times higher in a 66% 2˚C scenario than in a 50% 2˚C scenario (Hof et al., 2017). The need for more investment in a 66% 2˚C scenario will boost growth, however. Recycling of carbon revenues, which will be bigger in the 66% scenario, could also offset some of the mitigation costs. More importantly, the benefits from avoided damages from climate change would grow from the 50% 2˚C scenario, although more markedly so in the second half of the century, and with the above mentioned uncertainties.

Assessing the impact of a transition to a 66% 2˚C scenario is challenging, as it represents a non-linear step change from the pathway to reach 2˚C with a 50% probability – energy-related CO_2 emissions in 2050 would need to be roughly halved from their level under the 50% 2°C projection (IEA, 2017).

- First, the marginal returns of the additional investment required in the energy sector will most likely be lower, as all the easily attainable benefits will already have been grasped in a 50% 2˚C scenario.
- Second, reaching a 66% 2˚C target will require substantially more action on emissions sources related to energy use (for instance, retrofitting existing coal or gas power plants with carbon capture and storage; significant structural changes to the transport sector). The 66% scenario will also require even more stringent action on non-energy-use emissions, including from land use, which also has implications for the energy sector because of constraints on biomass supply. As a result, the carbon taxes will need to rise more than proportionately throughout the economy, reflecting the high marginal costs of emissions reductions.
- Third, the level of stranded assets would be higher than in a 50% 2˚C scenario, with a correspondingly higher impact on GDP outcomes. Although some global estimates exist for the different scenarios, reliable country estimates of stranded assets are not publicly available (see Chapter 3). The timing of the stranding of these assets is also uncertain.
- Finally, the availability, cost and future performance of key technologies has an important role in achieving ambitious climate targets. In many studies, remaining below the 2˚C target requires net global emissions in 2100 to be zero or negative (Dessens, Anandarajah and Gambhir, 2014). This requires relying on "negative emissions" technologies such as biomass energy with carbon capture and storage (BECS) to counterbalance unavoidable GHG emissions. Research is under way to better understand these different factors (see Chapter 2).

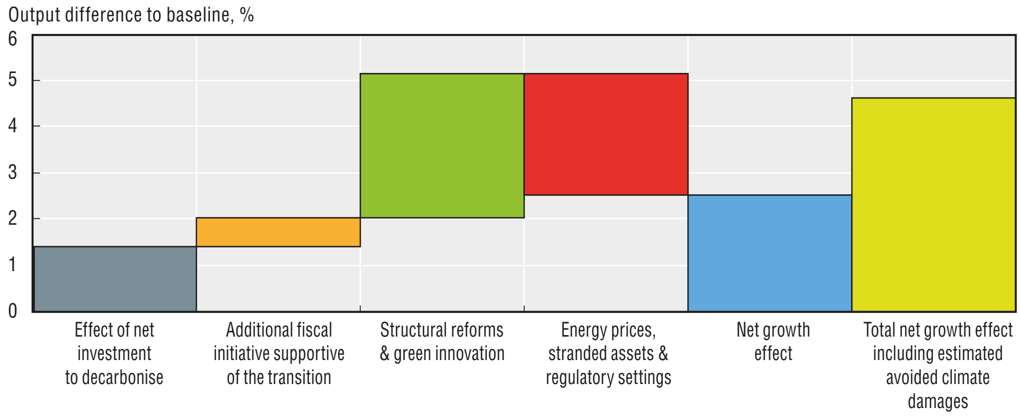
There has been little analysis of the outcome of a 66% 2˚C scenario and considerable uncertainties surround the estimates that are available. Most of the IPCC's Fifth Assessment Report (2014) scenarios for ambitious mitigation hover around 2˚C. These show consumption losses in the long term, with higher mitigation costs for more stringent scenarios. The special IPCC report asked for by Parties to the UNFCCC as part of the Paris Agreement should provide more insights into pathways leading to a maximum temperature increase of 1.5°C.

In addition to the very large uncertainties around estimates of mitigation costs in a 66% 2˚C scenario, it is extremely difficult to gauge the extent of the fiscal impetus that will be needed to offset mitigation costs in such a scenario. Such an impetus could amount to several percentage points of GDP in some economies that rely heavily on fossil fuels. There are also major uncertainties regarding the level of R&D spending that would be required to achieve this more ambitious climate target. Scenarios quantifying those needs are being developed, and will be available in the coming years.

With these caveats in mind, Figure 4.12 provides an illustration of the long-term output impact of a decisive transition to a 66% 2˚C scenario. The net impact on output in 2050 is estimated to be 2.5%. The results suggest that a larger pro-growth policy package will be required to offset the additional mitigation costs of the more stringent climate policy required to meet the goal. Incorporating the output impacts from avoided climate damages provides an additional boost to growth in the long term, with a total increase in output of 4.6% above the baseline in 2050.

Figure 4.12. **Illustration of the output impact of decisive transition to a 66% 2˚C scenario in 2050, including avoided damages**

Average of selected G20 economies



Note: The average G20 is a weighted average of selected G20 economies, representing 88% of the G20 countries (i.e. excluding the European Union). Energy prices and stranded assets are based on the IEA scenario and correspond to a move to a 2˚C climate objective with a 66% probability. Regulatory setting captures the reduced costs of the transition in a more flexible regulatory environment, based on firm level investment regression that interacts energy price inflation with product-market regulation settings. Fiscal initiative corresponds to an increase in public investment that complements the net investment from decarbonisation so that in total, investment would increase by 0.5% of GDP. This means that net fossil fuel exporters who experience disinvestment from mitigation policies are assumed to invest more to compensate for this disinvestment. The structural reform considered here is a lowering in barriers to investment by 0.35 point for the OECD member countries and by 0.85 point for emerging economies, which correspond to the average change in this measure in the past. The impact has been calculated using estimation of business regulation on income per capita by Égert (forthcoming) and Égert and Gal (2016). Innovation corresponds to a 0.1% of GDP increase in R&D spending. It is assumed that the stylised fossil fuel exporters recycle their carbon tax revenues into higher public consumption in the medium term, given their initial low level of public debt. No recycling is assumed for the net importers. For damages, simulations presented here include only a subset of potential damages, excluding for instance damages from extreme climate events, due to difficulties in projecting their frequency, severity and location. The exercise models global damages associated with temperature increases, using the Nordhaus (2016) damage function.

Acting now and acting together: implications of a delayed transition and of actions limited to a leadership group

The costs of delayed action

The decisive transition scenario requires a rapid change in the direction of investment, based on a set of incentives that may be disruptive at some level in the near term, even if combined with a broader economic package for growth. Faced with potential short-term costs, countries may be tempted to delay action to ward off the long-term climate threat, despite the availability of policies to manage adverse impacts on industry, labour markets, households and communities (Chapters 5 and 6).

The scenario presented in this section assumes the decisive transition (i.e. action and investment to limit global warming to 2°C with a probability of 50%) is delayed to 2025, at which point a reassessment of climate risks triggers an abrupt transition toward decarbonisation. The delay in investing in decarbonisation increases costs, as more stringent climate policies have to be introduced more rapidly, leading to more stranded assets of emission-intensive activities that for which investment continued up to 2025 under a less ambitious climate policy outlook. The scenario relies on the IEA global estimates of around USD 310 billion of additional stranded assets in the upstream oil sector alone (IEA, 2016). This amount is distributed across countries, over the first 10 years following the delay, following the methodology outlined in Glades and Ekins (2014).

Delaying action would be costly for all countries (Figure 4.13). The average output loss for selected G20 economies would amount to 2%, with most of the loss incurred a year after the delayed transition starts. Losses would be particularly marked in net fossil fuel exporters, with a significant amount of additional stranded assets compared with a non-delayed scenario. Broadening the scope of stranded assets beyond the upstream oil industry would also result in higher losses – coal-based power generation in particular can be a significant share of stranded assets in mitigation scenarios (see Chapter 3 for IEA, 2017 and IRENA, 2017 estimates).[4]

In addition, this result is based on a relatively conservative scope of stranded assets (Chapter 3). Capital losses may also trigger financial instability, which could lead to further economic losses through two principal channels:

- A stock market channel: stock market instability through the exposure of institutional investors such as banks, pension funds and insurance companies to stocks of listed oil and gas companies. This exposure could harm economies as a tightened credit supply – due to weakened bank balance sheets and increased volatilities – would further hamper investment. In addition, household exposure to stocks of affected companies could lead to a decrease in savings with negative effects on consumption.
- A debt and loan channel: potential default by some affected companies on their fixed income and bank loans due to capital losses, with similar implications for bank balance sheets and credit supply as the stock market channel.

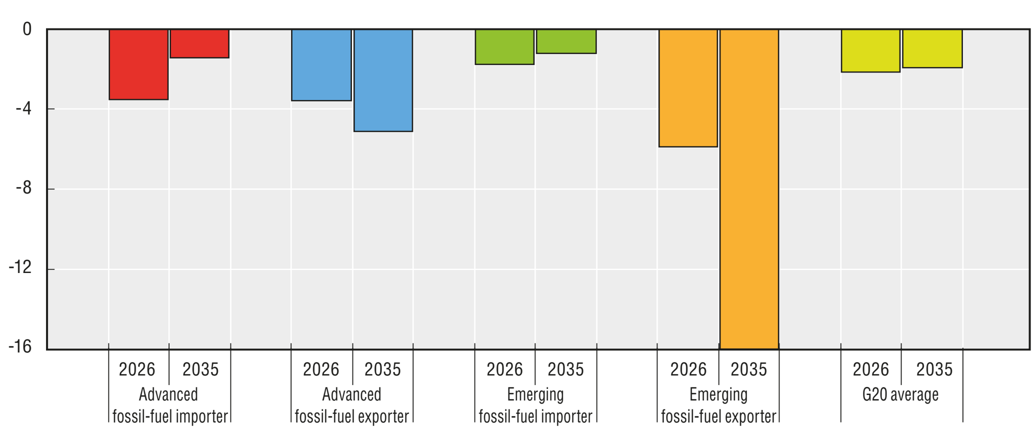
To illustrate the stock market channel, a full write-down of companies is simulated in the oil and gas sector on domestic equity markets. Although exposure of stranded assets of firms in climate-sensitive sectors is not likely to lead to a full write-down of all assets, a 100% shock to market capitalisation provides an upper bound estimate. This choice is consistent with Battiston et al. (2016) who stress test the EU banking system in order to identify systemic impacts of climate change policies.

The magnitude of additional economic losses triggered by financial instability from capital losses from stranded assets would depend on countries' reliance on fossil fuels and the extent of market capitalisation, with sizeable impacts limited to the short term.

Overall these results are in line with existing literature which also points to significant cost of delaying action and a trade-off between reduced short-term costs and higher economic adjustments caused by continued carbon lock-in. This implies the need to sharply increase carbon prices and to introduce more stringent regulations as governments seek to return to a 2°C-compatible pathway (Bosetti et al., 2009; Kriegler et al, 2015; Jakob et al., 2012). Inertia in the extraction sector is also found to be a factor affecting the benefit of climate change action and thus strengthens the case for early action (Bauer et al., 2016).

Figure 4.13. **Macro-economic implications of delaying action on climate (without growth-enhancing policies)**

GDP difference to 50% 2˚C scenario



Decisive action taken by a leadership group of countries

Decisive action on climate mitigation, beyond the Nationally Determined Contributions submitted for the Paris Agreement, may also be taken by a group of leading countries, even if multilateral action is lacking. Such action would require bigger structural adjustments than the multilateral case, as emission-intensive activities in coalition countries may move to other countries. This would reinforce the case for accompanying structural reforms to boost growth and facilitate economic adjustment in the leadership coalition countries (see above and Chapter 5). Countries outside the leading group may face more stranded assets later, and the costs of delayed action. Achieving climate change mitigation objectives would be compromised, resulting in substantial long-term costs and risks. Such a leadership group scenario cannot be accurately modelled, but the following discussion analyses qualitatively the likely forces at play.

Collective action is needed to mitigate climate change. Countries may be tempted to “free ride”, however, enjoying the benefit of climate change mitigation while limiting their own mitigation efforts to avoid the potential costs or loss of competitiveness. There is also an incentive to wait for low-carbon technologies to become less expensive. A group of countries may nevertheless choose to take the lead even if others do not: leader countries can gain from the co-benefits of climate change mitigation action, especially the positive impacts of lower air pollution for human health (see Chapter 3 and Tirole, 2012). Some large countries, in particular China, bear a significant share of the cost of global warming and may therefore have a stronger incentive for action. In addition, public opinion may put environmental concerns high enough on the political agenda to induce governments to take the lead. Leader countries may choose to act without an explicit agreement or in a coalition; there is a vast literature investigating the rationale for building environmental coalitions, their credibility and enforcement, and mechanisms to increase their breadth and stability (Barrett, 1994; Barrett, 2003; Nordhaus, 2015; Dellink, 2001; Finus et al., 2006). Annex 4.A1 looks in more detail at some of the mechanisms resulting from a group of countries taking the lead in terms of climate mitigation.

Evidence suggests that countries taking the lead on climate change may not suffer in aggregate macro-economic terms, particularly in the medium term (Dechezleprêtre and Sato, 2015). More stringent environmental policies do not seem to affect aggregate competitiveness, but do have small but significant effects on sectoral specialisation: countries with stringent environment policies (or high energy prices) tend to have an advantage in less pollution-intensive exports, after controlling for other factors such as capital intensity, endowments or geography (Koźluk and Timiliotis, 2016). Most technologically advanced firms are also more likely to further increase their productivity. Less advanced firms, especially those relying on carbon-intensive production, would either need to increase investment to reorient their production or exit the market (Albrizio et al., 2017). Caution is required when extrapolating these results to unprecedented increases in environmental stringency. However, a regulatory environment that is conducive to competition, entry of new firms and smooth reallocation of resources from exiting firms and activities makes it more likely that the economy will respond through higher innovation and productivity (see Box 4.3 above).

Conversely, if climate action is limited to a leadership group, high-emissions production in countries outside the group is likely to increase, as it would benefit from less stringent climate policies, lower associated costs (e.g. carbon taxes) and lower global fossil-fuel prices. Empirical evidence, as cited above, suggests these production cost differences may not be large. Nevertheless, the more easily production in the leadership coalition can be substituted by production in other countries (e.g. of energy-intensive manufacturing goods traded in world markets), the stronger the competitiveness gains of opt-out countries in carbon-intensive sectors. In the longer term, however, if the opt-out countries decide eventually to pursue mitigation, they would face the risk of substantially more stranded assets as well as higher adjustment costs. In the meantime, their populations would also suffer the health costs of higher local pollution and environmental degradation.

Attaining global climate goals in a leadership group scenario would require larger climate mitigation efforts within the leadership coalition than in the case of a global decisive action scenario, due to the lack of action in the opt-out countries. Hence, such a scenario can only be realistic if the coalition is sufficiently large. Moreover, the structural changes and associated costs would be more marked. Reforms to reduce the costs of structural change and boost technology diffusion would therefore be particularly relevant for the leading countries. Adjustment costs and redistributive effects across sectors would result in intensive lobbying against mitigation action. The leading countries could hence use carbon tax revenues for growth-enhancing tax reforms (e.g. to lower labour taxes) and to mitigate adjustment costs. Pollution haven effects could give rise to demands for tariffs (e.g. border carbon adjustments) or other restrictions on carbon-intensive imports – even if the welfare gains of freer trade are likely to outweigh the costs of abating the trade-induced leakage (Kuik and Gerlagh, 2003).

By pursuing climate mitigation policies, the leadership group would also accelerate the development of low-carbon technologies, reducing the cost of their deployment. In principle, they could gain "first-mover" advantages in these technologies, but these "learning by doing" benefits could spill over worldwide. This would have the benefit of reducing "carbon leakage" (Castelnuovo et al. 2005). This would result in lower emissions and reduce deployment costs for other countries through knowledge and technology. The positive technological spillover benefits from trade could even dominate the carbon leakage effect (Gerlagh and Kuik, 2014).

Structural and employment composition effects of low-emission pathways

The decisive transition requires advances in technology and policy measures to promote less polluting economic activity; these will inevitably result in structural change. The evidence on existing policies to foster decarbonisation, such as the Emissions Trading System in the European Union, suggests that the sectoral employment effects have been small (OECD, 2014a). The estimated competitiveness effects on employment through relocation of industry have also tended to be small. However, this may in part reflect the lack of ambition of policies and a tendency to grant concessions and exemptions to trade-exposed industry (OECD, 2014a).

Simulations with the OECD computable general equilibrium model ENV-Linkages (Chateau et al., 2014) consider the sectoral shifts under a global "mitigation-only" policy scenario to limit global warming to 2°C and find sectoral reallocation effects to be modest in terms of overall value-added and employment.[5] At the individual sectoral level, expansions and contractions are large for some sectors, however. Not surprisingly, fossil-fuel industries and energy-intensive manufacturing will experience the steepest declines and renewable-energy industries the sharpest increases. For example, by 2030, GHG mitigation policies are estimated to lower value-added in the coal-extraction sector by around 40% compared with a situation in which governments take no further action on climate. However, the impact of this reduction on aggregate global value-added would only be 0.1 percentage point. Conversely, value-added in solar and wind energy is estimated to increase by 40%.

Large impacts in individual sectors may not translate into a large overall reallocation of activity and jobs because the most carbon-intensive industries represent only a small share of total value-added and employment. Job reallocation as a result of climate action across sectors (summing up the creation and the shedding of jobs) is estimated at 1.5% of total employment by 2050. This adds a modest amount to the job reallocation to be expected on the basis of past experience. For example, between 1995 and 2005, the amount of sectoral job reallocation in OECD member countries amounted to 20% of employment (OECD, 2012).

In some countries where the scope for expansion of renewable energies (including hydro and geothermal) appears strong, manufacturing sectors may grow significantly as a result of competiveness gains, as countries collectively move to reduce GHG emissions from fossil fuels. This is the case in the United States and Brazil. By contrast, manufacturing is projected to shrink as a result of climate action in China and India, as their economies are more energy-intensive. Increases in non-transport services, including housing services, are estimated to be substantial in low-income countries because of their large weight in the economy (close to 2% of aggregate value-added in India, for example), whereas there may be reductions in high-income countries. In a few countries, including Brazil and Russia, downscaling of value added in land transport also has some weight relative to total economy value-added.

The model simulations also suggest that mitigation policies would result in modest additional employment reallocation world-wide by 2050, relative to total employment, as different sectors create and shed jobs (Figure 4.14). To focus on the reallocation effects across sectors, the model assumes that overall national employment levels remain unaffected by climate mitigation action in the long run. Job creation and job shedding balance, as wages adjust to changes in labour supply and demand across sectors. As argued above, higher GDP growth in the decisive action scenario – in which mitigation policies are implemented in an integrated way with growth-enhancing policies – is likely to result in higher employment in the short term. In the longer term, higher GDP growth would typically result in higher wage growth on aggregate, with employment effects largely depending on individual labour markets. Sectoral job creation and destruction are each estimated to amount to 0.7% of employment. Overall, job shedding in emissions-intensive energy sectors is only partly offset by job creation in low-emission energy sectors, reflecting the important role of improving energy efficiency. Individual country results would vary according to the type of renewables or fossil fuels they use. Where biofuels may expand, such as in Brazil, renewables may generate more employment, as this activity is labour intensive. Job creation may then exceed job loss in services and manufacturing sectors.

Job reallocation is estimated to be strongest in some of the emerging economies, notably in India, Indonesia and Russia, although these results need to be treated with caution in view of widespread labour-market informality in these countries (Figure 4.15). In India and Russia, climate change mitigation policies result in more substantial job losses in high-emissions energy production, whereas in Indonesia agriculture may shed jobs equivalent to about 1% of total employment. Non-transport services account for much of the job creation as a result of climate change action. In South American economies and South Africa, job reallocation is smaller. This is also true for all high-income countries, including Australia and Canada, where fossil-fuel extraction activities are relatively important.

Figure 4.14. **Sectoral composition of job reallocation in the world**

Deviation to baseline in 2050 in a 2°C scenario, percentage of total employment

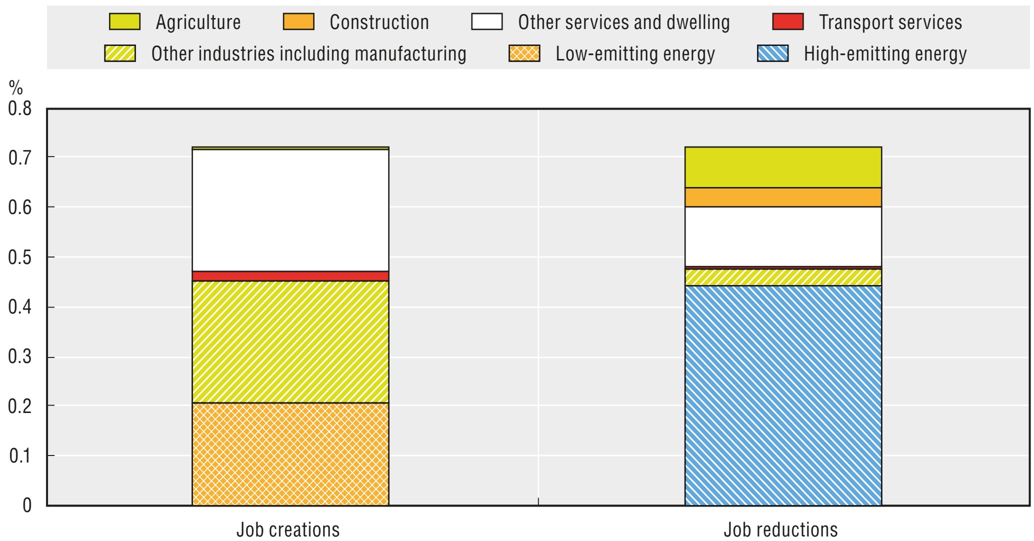
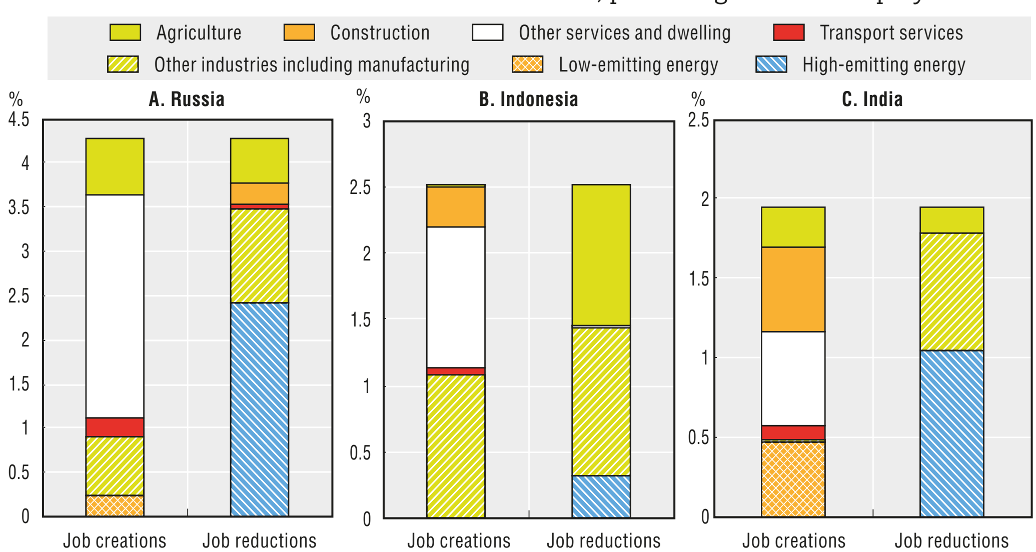


Figure 4.15. **Job reallocation is relatively strong in some emerging economies**

Deviation to baseline in 2050 in a 2°C scenario, percentage of total employment



Model simulations suggest that the majority of job reallocations from climate change mitigation action affect low-skilled workers, because they constitute over half of total labour costs in energy-producing sectors (OECD, 2016c). This is especially the case in emerging economies. In OECD member countries, high-skill occupations such as managerial staff and technical experts are also expected to undergo significant reallocation.

In the long term, the scale of change implied by the transition to low-emission and climate-resilient economies will be much greater than modelled here because such economies will ultimately require greater reliance on knowledge-based outputs and human capital, and less reliance on the use of material resources and environmental services

(OECD, 2014a). More generally, in the long run, it has been argued that low-carbon economies require more reliance on new ideas – the "knowledge economy" or "weightless economy" – and less on raw materials and energy, boosting demand for highly educated workers and workers providing services that do not require a lot of material inputs (OECD, 2014a). These are likely to require resource reallocation not only between the broadly defined sectors shown above, but also within sectors.

For mitigation policies, as for any policy resulting in structural change, the functioning of the labour market will have a significant impact on aggregate employment outcomes. Rigidities in the labour market may hamper structural adjustments, with negative effects on employment and GDP (OECD, 2012). Wage rigidity in the formal sector is more of a problem in rapidly growing developing countries, such as in China and India, because of the larger sectoral reallocations of labour necessary (OECD, 2014a).

The decisive transition policy scenario shows how climate policies combined with well-aligned pro-growth reforms and fiscal initiative can put economies on track for low-emission, climate-resilient growth, while also facilitating the reallocation of jobs across sectors. It is also essential that sector-level changes be accompanied by proactive measures to plan and invest in sustainable jobs, as discussed in Chapter 6.

Notes

1. The simulations presented in the chapter cover the G7 countries, Australia, China, India, Indonesia, Brazil, South Africa, and the Russian Federation. The G7 countries and Australia are considered to be advanced economies and China, India, Indonesia, Brazil, South Africa, and the Russian Federation emerging economies.
2. Studies based on integrated assessment models also find a negative impact of mitigation policies in the short to medium term, although the magnitude of the impact is more pronounced than in the current analysis (IPCC, 2014). Differences reflect the nature of the modelling tools used in the two approaches and – more important – the fact that the present analysis accounts for the specificity of the current macroeconomic environment of low growth and low interest rates. Another difference between simulations presented in this chapter and those cited in IPCC (2014) is the focus on selected G20 economies, primarily due to data constraints.
3. The implementation of a carbon tax and other energy taxes can reduce growth prospects in the short term. In the IEA scenario, carbon and other energy taxes lead to a fall in fossil fuel demand, including through the change in the sectoral composition of the economy and gains in energy efficiency. In practice, however, the simulation outcomes presented in this chapter are primarily explained by the magnitude of the investment needs estimates and carbon price increases to achieve the climate objectives.
4. There is no universally agreed definition of stranded assets: see the discussion in Chapter 3.
5. This scenario focused on the effects of global climate mitigation based on a price applied globally to all greenhouse gas emissions, without fiscal initiative and pro-growth reforms assumed elsewhere in this chapter. Overall impacts on GDP would be more negative in the absence of these measures (Chateau, Dellink and Lanzi, 2014).

References

Adalet McGowan, M., D. Andrews and V. Millot (2017), "The Walking Dead?: Zombie Firms and Productivity Performance in OECD Countries", OECD Publishing, Paris, www.oecd.org/eco/The-Walking-Dead-Zombie-Firms-and-Productivity-Performance-in-OECD-Countries.pdf.

Albrizio, S., T. Koźluk and V. Zipperer (2017), "Environmental Policies and Productivity Growth: Evidence across Industries and Firms", *Journal of Environmental Economics and Management*, Vol. 81, Elsevier, Amsterdam, pp. 209-226, https://doi.org/10.1016/j.jeem.2016.06.002.

Anthoff, D. and R. Tol (2013), The uncertainty about the social cost of carbon: A decomposition analysis using FUND, *Climatic Change*, Vol. 117, Springer Nature, London, pp. 515-530, http://doi.org/10.1007/s10584-013-0706-7.

Barrett, S. (2003), Environment and Statecraft: *The Strategy of Environmental Treaty-Making*, *Oxford University Press*, *Oxford* and *New York*.

Barrett, S. (1994), "Self-Enforcing International Environmental Agreements", *Oxford Economic Papers, Vol. 46*, *Oxford University Press*, *Oxford*, pp. 878-894.

Bosello, F. and S. Dasgupta (2015), *Development, Climate Change Adaptation, and Maladaptation: Some Econometric Evidence*, Fondazione Eni Enrico Mattei, Milan.

Bosetti, V. et al. (2009), "Delayed action and uncertain stabilisation targets. How much will the delay cost?", *Climatic Change*, Vol. 96, Springer Nature, London, pp. 299-312, http://doi.org/10.1007/s10584-009-9630-2.

Castelnuovo et al. (2005), "Learning-by-Doing vs. Learning by Researching in a model of climate change policy analysis", *Ecological Economics*, Vol. 54/2-3, Elsevier, Amsterdam, pp. 261-276, https://doi.org/10.1016/j.ecolecon.2004.12.036.

Cavallo et al. (2013), "Catastrophic natural disasters and economic growth", *The Review of Economics and Statistics*, Vol. 95/5, MIT Press, Cambridge, Massachusetts, pp. 1549–1561, http://doi.org/10.1162/REST_a_00413.

City of New York (2013), "A stronger, more resilient New York", http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Lo_res.pdf.

Chateau, J., R. Dellink and E. Lanzi (2014), "An Overview of the OECD ENV-Linkages Model: Version 3", *OECD Environment Working Papers, No. 65,* OECD Publishing, Paris, http://doi.org/10.1787/5jz2qck2b2vd-en.

Clarke L. et al. (2014), "Assessing Transformation Pathways", in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York.

Cummins, J. and O. Mahul (2009), Catastrophe *Risk Financing in Developing Countries: Principles for Public Intervention*, World Bank, Washington DC.

Dechezleprêtre, A. and M. Sato (2015), "Asymmetric industrial energy prices and international trade", *Energy Economics*, Vol. 52, Supplement 1, pp. S130–S141.

Dessens O., G. Anandarajah and A. Gambhir (2014), "Review of Existing Emissions Pathways and Evaluation of Decarbonisation Rates", AVOID 2, London.

Dlugosch, D. and T. Kozluk (2017), "Energy prices, environmental policies and investment: Evidence from listed firms", *OECD Economics Department Working Papers*, No. 1378, OECD Publishing, Paris, http://dx.doi.org/10.1787/ef6c01c6-en.

Egert (forthcoming): "Regulation, Institution and economic growth in advanced, emerging and developing countries", *OECD Economics Department Working Paper.*

Egert, B. And P.Gal (2016), "The Quantification of Structural Reforms in OECD Countries: A New Framework", *OECD Economics Department Working Papers*, No. 1354, OECD Publishing, http://dx.doi.org/10.1787/2d887027-en.

Finus, M., E. van Ierland and R. Dellink (2006), "Stability of climate coalitions in a cartel formation game",Economics of Governance, Vol. 7/3, Springer Nature, London, pp. 271–291, http://doi.org/10.1007/s10101-005-0009-1.

Fournier J.-M. (2016), "The Positive Effect of Public Investment on Potential Growth", *OECD Economics Department Working Papers*, No. 1347, OECD Publishing, Paris, http://dx.doi.org/10.1787/15e400d4-en.

Fournier, J.-M. and Å. Johansson (2016), "The Effect of the Size and the Mix of Public Spending on Growth and Inequality", *OECD Economics Department Working Papers*, No. 1344, OECD Publishing, Paris, http://dx.doi.org/10.1787/f99f6b36-en.

Gal, P. and A. Hijzen (2016), "The Short-Term Impact of Product Market Reforms: A Cross-Country Firm Level Analysis", *OECD Economics Department Working Papers*, No. 1311, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jlv2jm07djl-en.

Gerlagh, R. and Kuik, O. (2014), "Spill or leak? Carbon leakage with international technology spillovers: ACGE analysis", *Energy Economics*, Vol. 45, Elsevier, Amsterdam, pp. 381-388, https://doi.org/10.1016/j.eneco.2014.07.017.

Greenstone M., E. Kopits and A. Wolverton (2013), "Developing a Social Cost of Carbon for US Regulatory Analysis: A Methodology and Interpretation", *Review of Environmental Economics and Policy*, Vol. 7/1, MIT, Cambridge, Massachusetts, pp. 23–46, http://hdl.handle.net/1721.1/85655.

Hallegatte, S. et al. (2017), *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*, World Bank, Washington DC, http://hdl.handle.net/10986/25335.

Handmer, J. et al. (2012), "Changes in impacts of climate extremes: Human systems and ecosystems", in *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: IPCC Special Report*, Cambridge University Press, Cambridge and New York, www.ipcc.ch/pdf/special-reports/srex/SREX-Chap4_FINAL.pdf.

IEA (2017), Chapter 2 in *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System,* International Energy Agency, Paris, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IEA (2016), World Energy Outlook 2016, IEA/OECD Publishing, Paris, http://dx.doi.org/10.1787/weo-2016-en.

IRENA (2017), "Global Energy Transition and the Role of Renewables", Chapter 3 of *Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System*, International Renewable Energy Agency, Abu Dhabi, www.energiewende2017.com/wp-content/uploads/2017/03/Perspectives-for-the-Energy-Transition_WEB.pdf.

IPCC (2014), *Climate Change 2014: Mitigation of Climate Change. Contribution of* Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.

IPCC (2013), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Chang*e, Cambridge University Press, Cambridge and New York.

Jakob, M. et al. (2012), "Time to Act Now? Assessing the Cost of Delaying Climate Measures and Benefits of Early Action", *Climatic Change*, Vol. 114/1, Springer Nature, London, pp. 79-99, http://doi.org/10.1007/s10584-011-0128-3.

Kalkuhl, M. and O. Edenhofer (2016), "Knowing the Damages is not Enough: The General Equilibrium Impacts of Climate Change", CESifo, Munich.

Kozluk, T., and C. Timiliotis (2016), "Do environmental policies affect global value chains? A new perspective on the pollution haven hypothesis", *OECD Economics Department Working Papers*, No. 1282, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jm2hh7nf3wd-en.

Kriegler, E. et al. (2015), "Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy", *Technological Forecasting and Social Change*, Vol. 90/A, Elsevier, Amsterdam, http://doi.org/10.1016/j.techfore.2013.09.021.

Lis, E. M. and C. Nickel (2010), "The impact of extreme weather events on budget balances", *International Tax and Public Finance*, Vol. 17/4, Springer Nature, London, pp. 378-399, http://doi.org/10.1007/s10797-010-9144-x.

Marangoni, G. and M. Tavoni (2014), "The clean energy R&D strategy for 2°C", *Climate Change Economics*, Vol. 5/1, World Scientific Publishing, Singapore, http://doi.org/10.1142/S201000781440003X.

Meinshausen, M., S.C.B. Raper, and T.M.L. Wigley (2011), "Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 — Part 1: Model description and calibration", *Atmospheric Chemistry and Physics*, Vol. 11/4, European Geosciences Union, Munich, pp. 1417-1456, http://doi.org/10.5194/acp-11-1417-2011.

Mourougane, A., et al. (2016), "Can an Increase in Public Investment Sustainably Lift Economic Growth?", *OECD Economics Department Working Papers*, No. 1351, OECD Publishing, Paris, http://dx.doi.org/10.1787/a25a7723-en.

Nordhaus, W.D. (2017), *Econonomic Policy Reforms* 2017: "Revisiting the Social Cost of Carbon", PNAS, Vol. 14/117, National Academy of Sciences of the United States of America, Washington DC, pp. 1518-1523, http://doi.org/10.1073/pnas.1609244114.

Nordhaus, W. D. (2016), "Projections and Uncertainties About Climate Change in an Era of Minimal Climate Policies", National Bureau of Economic Research, Cambridge, Massachusetts, http://doi.org/10.3386/w22933.

Nordhaus (2015), "Climate Clubs: Overcoming Free-riding in International Climate Policy", *American Economic Review*, Vol. 105/4, American Economic Association, Pittsburgh, pp. 1339-1370, http://doi.org/10.1257/aer.15000001.

OECD (2017), *Economic Policy Reforms 2017: Going for Growth*, OECD Publishing, Paris, http://dx.doi.org/10.1787/growth-2017-en.

OECD (2016a), *OECD Economic Outlook, Volume 2016*, Issue 1, OECD Publishing, Paris, http://dx.doi.org/10.1787/eco_outlook-v2016-1-en.

OECD (2016b), *Economic Survey of Indonesia*, OECD Publishing, Paris, www.oecd.org/eco/surveys/economic-survey-indonesia.htm.

OECD (2016c), *The Economic Consequences of Outdoor Air Pollution*, OECD Publishing, Paris, http://doi.org/10.1787/9789264257474-en.

OECD (2015a), *The Future of Productivity*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264248533-en.

OECD (2015b), *OECD Environmental Performance Reviews: Brazil 2015*, OECD Publishing, Paris, http://doi.org/10.1787/9789264240094-en.

OECD (2015c), *OECD Economic Outlook*, Volume 2015, Issue 1, OECD Publishing, Paris, http://dx.doi.org/10.1787/eco_outlook-v2015-1-en.

OECD (2015d), *The Economic Consequences of Climate Change*, OECD Publishing, Paris, http://doi.org/10.1787/9789264235410-en.

OECD (2014a), *Addressing Social Implications of Green Growth: Inclusive Labour Markets For Green Growth*, Issue Note, Green Growth And Sustainable Development Forum, 13-14 November 2014, OECD, Paris, http://www.oecd.org/greengrowth/Issue%20Note%20Session%20Two_final.pdf.

OECD (2012), *Employment Outlook*. OECD Publishing, Paris, http://dx.doi.org/10.1787/empl_outlook-2012-en.

OECD (2009), *The Economics of Climate Change Mitigation: Policies and Options for Global Action Beyond 2012*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264073616-en.

Porter, M. (1991), "America's green strategy", *Scientific American*, Vol. 264/4, Springer Nature, London.

Porter, M. E. and C. van der Linde (1995), "Toward a New Conception of the Environment Competitiveness Relationship", *Journal of Economic Perspectives*, American Economic Association, Pittsburgh, Vol. 9/4, pp. 97-118, http://doi.org/10.1257/jep.9.4.97.

Weitzman, M.L. (2012), "GHG targets as insurance against catastrophic climate damages", *Journal of Public Economic Theory*, Vol. 14/2, Association for Public Economic Theory/Wiley, Hoboken, pp. 221-244.

ANNEX 4.A1. Collective mitigation policies, world fossil fuel prices, substitution effects and innovation

Introduction

Collective global action by definition excludes free-riding and carbon leakage, and provides the scale necessary to tackle the climate change challenge.[1] However, incentives to free-ride can be substantial. Countries refraining from climate mitigation could benefit from lower global fossil fuel prices, gaining a competitive edge in carbon-intensive production. They could also be tempted to wait till low-carbon technologies become cheaper before avoiding high upfront costs. Some countries may have incentives to take the lead in terms of climate mitigation, however (Tirole, 2012). Countries will want to minimise local collateral damage such as air pollution. Moreover, the largest actors, such as China, expect to bear a non-negligible cost of climate change and officials tend to prefer policy options consistent with public opinion.

The magnitude of the necessary climate mitigation action and the feasibility of achieving climate goals are likely to depend on the size and composition of the set of countries taking up climate mitigation. What would be the consequences of partial and heterogeneous action, as opposed to a collective action? This annex addresses this question by looking at three key aspects of the global economy: the role of global fossil fuel prices, the effects via the trade channel and the role of innovation.

In practice, policy decisions are not exogenous, and they are interdependent. There is a vast literature investigating the rationale for building coalitions. Barrett (1994) emphasises credible or "self-enforcing" treaties that combine individual and collective rationality. Barrett's (2003) book on international environmental agreements discusses the "small coalition paradox" (as called by Nordhaus, 2015) according to which coalitions are either small or shallow. Dellink (2001) discusses incentives that stabilise large coalitions, and Finus, Ierland and Dellink (2006) show that a transfer scheme can help. Nordhaus (2015) strengthens the concept of coalition stability in adding rationality for each subset of the players. Lessmann, Marschinski and Edenhofer (2009) show that trade sanctions can significantly raise participation in coalitions. Lessmann and Edenhofer (2011) show that research co-operation can foster coalition stability when it focuses on research co-operation in mitigation technology rather than co-operation on augmenting productivity in the private good sector. This discussion on determinants of policy decisions goes beyond this annex that discusses their consequences.

This illustrative modelling exercise presents very simple, stylised relationships – in a world of two principal regions which are *the coalition* (where fossil fuels are subject to a carbon tax) and the *opt-out countries*, where no equivalent policies are undertaken. In practice, similar reasoning can be applied to sectors (rather than countries) and other climate policies that increases the cost of carbon emissions (e.g. emissions trading schemes). The qualitative conclusions present similarities with those derived from more detailed general equilibrium models, such as in Burniaux and Oliveira Martins (2012), reflecting a supply-side leakage related to the negative effect on fossil fuel price and a specialisation leakage effect due to changes in relative production costs (see also a discussion of leakage channels in Marschinski, Jakob and Edenhofer, 2009).

The following points are discussed:

- Carbon-pricing in a subset of countries (or sectors) can be less effective in reducing global emissions than full carbon pricing, not only because the scale of the climate change challenge requires broad action, but also because exempted entities benefit from lower fossil fuel prices and from a leakage effect.
- As climate action in individual countries spurs technological progress in low-carbon technologies, the effect on emissions may be broader due to knowledge diffusion across countries, including those not taking up climate mitigation. In the context of partial action, it may thus be even more important to assure that climate mitigation policies support both innovation and its diffusion.
- Efficiency gains in sectors with low demand elasticity (e.g. heating efficiency in advanced economies where demand is already saturated), rather than sectors with high demand elasticity are likely to result in less of a rebound effect.
- The rebound effect can be mitigated with carbon taxes.
- Should carbon-pricing cover a subset of sectors, the largest emissions reductions are expected to be reaped in sectors in which price-elasticity of demand is the highest (e.g. cases where an alternative zero-emissions option already exists). Leakage will be lowest where the elasticity of substitution with exempted items or imported items that may bear a lower carbon tax is the lowest (e.g. non-tradable goods).
- The appropriate amount of the carbon tax depends on numerous factors, including long-run fossil fuel supply-side and demand-side elasticities, which cannot be observed with precision, and the availability of technologies, suggesting that the appropriate pace of a carbon tax may need to be adjusted on a regular basis by governments informed by market developments.

Three main mechanisms are investigated in this exercise: the role of endogenous world fossil fuel prices in the leakage of emissions abroad; the role of substitution towards exempted fossil fuels; and some aspects of the role of innovation. In the first section, the computation takes into account the fossil fuel price mechanism, while ignoring the substitution effect. In the second step, the computation is augmented with a substitution effect to get an overall effect of the carbon tax on fossil fuel quantities emitted. In a third step, the role of innovation is discussed. In a final step, the theoretical channels are combined with key findings in the literature to draw policy implications.

A leadership coalition and a world fossil fuel price with a partial carbon tax and without explicit substitution between goods

In a stylised world in which agents consume or produce a composite fossil fuel good, the consumption of fossil fuels is assumed to be proportionally linked to carbon emissions. In the coalition region A, agents consuming fossil fuels are subject to a carbon tax T (or an equivalent environmental policy) that increases the end-user fossil fuel price to p^W+T, where p^W is the fossil fuel world price. In the opt-out region B, agents are also consuming fossil fuels, but are not subject to a carbon tax. All fossil fuel producers are in a third entity C. Let's denote α_T and $(1- \alpha_T)$ are the relative size of entities A and B. Fossil fuel demand is a decreasing function $d(p^W)$ of price and fossil fuel supply is an increasing function $s(p^W)$ of price. Formulated as such, this modelling is stylised, but also quite general: it can refer to any shape of demand and supply curves. Then, one can write the demand and supply functions determining quantities of fossil fuels consumed by region A (q_A), consumed by region B (q_B) and produced in the world (q_C) as:[2]

(1) $$q_A = \alpha_T d_A(p^W + T)$$

(2) $$q_B = (1 - \alpha_T) d_B(p^W)$$

(3) $$q_C = s(p^W)$$

The static equilibrium world fossil fuel consumption $q=q_A+q_B$ depends on the carbon tax T.[3] In a first step, one can see that the overall effect of the carbon tax on reducing emissions in the coalition is partly offset by the increase of consumption in response to the world (pre-tax) fossil fuel price decrease:

(4) $$\frac{\partial q}{\partial T} = \underbrace{\alpha_T d'_A(p^W + T)}_{\substack{Direct\ effect\ in\ coalition\ A,\\ holding\ world\ price\ constant}} + \underbrace{d'_G(p^W)\frac{\partial p^W}{\partial T}}_{World\ price\ effect}$$

where $d_G(p^W) = \alpha_T d_A(p^W + T) + (1 - \alpha_T) d_B(p^W)$

is the global demand function for fossil fuels.

The clearance of the fossil fuel market provides the world fossil fuel price, as the solution of the following system:

(5) $$\begin{array}{rcl} q_A + q_B & = & q_C \\ \alpha_T d_A(p^W + T) + (1 - \alpha_T) d_B(p^W) & = & s(p^W) \end{array}$$

Hence, one can derive the effect of a carbon price on the world fossil fuel price:[4]

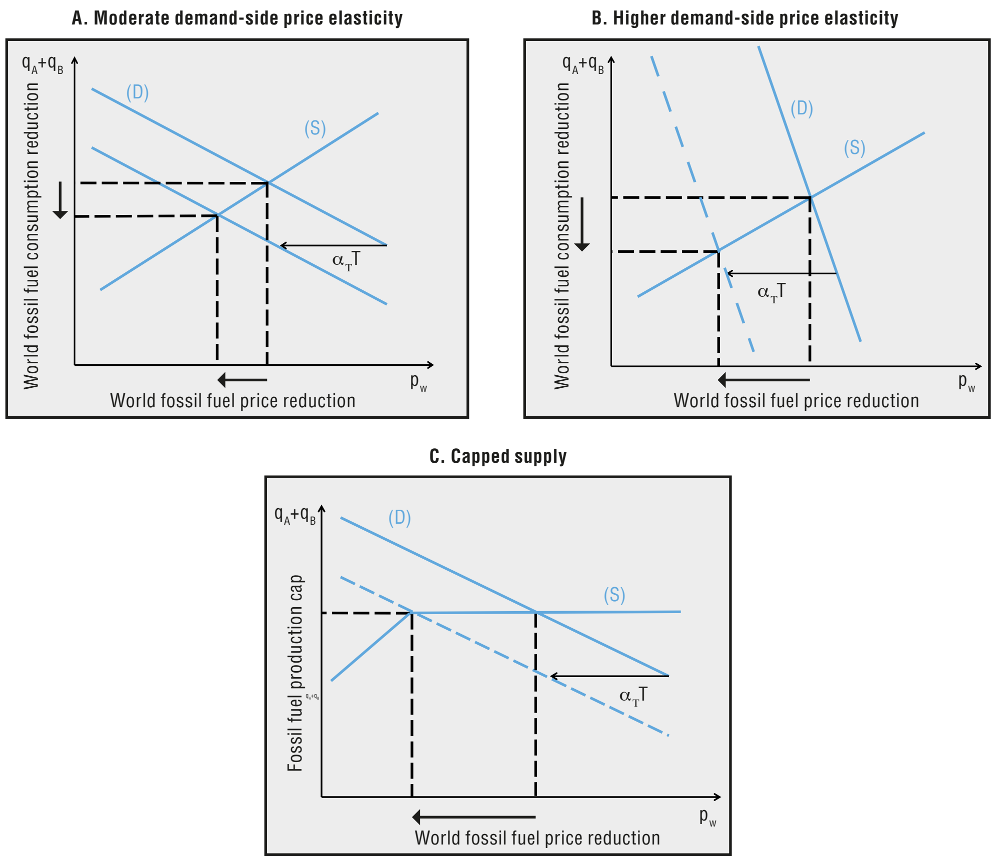
(6) $$\frac{\partial p^W}{\partial T} = \frac{\alpha_T dA'(p^W + T)}{s'(p^W) - d'_G(p^W)}$$

Inserting equation (6) in equation (4) provides a global effect of a coalition carbon tax on fossil fuel consumptions (and hence emissions):

(7) $$\frac{\partial q}{\partial T} = \frac{\alpha_T dA'(p^W + T) s'(p^W)}{s'(p^W) - d'_G(p^W)} < 0$$

The direct effect in coalition region A dominates the world price effect, so that fossil fuel consumption decreases at the world level. In the opt-out region B however, the world price effects pushes fossil fuel consumption up.[5] A carbon tax in the coalition will deliver larger gains the larger the size of the coalition and the higher the sensitivity of fossil fuel supply and output to fossil fuel prices. For instance, Figure A1.1 illustrates the effect of the same carbon tax in a low demand elasticity case (Panel A) and in a high demand elasticity case (Panel B).[6]

Figure A1.1. **The effect of a carbon tax on the fossil fuel world equilibrium**



Note: (D) and (S) denote demand and supply functions, P_w the world fossil fuel price, $q_A + q_B$ the quantity of fossil fuel consumed and T a carbon tax scaled by the share α_T.

The importance of supply elasticity in emissions outcomes can be better understood with a stylised extreme case. In the extreme case where supply is inelastic: s'(p^w), quantities (and emissions) do not adjust (Figure 4.16, Panel C). This would correspond for instance to a fossil fuel supplier setting a world-level quantity cap with no reaction to the introduction of a carbon tax. In this particular case, prices are changing, so that fossil fuel consumers can capture the price premium that would otherwise be captured by the fossil fuel supplier[7]. As a result, world fossil fuel prices are more sensitive to a carbon tax, and fossil fuel quantities remain constant – with perfect leakage of emissions to the opt-out region. In practice, a fossil fuel supplier cartel can reduce the price-elasticity of supply.

A world fossil fuel price with a partial carbon tax and substitution between taxable and non-taxable fossil fuels

In practice, the demand for a good depends on the imported substitutes and their prices. This was implicit in the previous section; making the role of substitution explicit helps to think about the trade channel. The demand equations (1) and (2) are thus replaced here by equations in which demand depends both on the price in the region and on the price of the imported substitute from the alternative region, while the supply side function is left unchanged:[8]

(1') $$q_A = d_A(p_A = p^W + T, p_B = p^W)$$

(2') $$q_B = d_B(p_A = p^W + T, p_B = p^W)$$

(3') $$q_C = s(p^W)$$

One should then rewrite equation (4), including an additional substitution (or trade) effect:

(4') $$\frac{\partial q}{\partial T} = \underbrace{\frac{\partial d_A}{\partial p_A}(p^W + T, p^W)}_{Direct\ effect\ in\ coalition\ A} + \underbrace{d'_G(p^W)\frac{\partial p^W}{\partial T}}_{World\ price\ effect} + \underbrace{\frac{\partial d_B}{\partial p_A}(p^W + T, p^W)}_{Substitution\ effect\ in\ region\ B}$$

The effect of a change in the carbon tax on the world oil price is dampened by this substitution effect, as the substitution effect mitigates the demand reduction:

(6') $$\frac{\partial p^W}{\partial T} = \frac{\frac{\partial d_A}{\partial p_A}(p^W+T,p^W)+\frac{\partial d_B}{\partial p_A}(p^W+T,p^W)}{s'(p^W)-d'_G(p^W)}$$

where $d'_G(p^W) = \frac{\partial d_A}{\partial p_A}(p^W + T, p^W) + \frac{\partial d_A}{\partial p_B}(p^W + T, p^W) + \frac{\partial d_B}{\partial p_A}(p^W + T, p^W) + \frac{\partial d_B}{\partial p_B}(p^W + T, p^W)$

In sum, the overall reduction of emissions is lower, as the demand for fossil fuels is increasing in region B when prices increase in the coalition A:

(7') $$\frac{\partial q}{\partial T} = \frac{\frac{\partial d_A}{\partial p_A}(p^W+T,p^W)s'(p^W)}{s'(p^W)-d'_G(p^W)} + \underbrace{\frac{\frac{\partial d_B}{\partial p_A}(p^W+T,p^W)s'(p^W)}{s'(p^W)-d'_G(p^W)}}_{positive\ substitution\ effect}$$

The relationships presented here can also be used to think about the consequence of a carbon tax (or any equivalent policy) that covers a subset of sectors only. For this purpose, regions *A* and *B* could be replaced by two sectors, one that is subject to the carbon tax, and one that is not. Of course, the calibration would then need to reflect price elasticities in each sector.

The role of innovation is uncertain a priori

Another important factor that plays a role in the move to a low-carbon environment is innovation, which leads to improvements in energy and fossil fuel efficiency, i.e. the ability to produce with lower fossil fuel inputs. The sign of the effect on improving fossil fuel and energy efficiency on carbon emissions is ambiguous. On the one hand, for a given unit of consumption, less fossil fuels and emissions are used. On the other hand, the efficiency improvements make energy-intensive goods cheaper, increasing the demand for them and hence emissions: this is the so-called "rebound effect". The rebound effect was observed in the nineteenth century by Jevons (1865): efficiency improvements to the steam engine technology had increased coal consumption.[9] The magnitude of the rebound effect is subject to much debate. In particular, Grubb (1990) argues that the rebound effect depends to the extent to which energy prices and availability constrain demand or not. He also argues this effect can be lower when price changes are policy driven and when fossil fuel prices are higher. This would be the case if policies boosting efficiency focus on price-inelastic activities where market incentives to increase efficiency are poorer.

If one assumes that fossil fuels q are used to produce a final good C with a technology A, so that $C = A\,q$, then one can write the following elasticity of fossil fuel demand to technology:

$$(8) \qquad \frac{\partial \ln(q)}{\partial \ln(A)} = \frac{\partial \ln(C)}{\partial \ln(\pi)} \frac{\partial \ln(\pi)}{\partial \ln(A)} - 1$$

where $\frac{\partial \ln(C)}{\partial \ln(\pi)}$ is the elasticity on the final good C to its price and $\frac{\partial \ln(\pi)}{\partial \ln(A)}$ the sensitivity of the price of the final good to the efficiency improvement. In other words, the rebound effect is larger when demand for the final good is price-elastic, and offsets the emissions reductions when the good is fossil fuel-intensive, such as transport. At the macroeconomic level, the long-term declining share of energy in GDP suggests implies a decreasing sensitivity of consumer price to fossil fuel prices: this second component driving the rebound effect has declined.

Similarly, the effect of carbon prices on energy efficiency innovation is ambiguous from a theoretical perspective. A stylised way to discuss the ambiguities is to look to what extent consumers' utility improves in case of innovation. Let's denote *U(C=Aq)* the utility with decreasing marginal returns. Then, the sensitivity of utility with respect to energy efficiency gain can be decomposed into two components. On one side, the price increase of fossil fuels should decrease their quantity consumed, decreasing the relevance of innovating in this field: there is a negative market size effect. On the other side, at lower consumption level, the welfare effect of a slight increase in consumption is larger. The utility is more sensitive to marginal gains, this is a positive scarcity effect:

$$(9) \qquad \frac{\partial U}{\partial A} = \underbrace{q_A}_{market\ size\ effect} \cdot \underbrace{U'(Aq_A)}_{scarcity\ effect}$$

where *U(.)* is a utility function with decreasing marginal gains.

The learning-by-doing channel presents no theoretical ambiguity about the effect of environment policy stringency (see Castelnuovo et al. 2005, for simulations with a learning-by-doing channel). In this channel, the pace of technology improvement increases with the size of the market. As a result, a carbon-pricing policy will increase innovation in zero-carbon energy, and as this innovation spills over, this should lead to worldwide gains. Di Maria and van der Werf (2008) build on the spillover argument to argue that the induced-technology effect of climate policy reduces carbon leakages. In this channel, first movers can benefit from this learning-by-doing effect, but they may also support a short-term cost of starting to use new methods before the technology has matured: early investment can be depreciated faster.

Insights from the empirical literature and policy implications

The empirical literature provides evidence on the pollution haven hypothesis, namely that highly polluting industries can concentrate in countries with low environmental policy stringency – after controlling for other factors, such as capital intensity, endowments or geography (see for instance Aichele and Felbermayr, 2015; and Koźluk and Timiliotis, 2016). This illustrates the importance of the substitution effect across countries. At the same time, Koźluk and Timiliotis (2016) show a significant but small shift in specialisation: in countries with high environmental policy stringency, firms tend to specialise in low-pollution goods so that overall net exports are not affected by disparities in environmental policies. The pollution haven hypothesis can raise the issue of the net gains of openness. Kuik and Gerlagh (2003) find that welfare gains of freer trade outweigh the costs of abating the trade-induced leakage. In addition, Gerlagh and Kuik (2014) argue that the positive technological spillover effect can dominate the carbon leakage effect.

OECD (2016) shows that effective carbon prices are highly uneven within countries. Effective carbon prices are typically high on final goods that consumers cannot substitute with carbon-tax exempted goods, such as gasoline, and low on other tradable goods, such as manufacturing goods. This is consistent with a rational non-co-operative behaviour in which governments prefer to avoid a carbon tax in cases where the elasticity of substitution is the highest.

Fossil fuel consumption need not always be proportional to carbon emissions. In some cases, carbon emissions can be reduced without reducing fossil fuel consumption (e.g. carbon capture and storage, reforestation). In these cases, the world fossil fuel price channel does not operate.

Many academic studies have investigated the price elasticity of energy demand. End-user price elasticity estimates are summarised in a meta-analysis by Labandeira, Labeaga and Lopéz-Otero (2017), and Fournier et al. (2013) provide an overview of selected empirical studies of the oil price elasticity. There is large uncertainty surrounding the estimates. In addition, long-term elasticity is much larger than short-term elasticity. This is expected because some of the adjustments take time to materialise (e.g. switching to low-consumption cars). Coal supply elasticity is typically assumed to be larger, and plays a critical role as carbon intensity of coal is high (Burniaux and Oliveira Martins, 2012). As regards magnitudes, there is a difference between end-user price elasticity and world prices elasticity: a 1% change in a world price does not translate into a 1% change in end-user price in the presence of an excise tax. Long-term demand elasticity to end-user energy prices is about -0.5 (ranging from about -1.2 to about 0 in a selected sub-sample of estimates) according to Labandeira, Labeaga and Lopéz-Otero (2017), and long-term demand elasticity to oil prices is about -0.2 (from about -0.6 to about 0) according to Fournier et al. (2013).

The few studies estimating supply-side elasticity provide mixed results (e.g. Lin, 2008). Such studies are scare, in part because it is even more difficult to isolate demand shocks than supply shocks. The global financial crisis provides a particular experiment, with the sharp demand-driven collapse of the oil price at the end of 2008 suggesting that short-term supply elasticity is very low. However, this should be read with great care as this is a single event, during which financial market disruptions could also have affected the world price; the shale gas revolution could also have played a role. To overcome this problem, some papers (e.g. Dées et al., 2007) model the supply of oil using a curve-fitting technique along the lines of Hubbert (1962). However, such techniques are inherently difficult and tend to be consistent with a wide range of possible supply paths, particularly if peak production is unknown.

The fact that short-term supply and demand-side elasticities are much lower than long-term elasticities has a policy implication on the appropriate tax level to reach tighter emissions targets. Rapid increases in the stringency of environmental policies are likely to require a particularly large carbon price, supporting the case for a gradual increase in environmental policies over a long period. Should short-term supply-side elasticity be much lower than short-term demand-side elasticity, then the short-term effect of a sharp increase in a carbon tax could be a sharp collapse of fossil fuel prices, dampening substantially the emissions effect. In particular, this raises concerns about any delayed action scenario that necessitates a quick and large rise of carbon price to compensate for the delay. The pace of increase of carbon prices needs to remain reasonable; it is all the more necessary to start tightening emissions targets early. This also means that mitigation policies need to be announced in advance with credible commitments, so that agents can anticipate changes that need time to be implemented.

Recent literature suggests that there is evidence of a rather limited rebound effect – that is, that energy efficiency gains are only partially offset by demand increases. In particular, Dimitropoulos, Oueslati and Sintek (2016) find in a recent meta-analysis that the direct rebound effect in transport is around 12% in the short run and 32% in the long run. This analysis does not include indirect macroeconomic effects, so the overall rebound effect may be larger but is still likely to be limited.

The technological spillover effect is a strong argument in theory to claim that a leadership coalition can be successful in mitigating climate change, but this spillover should not be taken for granted. In practice, stylised facts suggest that spillovers take time. The dispersion of energy efficiency across the world is large and stable over a long period. More broadly, Barro (2015) investigates the pace of GDP per capita convergence. He provides evidence in support of the "iron law of convergence" according to which countries eliminate gaps in levels of real per capita GDP at a rate of around 2% per year. Convergence at a 2% rate implies that it takes 35 years for half of an initial gap to vanish. This suggests that for the technological spillover effect to help in mitigating climate change, additional policy action would be useful. For example, policies in favour of foreign direct investment (FDI) may help to transfer technologies; Meyer and Sinani (2009) provide a meta-analysis to understand when and where FDI generates positive spillovers.

Notes

1. For instance, Kriegler et al. (2015) explore a scenario in which a front runner coalition embarks on immediate ambitious climate action while the rest of the world makes a transition after 2030. They find that the resulting climate outcome is unlikely to be consistent with the goal of limiting global warming to 2 degrees.
2. This set-up ignores the effect of emissions on temperatures, which is turn is expected to reduce heating demand. It is reasonable to ignore this link in the short to medium run as global temperature is a function of the stock of past emissions and hence a change in emissions takes a long time to translate into a change of the pace of temperature. For a model in which oil price demand depends on temperature, see Cho et al. (2016).
3. The intertemporal dimension is ignored here for the simplicity of the exposure. Sinn (2008) finds a similar world fossil fuel channel in an intertemporal supply-side perspective, introducing the "green paradox": suppliers can even boost current supply in the presence of climate mitigation policies that depress future fossil fuel demand. Edenhofer and Kalkuhl (2011) show this green paradox occurs for carbon taxes that increase at a rate higher than the effective discount rate of the resource owners.
4. This derivation is computed with the implicit function theorem.
5. Strictly speaking, the overall effect includes an implicit substitution effect as demand depends on available imported substitutes. This is ignored for the sake of the simplicity of the presentation at this stage and is introduced in the next section.
6. Equation (7) shows the role of derivatives with respect to the level of prices. One can convert such derivatives into elasticities by multiplying by the price to quantity ratio.
7. If one assumes that this supplied quantity is optimised after the environmental policy change, one can show that the supplier side optimal quantity would be shifted downward, so that overall fossil fuel consumption is decreased.
8. For the sake of simplicity, entities A and B are assumed to have the same share here.
9. The Jevons paradox has been revisited by Khazzoom (1980) and Brookes (1990) and renamed Khazzoom–Brookes postulate by Saunders (1992).

References

Aichele R. and G. J. Felbermayr (2015), "Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade", The Review of Economics and Statistics, Vol. 97/1, MIT Press, Cambridge, Massachusetts, pp. 104-115, http://doi.org/10.1162/REST_a_00438.

Barrett, S. (1994), "Self-Enforcing International Environmental Agreements", Oxford Economic Papers, Vol. 46, Oxford University Press, Oxford, pp. 878-894.

Barrett, S. (2003), Environment and Statecraft: The Strategy of Environmental Treaty-Making, Oxford University Press, Oxford and New York.

Barro, R. (2015), "Convergence and Modernisation", The Economic Journal, Vol. 125, Wiley, Hoboken, pp. 911-942, http://doi.org/10.1111/ecoj.12247.

Brookes, L. (1990), "The greenhouse effect: the fallacies in the energy efficiency solution", Energy Policy, Vol. 18/2, Elsevier, Amsterdam, pp. 199-201, https://doi.org/10.1016/0301-4215(90)90145-T.

Burniaux, J.-M. and J. Oliveira Martins (2012), "Carbon leakages: a general equilibrium view", Economic Theory, Vol. 49/2, Springer Nature, London, pp. 473-495, http://doi.org/10.1007/s00199-010-0598-y.

Castelnuovo et al. (2005), "Learning-by-Doing vs. Learning by Researching in a model of climate change policy analysis", Ecological Economics, Vol. 54/2-3, Elsevier, Amsterdam, pp. 261-276, https://doi.org/10.1016/j.ecolecon.2004.12.036.

Cho, C.-H. et al. (2016) "The effect of global activities and warming on oil price", Energy Sources, Part B: Economics, Planning, and Policy, Vol. 11/3, Taylor and Francis, Abingdon, United Kingdom, pp. 274-281, http://doi.org/10.1080/15567249.2011.596896.

Dées et al. (2007), "Modelling the world oil market: Assessment of a quarterly econometric model", Energy Policy, Vol. 35, Elsevier, Amsterdam, pp. 178-191, https://doi.org/10.1016/j.enpol.2005.10.017.

Kriegler, E. et al. (2015), "Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy", *Technological Forecasting and Social Change*, Vol. 90/A, Elsevier,Amsterdam, http://doi.org/10.1016/j.techfore.2013.09.021.

Dellink, R. (2001) "Drivers of Stability of Climate Coalitions in the STACO Model", Climate Change Economics, Vol. 2/2, World Scientific Publishing, Singapore, pp. 105–128, http://doi.org/10.1142/S2010007811000231.

Di Maria, C. and E. van der Werf (2008), "Carbon leakage revisited: unilateral climate policy with directed technical change", Environmental and Resource Economics, Vol. 39, Springer Nature, London, pp. 55–74, http://doi.org/10.1007/s10640-007-9091-x.

Dimitropoulos, A., W. Oueslati and C. Sintek (2016), "The Rebound Effect in Road Transport: A Meta-analysis of Empirical Studies", *OECD Environment Working Papers*, No. 113, OECD Publishing, Paris, http://dx.doi.org/10.1787/8516ab3a-en.

Edenhofer, O. and M. Kalkuhl (2011), "When do increasing carbon taxes accelerate global warming? A note on the green paradox", Energy Policy, Vol. 39/4, Elsevier, Amsterdam, pp. 2208–2212, https://doi.org/10.1016/j.enpol.2011.01.020.

Finus, M., E. van Ierland and R. Dellink (2006), "Stability of climate coalitions in a cartel formation game", Economics of Governance, Vol. 7/3, Springer Nature, London, pp. 271–291, http://doi.org/10.1007/s10101-005-0009-1.

Fournier, J.-M. et al. (2013), "The Price of Oil – Will it Start Rising Again?", *OECD Economics Department Working Papers*, No. 1031, OECD Publishing, Paris, http://dx.doi.org/10.1787/5k49q186vxnp-en.

Gerlagh, R. and Kuik, O. (2014), "Spill or leak? Carbon leakage with international technology spillovers: A CGE analysis", Energy Economics, Vol. 45, Elsevier, Amsterdam, pp. 381-388, https://doi.org/10.1016/j.eneco.2014.07.017.

Grubb, M. J. (1990), "Communication – Energy Efficiency and Economic Fallacies", Energy Policy, Vol. 18/8, Elsevier, Amsterdam, pp. 783-785, https://doi.org/10.1016/0301-4215(90)90031-X.

Khazzoom, J. D. (1980), "Economic Implications of Mandated Efficiency in Standards for Household Appliances", The Energy Journal, Vol. 1/4, International Association for Energy Economics, Cleveland, pp. 21-40.

Kuik, O. and R. Gerlagh (2003), "Trade Liberalization and Carbon Leakage", The Energy Journal, Vol. 24/3, International Association for Energy Economics, Cleveland, pp. 97-120.

Hubbert, M. K. (1962), "Energy Resources: A Report to the Committee on Natural Resources of the National Academy of Sciences – National Research Council", National Academy of Sciences – National Research Council, Washington DC.

Jevons, W. S. (1865), "The Coal Question: Can Britain Survive?", first published in 1865, reprinted by Macmillan in 1906.

Koźluk, T. and C. Timiliotis (2016), "Do environmental policies affect global value chains? A new perspective on the pollution haven hypothesis", *OECD Economics Department Working Papers*, No. 1282, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jm2hh7nf3wd-en.

Kriegler, E. et al. (2015), "Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy", Technological Forecasting and Social Change, Vol. 90/A, Elsevier, Amsterdam, http://doi.org/10.1016/j.techfore.2013.09.021.

Labandeira, X., J.M. Labeaga and X. Lopéz-Otero (2017), "A meta-analysis on the price elasticity of energy demand", Energy Policy, Vol. 102, Elsevier, Amsterdam, pp. 549-568, https://doi.org/10.1016/j.enpol.2017.01.002.

Lessmann, K. and O. Edenhofer (2011), "Research Cooperation and International Standards in a Model of Coalition Stability", Resource and Energy Economics, Vol. 33/1, Elsevier, Amsterdam, pp. 36-54, https://doi.org/10.1016/j.reseneeco.2010.01.001.

Lessmann, K., R. Marschinski and O. Edenhofer (2009), "The effects of tariffs on coalition formation in a dynamic global warming game", Economic Modelling, Vol. 26/3, Elsevier, Amsterdam, pp. 641-649, https://doi.org/10.1016/j.econmod.2009.01.005.

Lin, C.Y.C. (2008), "Estimating Supply and Demand in the World Oil Market", The Journal of Energy and Development, Vol. 34/1-2, International Research Center for Energy and Economic Development, Boulder, Colorado.

Marschinski, R., M. Jakob and O. Edenhofer (2009), "Analysis of carbon leakage in an extended Ricardo-Viner model", presented at the Conference on the International Dimensions of Climate Policies, Bern, 21-23 January 2009.

Meyer, K. E. and E. Sinani (2009), "When and Where Does Foreign Direct Investment Generate Positive Spillovers? A meta-analysis", Journal of International Business Studies, Vol. 40/7, Springer Nature, London, pp. 1075-1094, http://doi.org/10.1057/jibs.2008.111.

Nordhaus (2015), "Climate Clubs: Overcoming Free-riding in International Climate Policy", American Economic Review, Vol. 105/4, American Economic Association, Pittsburgh, pp. 1339-1370, http://doi.org/10.1257/aer.15000001.

OECD (2016), Effective Carbon Rates: Pricing CO_2 through Taxes and Emissions Trading Systems, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264260115-en.

Saunders, H. D. (1992), "The Khazzoom-Brookes Postulate and Neoclassical Growth", The Energy Journal, Vol. 13/4, pp. 131-148, International Association for Energy Economics, Cleveland.

Sinn, H.-W. (2008), "Public policies against global warming: a supply side approach", International Tax and Public Finance, Vol. 15/4, Springer Nature, pp. 360-394, http://doi.org/10.1007/s10797-008-9082-z.

Tirole, J. (2012), "Some Political Economy of Global Warming", Economics of Energy and Environmental Policy, Vol. 1/1, International Association for Energy Economics, Cleveland, http://dx.doi.org/10.5547/2160-5890.1.1.10.

ANNEX 4.A2. Brief description of the models

The YODA model

The Yoda model encompasses structural features (such as hysteresis, impact of credit risks premium faced by governments on public debt) and some international dimensions. By incorporating some non-linearities, this model specifically depends on the current state of economies, and in particular their position in the business cycle. For instance, the extent to which hysteresis affects economies will depend not only on the degree of labour-market rigidity but also on the extent to which the economy is experiencing a shortage of demand. This is an important difference from standard macroeconomic models. This model also allows for monetary policy to be constrained at the zero-lower bound.

In the current version the major advanced economies, major emerging-market economies and the rest of the world are modelled. Each country model comprises about 20 key reduced-form equations. In total, the model comprises about 700 equations.

Countries and regions are connected through trade volume linkages. One main advantage of this instrument is that it is flexible and can be easily amended to address specific issues such as the treatment of structural reforms.

With this model, simulations can be run up to 2050.

Specification of the main equations

This section reports the key equations that are driving the simulations.

Economic growth, which is modelled in reduced form, depends on potential growth, real interest rates and discretionary fiscal policy.

$$(1) \qquad \Delta y_t = \Delta y_t^* + a_{y,gap} gap_{t-1} + a_{y,r}\Delta r_t + \lambda_1 \Delta ig_t + \lambda_2 \Delta cg_t - \lambda_3 \Delta tax_t - \theta_p \Delta ep + \varepsilon_{y,t}$$

With y_t the log of actual output, $y_t{}^*$ the log of potential output, r_t the real long-term interest rate, ig, cg and tax are respectively public investment, public consumption and tax in percentage of potential GDP, and the output gap. λs fiscal multipliers. Ep is the log of (after tax) energy prices. The gap term captures the effect of other market mechanisms and stabilisation policies that are not explicitly modelled (*e.g.* unconventional monetary policy).

International trade spillovers are introduced in the growth equation when the model is simulated jointly for several countries (linked mode).

Potential output is affected by past developments in demand. Hysteresis has a permanent impact on the level of potential:

$$(2) \qquad \Delta y_t^* = \Delta y_{t-1}^* + \mu * \text{Min}(gap_{t-1}, 0) + \frac{\epsilon}{(1-deprec)} \Delta ig_t + \delta * (\Delta y_{t-1}^* - \Delta y_{ss}^*) + \varepsilon_{y^*,t}$$

with μ>0 the degree of labour market hysteresis, ε is the elasticity of public capital in the production function, deprec the depreciation rate, δ the speed of convergence of potential output to the steady state, y^*_{SS} and error term $\varepsilon_{y^*,t}$ is a supply shock.

Inflation is driven by an expectation-augmented Phillips curve where expectations are anchored to an inflation target.

(3) $$\pi_t = a_{\pi,\pi}\pi_{t-1} + \left(1 - a_{\pi,\pi}\right)\pi_t^T + a_{\pi,gap} * gap_t + \varepsilon_{\pi,t}$$

With π_t inflation, π_t^T inflation target and $\varepsilon_{\pi,t}$ an inflation shock. The specification assumes dynamic homogeneity (*i.e.* that the coefficients on past and expected inflation sum to unity).

Monetary policy settings follow a Taylor rule:

(4) $$i_t = Max\left(\theta_1 i_{t-1} + (1 - \theta_1) * (i^* + \sigma_1\left(\pi_t - \pi_t^T\right) + \sigma_2 * gap_t), \bar{\imath}\right)$$

With i_t nominal short-term interest rate, $\bar{\imath}$ a lower threshold under which i_t cannot go and i^* the neutral rate which varies over time. The neutral rate is always consistent with targeted inflation and potential output developments. In euro area countries, monetary policy responds to euro area-wide inflation and output gap, so that country-specific inflation and output gap affect monetary policy to the extent of the weight of the respective country in euro area nominal GDP.

The long-term nominal interest rate on public debt is assumed to follow the short-term rate with a term premium and a fiscal risk. Fiscal risk increases by φ basis points for each additional percentage point of gross debt. The implicit assumption here is that financial markets impose a risk premium on the interest rate applied to debt, that is function of the level of debt.

(5) $$irl_t = i_t + term_t + risk_f + \varepsilon_{i,t}$$

with

(6) $$term_t = \vartheta term_{t-1} + \overline{term}$$

and

(7) $$risk_f = \varphi d_{t-1}$$

where irl_t is the long-term nominal interest rate bearing on public debt, *term* the term premium, $risk_f$ fiscal risk, d_t public debt-to-GDP ratio, and $\varepsilon_{i,t}$ a shock. The term premium is time-varying, with an auto-regressive component, and in the medium term it converges to its historical average (term).

The real interest rate is computed as the difference between the nominal interest rate and inflation.

(8) $$r_t = irl_t - \pi_t$$

Public balance is broken down into a structural component and a cyclical one, which moves with the output gap.

(9) $$pb_t = \overline{ig}_t + \overline{cg}_t + \overline{tax}_t + (\alpha_{cg} + \alpha_{tax})gap_t + \varepsilon_{pb,t}$$

where pb_t is the public balance, in percentage of GDP and α semi-elasticity of the respective fiscal variable to the output gap. $\overline{pb}_t$ is the cyclically-adjusted primary balance and comprises cyclically-adjusted public investment, public consumption and tax. One option in the model is to activate a fiscal reaction function whereby the primary balance is derived to stabilise the debt-to-GDP ratio over the long term.

Finally, the debt-to-GDP ratio is calculated using a standard debt accumulation formula.

$$(10)\qquad \Delta d_t = \frac{(r_t - \Delta y_t)}{(1 + \Delta y_t)} d_{t-1} - pb_t$$

Parameters and calibration

The model has been constructed for selected OECD economies (Australia, Canada, France, Germany, Italy, Japan, United States) and emerging economies (Brazil, China, India, Indonesia, the Russian Federation and South Africa).

Parameters have been estimated, wherever possible. This is in particular the case for the growth and Phillips curve equations (Table A2.1). Those coefficients have been estimated using annual Economic Outlook data and IMF WEO data.

Some parameters were calibrated using existing literature. Fiscal multipliers have been calibrated using Coenen et al. (2012).

The elasticity of public capital is calibrated using a meta-analysis on the impact of public investment on growth (Bom and Ligthart, 2014). Following Fournier (2016), it is also assumed that the lower the initial stock of public capital in the country, the higher this elasticity. In practice, this means it is lower in Japan and higher in emerging economies.

The hysteresis parameter measures the effect of persistent weak demand on potential output. It is calibrated following Kapadia (2005) and Delong and Summers (2012) to 0.1 in English-speaking economies and 0.2 in continental European countries and in Japan. These values are consistent, though on the low side, with those estimated by Mourougane (2016) using a panel of OECD member countries. Hysteresis is set to zero in emerging economies, which are characterised by widespread informality.

Although there is now a broad recognition that it is important to incorporate the feedback effect of financial markets, no consensus has emerged on the best way to model fiscal risks. The approach adopted in this model is to opt for simplicity and assume the premium depends on the level of the debt-to-GDP ratio.

The parameters entering the Taylor rule are standard. The inflation target is set at the official inflation target in OECD and emerging economies. Central banks are assumed to avoid abrupt jumps in the policy rate by smoothing its adjustment. It is assumed the ECB reaction function is consistent with its de jure mandate and that the central bank targets only inflation.

The cyclical part of the budget is calculated using the elasticities of budget items to the output gap derived in Price, Dang and Botev (2015). The resulting budget semi-elasticity ranges from 0.41 in Japan to 0.61 in France. It has been estimated with error-correction models using disaggregated spending and revenue data.

The steady-state term premium is computed using the average of the observed difference between short and long-term rates over the period 1999 to 2014 in the euro area countries and 1995 to 2014 in the other economies.

Table A2.1. **Calibration**

	Parameter or variable	Value	Source
		Equation g*	
μ	Degree of labour-market hysteresis	0.1 in the United States, the United Kingdom and Canada 0.2 in European countries and in Japan	Calibrated using Kapadia (2005); Delong and Summers (2012)
ε	Elasticity of public capital in the production function	Between 0.05 to 0.25 depending on the initial stock of capital	Bom and Ligthart (2014) and Fournier (2016)
Deprec	Depreciation rate	5%	Average general government capital in the United States using data from the Statistical office (4.6%)
δ	Potential output speed of convergence	-0.3	Calibrated
y^*_{ss}	Steady state rate of potential output growth	2% for the United States, 0.5% for Japan and 1% for the euro area countries	Calibrated
λ_1	Fiscal multiplier public investment	1.1 (0.7 for Japan)	Calibrated using Gechert et al. (2015) and Auerbach and Gorodnichenko (2014)
λ_2	Fiscal multiplier other public spending	1	
λ_3	Fiscal multiplier tax	0.3	
θ_p	Elasticity of energy prices on g	Country specific	Calibrated using energy consumption
		Taylor rule and interest rates	
θ_1	Inertia in interest premium in the Taylor rule	0.5	Calibrated
σ_1	Weight on inflation in the Taylor rule	1	Calibrated
σ_2	Weight on the gap in the Taylor rule	0.5	Calibrated
π_t^T	Inflation target	2% for OECD countries. Set to official objectives in other	Calibrated
$\bar{i}$	Lower limit on the interest rate	-5%	Calibrated
φ□	Influence of debt on interest premium	0.5 basis point; 0.1 basis point for Japan	Calibrated
Term	Steady-state term premium	Average difference between long and short-term rates	
		Public deficit	
$\alpha_{cg}, \alpha_{tax}$	Elasticity of fiscal variables to the output gap	Country-specific value, their sum is around 0.4-0.6 and takes into account changing share of each component in GDP and in total government spending/ revenue	Calibrated using Price, Dang and Botev (2015)
Equation g	Panel with same coefficient for all the countries , λs calibrated		SURE Estimation 1990-2014 – OECD countries and emerging economies are estimated in two different panels
Equation Phillips	Panel with same coefficient for all the countries		SURE Estimation 1990-2014 – OECD countries and emerging economies are estimated in two different panels

The Oxford Economics' Global Economic Model (GEM)

The Oxford Economics' Global Economic Model (GEM) is a quarterly system of macro-econometric interlinked equations for a broad set of economic variables. The GEM includes around 100 different countries, both advanced and emerging economies.

The overall economic structure of the GEM consists of a Keynesian paradigm in the short term and a monetarist point of view in the long run. Output is driven by demand-side factors in the short run and supply-side factors in the long run. The long-run output is determined by a Cobb-Douglas production function that uses the capital stock, labour supply and technological progress as inputs. In the simulations presented in this chapter, the potential output equation has been modified to introduce an explicit effect of public capital in output in the long term.

Large G20 economies models pool more than 600 variables and those of smaller economies 400 to 500 variables. The rest of the world is modelled as six regional aggregates of smaller size (100 to 250 variables).

The detailed breakdown of economies includes labour, financial and energy markets. This breakdown and the rich set of countries enable examination of a multitude of various shocks and systemic interactions between the most important economies. In addition, GEM enables sector-level analysis since aggregate output and employment are split into various manufacturing and services industries. In particular, one of the main advantages of this model is that the energy sector (oil, coal and gas) is extensively detailed for the major economies, so consistency between energy prices and supply/demand balances is ensured. Carbon taxes are also incorporated in the model.

The macro-econometric equations are single-variable error-correction model (ECM) estimated using historical data. The ECM makes it possible to disentangle short- and long-run dynamics in a concise manner. In the majority of cases, the functional form for equations is similar across countries and differences in simulation outcomes will reflect mostly differences in estimated parameters. There are some exceptions though, where countries are heavily dependent on a particular sector, such as oil, or where FDI plays a major role, for instance in emerging economies.

The model encompasses a number of options in terms of monetary policy. It usually assumes adaptive expectations, though it can introduce rational expectations for some variables.

Country/region models are linked through trade, prices, exchange rates and interest rates, capital flows and commodities prices.

With the 25-year horizon version of this model, it is possible to run simulations up until 2045 .

The GEM is a widely used macroeconomic model with clients including the IMF, World Bank and a couple of private sector entities, and has been used for modelling economic consequences of climate change before (e.g. University of Cambridge Institute for Sustainability Leadership, 2015).

References

Auerbach, A.J. and Y. Gorodnichenko (2014), "Fiscal Multiplier in Japan", *NBER Working Paper*, No. 19911.

Bom, P. and J. Ligthart (2014), "What Have we Learned from Three Decades of Research on the Productivity of Public Capital?", *Journal of Economic Surveys*, Vol. 28/5, Wiley, Hoboken, pp. 889-916, http://doi.org/10.1111/joes.12037.

Coenen, G., et al. (2012), "Effects of Fiscal Stimulus in Structural Models", *American Economic Journal: Macroeconomics*, Vol. 4/1, American Economic Association, Pittsburgh, http://doi.org/10.1257/mac.4.1.22.

Delong, J. and L. Summers (2012), "Fiscal Policy in a Depressed Economy", *Brookings Papers on Economic Activity*, Brookings Institution, Washington DC, www.brookings.edu/bpea-articles/fiscal-policy-in-a-depressed-economy/.

Fournier, J.-M. (2016), "The positive effect of public investment on potential growth", *OECD Economics Department Working Papers*, No. 1347, OECD Publishing, Paris, http://dx.doi.org/10.1787/15e400d4-en.

Gechert S., A. Hughes Hallet and A. Rannenberg (2015), "Fiscal Multipliers in Downturns and the Effects of Eurozone Consolidation", *CEPR Policy Insight*.

Kapadia, S. (2005), "Optimal Monetary Policy under Hysteresis", Department of Economics, University of Oxford, www.economics.ox.ac.uk/Department-of-Economics-Discussion-Paper-Series/optimal-monetary-policy-under-hysteresis.

Mourougane, A. (2016), "Crisis, Potential Output and Hysteresis", *International Economics*, Vol. 149, Elsevier, Amsterdam, http://doi.org/10.1016/j.inteco.2016.07.001.

University of Cambridge Institute for Sustainability Leadership (2015), "Unhedgeable risk: How climate change sentiment impacts investment", Cambridge.

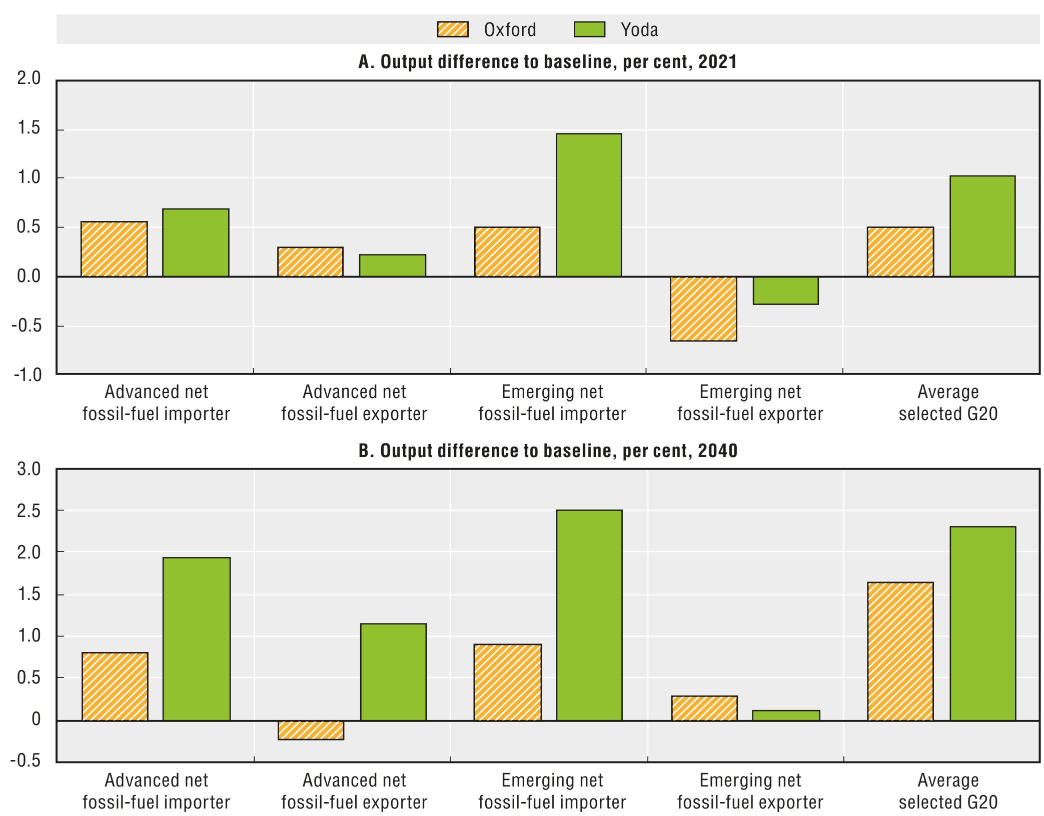
Price, R.W., T. Dang and J. Botev (2015), "Adjusting Fiscal Balances for the Business Cycle: New Tax and Expenditure Elasticity Estimates for OECD countries", *OECD Economics Department Working Papers*, No. 1275, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jrp1g3282d7-en.

ANNEX 4.A3. Robustness checks on the model simulations

To obtain insights into the sensitivity of the results to model specification, the simulations of a decisive transition have also been run using the large-scale macroeconomic Oxford model (Figure A3.1). Outcome differences between the two tools appear to be small, well within the margin of error. Differences are more noticeable for the short to medium term for emerging economy fossil fuel importers, reflecting the different pace of adjustment embodied in the two models. Differences are larger over the long term, notably for some fossil fuel net exporters, underlining the large uncertainties of the results at this time horizon. They reflect differences in model specifications, notably regarding the reaction of business investment in both models to the fiscal initiative.

This apparent similarity does, however, mask large uncertainties. In particular, GDP outcomes remain sensitive to the assumptions on fiscal multipliers in the short term and the rate of return of public capital in the long run. For instance, in the Yoda model, the output impact could range from 0.1% to 1.25% in the short to medium term in an advanced net fossil fuel importer, depending on how large the short-term fiscal multiplier is in the range between 0 and 2 (Figure A3.2). At this horizon, the effect could be negative in some net fossil fuel exporters, assuming a typical pro-growth package is implemented. A package that is more adapted to the country's needs would enhance the positive counterbalancing effect. Uncertainties are increasing over the long term, especially for emerging economies.

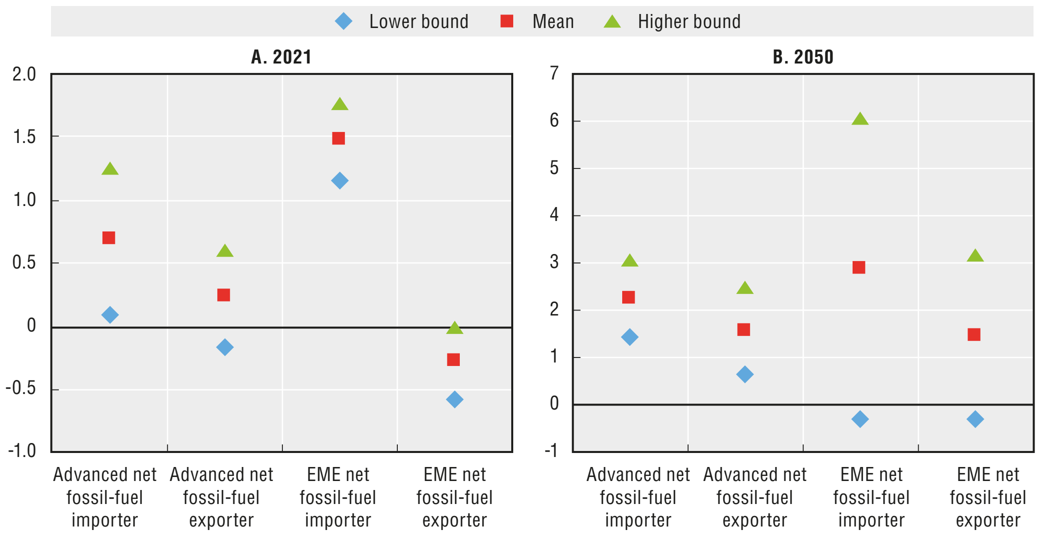
Figure A3.1. **Output impact of a decisive transition to decarbonisation using different models**



Note: See Figure 4.5.

Figure A3.2. **Uncertainties around output impact of a decisive transition to decarbonisation**

Output difference to baseline, per cent



Note: Bounds were computed by varying the short-term fiscal multiplier from 0 to 2, and multiplying the long-term rate of return of public capital by +/-10%. Both assumptions are consistent with estimates from the economic literature.

ANNEX 4.A4. Flexible economies adapt better to climate-change mitigation action

With policies stimulating private investment and innovation in low-carbon technologies, firms are likely to need a flexible environment to be able to adapt to new incentives. This annex presents evidence validating this hypothesis: the effect of energy prices on business investment and the effect of environmental policy stringency on productivity can be significantly positive if product market regulations are "flexible", or, more specifically, conducive to competition and the entry of new firms into markets. These effects are significantly negative if product market regulations restrict competition or firm entry.

Methodology and data

Two separate approaches are considered here to show evidence that a flexible economy helps to adapt to the climate change action. First, the relationship between energy price inflation and manufacturing firms' investment is shown to depend on the flexibility of domestic product market regulations. In a second one, a similar story is found for manufacturing industries' productivity growth.

Manufacturing investment, energy prices and regulations

The evidence on manufacturing investment effects is built on the specification and the data used by Dlugosch and Koźluk (2017) to estimate the effect of energy prices on business investment at the firm level. Their baseline specification (DK hereafter) is estimated with a linear fixed-effect least square estimator. In particular, the time fixed effect rules out worldwide demand shocks that can affect both energy prices and investment. It is augmented with an interaction term between the product regulation indicator and energy price inflation:

$$(1) \qquad \frac{I_{isct}}{K_{isct}} = \beta_1 * \Delta EPI_{sct-1} + \beta_2 * \mathrm{PMR}_{ct-1} + \boldsymbol{\beta_3 * \mathrm{PMR}_{ct-1} \Delta EPI_{sct-1}} + \beta_4 \mathrm{X}_{isct} + \alpha_i + \theta_t + \varepsilon_{isct}$$

where:

- $\frac{I_{isct}}{K_{isct}}$ is the ratio of investment to the capital stock using the book values of capital expenditure (I) and capital stock (K) of firm *i* in sectors s and *c* countries at time *t*.
- ΔEPI is the three-year moving average of energy prices inflation.[1]
- PMR denotes the OECD's product market regulation indicator
- X_{isct} is a vector of additional control variables
- α_i is a firm-specific intercept, and θ_t a year fixed effect.

Productivity, environmental stringency and regulations

The effect of environmental stringency on productivity is analysed at the sector level, following the specification and data used in Albrizio, Koźluk and Zipperer (2017).[2] For this analysis, the specification is augmented with the OECD's Product Market Regulation (PMR) indicator as follows:

$$\Delta \ln MFP_{cit} = \propto_1 + \propto_2 (ED_{i\,1987} \Delta EPS_{ct}^{3MA}) + \propto_3 gap_{cit-1} (ED_{i\,1987} \Delta EPS_{ct}^{3MA}) + \propto_4 gap_{cit-1}$$

$$+ \propto_5 \Delta \ln \widetilde{MFP}_{it} + \propto_6 \boldsymbol{PMR_{ct-1} (ED_{i\,1987} \Delta EPS_{ct}^{3MA})} + \propto_7 PMR_{ct-1} + x_{cit}\gamma + \eta_t + \delta_{ci} + \epsilon_{cit}$$

where:

- $\Delta \ln MFP_{cit}$ is the multifactor productivity growth for each combination of country c and industry *i*.
- ΔEPS^{3MA} is a three-year moving average of the change of the country EPS and captures the tightening of country's environmental policy stringency. A change in a country's EPS is interacted with pre-sample industry environmental dependence (*ED*).[3]
- The third term allows for nonlinear effects of the policy as a function of the technological gap, defined as the distance to the country-industry frontier $gap = \ln\left(\frac{MFP_i}{MFP_{ci}}\right)$.
- The fourth term is the distance to the productivity frontier, which allows for technological catch-up effects.
- The fifth term is the growth in the leader MFP and represents the technological pass-through.
- x_{cit} is a vector of additional country and industry controls, which varies across the econometric specifications considered (see section "Results").
- PMR denotes the product market regulation indicator. Higher values indicate a higher degree of restrictiveness.
- Finally, aside from the above, the specification controls for a common time trend , the financial crisis, output gap and country-industry fixed effects (δci) or, alternatively, country and industry-fixed effect are included separately: δc and δi.

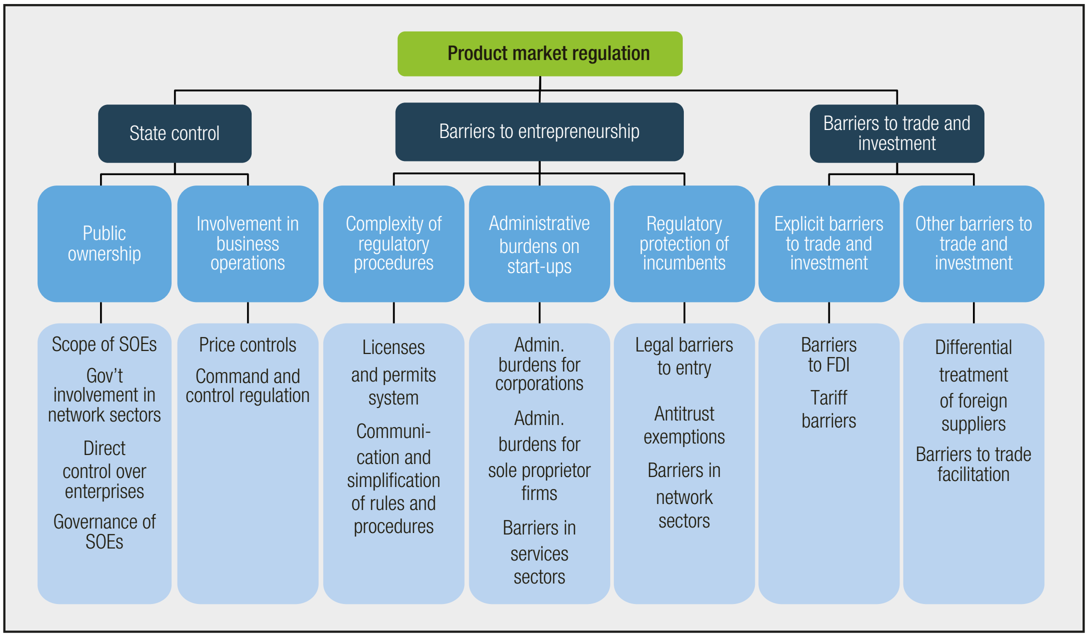
Data

Data used for the investment estimates are described in detail in Dlugosch and Koźluk (2017). Firm level data are from Thomsons Reuters Worldscope, which reports mandatory data for listed companies. A main advantage of data reported mandatorily lies in its reliability. However, there are two caveats. First, listed companies may differ from non-listed firms, which cannot be observed. However, Dlugosch and Koźluk (2017) find a striking similarity in practice between manufacturing industry numbers from the OECD STAN database and aggregates from Worldscope, supporting the notion that a large part of outcomes can be explained by a small number of large firms (Gabaix, 2011). Second, investment figures include investment in foreign subsidiaries that is likely to mitigate the role of domestic regulation, so one can assume that the true importance of regulation is larger than the one identified here. The energy price index is constructed by Sato et al. (2015) for 12 sectors in each country over 1995-2011, by weighting country-level IEA fuel prices for four different types of fuel – oil, gas, coal and electricity – by the consumption of these fuels in each country-sector.

Data used for the productivity estimates are described in detail in Albrizio, Koźluk and Zipperer (2017). The index of multifactor productivity is the residual from a log Cobb-Douglas production function, with the labour factor intensity equal to two-thirds, constructed using the OECD Structural Analysis database (STAN) and the Productivity Database By industry (PDBi). The technological frontier at the industry level as well as the distance to frontier (DTF), are constructed following Bas et al. (2016). The environmental policy stringency (EPS) is measured with a new composite index developed by the OECD. This index covers 24 OECD countries over the period 1990-2012 and summarises environmental policy stringency across selected instruments, primarily for energy and transport (for a detailed description, see Botta and Koźluk, 2014).

The stringency of product market regulation is measured here with the OECD product market regulation (PMR) indicator. This indicator comprises three high-level components: state control, barriers to entrepreneurship, and barriers to foreign trade and investment, and several subcomponents (Figure A4.1). It was developed in 1998 (Nicoletti et al., 2000), is available every five years, and was last updated for 2013 (Koske et al., 2015). In OECD countries, the economy-wide indicator shows a decline in regulation between 1998 and 2008, and broad stabilisation since then.

Figure A4.1. **The tree structure of the PMR indicator set**



Source: Koske et al. (2015).

Empirical results

The interaction between product market regulation and energy price inflation significantly affects manufacturing investment (Table A4.1). The first column is the baseline specification without product market regulation (Dlugosch and Koźluk, 2017, Table A2.1). The second column shows the effect of shrinking the sample to years for which the product market regulation indicator is available. The third to sixth columns provide the evidence that the interaction between product market regulations and energy price inflation matters. First, results are reported with interpolated product market regulation data to preserve the year coverage. This setting is used to illustrate that the effect could be slightly larger if one only considers periods of energy inflation that rise above a typical core inflation target (2%): the adaptation issue should be more prominent when energy prices increase. If a more rigid economy implies postponing or spreading the necessary adjustment over time rather than avoiding it, one should expect a bounce-back effect in a highly regulated economy. Such an effect cannot be identified in the estimates (column 5).[4] Columns 3 to 5 need to be interpreted with care as interpolation can generate serial autocorrelation, which would lead to underestimated standard errors. Column 6 thus provides a more reliable baseline, in which the magnitude of the interaction effect is similar to the one observed in the other columns.

Table A4.1. **Interaction between energy price inflation and overall product market regulation stringency**

Dependent variable: Investment / Total Assets	(1) Baseline (DK)	(2) Baseline with PMR sample	(3) Interact. PMR (interpolated)	(4) Interact. PMR (interpolated)	(5) Interact. PMR (interpolated)	(6) Interact. PMR (non-interp.)
EPI Inflation sample	all	all	all	EPI>2%	all	all
PMR (t-1) * EPI (MA) (t-1)			**-0.0860*** **	**-0.0965*** **	**-0.1213*** **	**-0.1116*** **
			(0.0189)	**(0.0292)**	**(0.0216)**	**(0.0368)**
PMR (t-1) * EPI (MA) (t-4)					-0.0030	
					(0.0206)	
PMR (t-1)			-0.0013	0.0146***	0.0132***	0.0033
			(0.0022)	(0.0033)	(0.0030)	(0.0048)
EPI (MA) (t-1)	-0.0107*	0.0177	0.1215***	0.1777***	0.1947***	0.1915***
	(0.0057)	(0.0154)	(0.0291)	(0.0433)	(0.0330)	(0.0597)
EPI (MA) (t-4)					-0.0054	
					(0.0311)	
Layoff rates *	-0.0036***	-0.0114***	-0.0035***	-0.0012*	-0.0021***	-0.0101***
Employment Protection (t-1)	(0.0006)	(0.0012)	(0.0006)	(0.0007)	(0.0006)	(0.0014)
Dependency External Fin. *	0.0120*	0.0611***	0.0098	-0.0069	0.0141*	0.0560***
Fin. Dev. (t-1)	(0.0065)	(0.0185)	(0.0065)	(0.0069)	(0.0072)	(0.0185)
Observations	68,334	12,359	68,332	46,679	54,638	12,359
Adj. R2	0.412	0.354	0.412	0.429	0.420	0.355

Note: All models include firm- and time-fixed effects, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPI inflation (MA) denotes the three-year moving average of changes in the energy price indicator. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The energy intensity has been demeaned before application. Low energy-intensive sectors thus have a negative sign. Time sample: 1999-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

The setup allows some insights into what types of regulations may matter most. Estimates with disaggregated PMR indicators suggest that barriers to entrepreneurship and international barriers to trade and investments matter the most, while there is a lack of evidence on the role of the state involvement in business operation (Table A4.2, column 1). Among these two main fields of regulations, there are five sub-items. Their relative roles are explored in two different ways: either by including all the interaction terms together (Table A4.2, column 2), or including them one by one and reporting cases where the interaction term is significant at least at the 10% level (Table A4.2, columns 3 to 5). There is evidence that administrative burdens on start-ups, complexity of regulatory procedure and explicit barriers to international trade and investment are more likely to matter. Notably, the results using disaggregated PMR indicators should be interpreted with caution as it is hard to disentangle the role of each regulation; in practice, there is a substantial correlation across subdomains.[5]

Table A4.2. **Interaction between energy price inflation and subdomain product market regulation stringency**

Dependent variable: Investment / Total Assets Interpolated PMR	(1) no	(2) no	(3) no	(4) no	(5) no
EPI Inflation sample	all	all	all	all	all
State Control (t-1) * EPI (MA) (t-1)	**0.0237**				
	(0.0398)				
Barriers to Entrepreneurship (t-1) *	**-0.0743****				
EPI (MA) (t-1)	(0.0365)				
Administrative burdens on start-ups (t-1)		-0.0593*	-0.0476**		
* EPI (MA) (t-1)		(0.0314)	(0.0194)		
Complexity of regulatory procedures (t-1) *		-0.0177		-0.0335**	
EPI (MA) (t-1)		(0.0144)		(0.0130)	
Regulatory protection of incumbent (t-1) *		0.0087			
EPI (MA) (t-1)		(0.0541)			
Barriers to trade and investment (t-1) *	**-0.0752****				
EPI (MA) (t-1)	**(0.0356)**				
Explicit barriers to trade and investment (t-1) *		-0.1187***			-0.0941***
EPI (MA) (t-1)		(0.0361)			(0.0254)
Other barriers to trade and investment (t-1)		0.0466			
* EPI (MA) (t-1)		(0.0363)			
State control (t-1)	0.0071**				
	(0.0028)				
Barriers to entrepreneurship (t-1)	-0.0038				
	(0.0042)				
Administrative burdens on start-ups (t-1)		-0.0000	-0.0005		
		(0.0044)	(0.0025)		
Complexity of regulatory procedures (t-1)		-0.0022		-0.0020	
		(0.0019)		(0.0017)	
Regulatory protection of incumbent (t-1)		-0.0064			
		(0.0062)			
Barriers to trade and investment (t-1)	0.0029				
	(0.0051)				
Explicit barriers to trade and investment (t-1)		-0.0091*			-0.0081**
		(0.0047)			(0.0041)
Other barriers to trade and investment (t-1)		0.0035			
		(0.0044)			
EPI (MA) (t-1)	0.1850**	0.1796***	0.1081***	0.1055***	0.0760***
	(0.0760)	(0.0688)	(0.0412)	(0.0296)	(0.0218)
Observations	12.359	12.359	12.359	12.359	12.359
Adj. R2	0.356	0.357	0.354	0.355	0.355

Note: All models include firm- and time-fixed effects, Layoff rates * Employment Protection, Dependency External Fin. * Financial development, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPI inflation (MA) denotes the three-year moving average of changes in the energy price indicator. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The energy intensity has been demeaned before application. Low energy intensive-sectors thus have a negative sign. Time sample: 1999-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.
Source: OECD calculations.

There is similar evidence that the interaction between product market regulation and environment policy stringency significantly affects industry productivity (Table A4.3). The so-called Porter Hypothesis – according to which strict environment regulations can induce incentives for innovation, efficiency improvements and within-firm reallocation that may lead to higher productivity (Porter, 1991; Porter and van der Linde, 1995) – is controversial (Ambec et al. 2011; Lanoie et al. 2011; Kozluk and Zipperer, 2015), but in more flexible economies, firms should be more inclined to reap such gains. This would imply that the less regulation impedes competition, the higher the multifactor productivity gains reaped from environmental policy incentives. Empirical results appear in line with the Porter Hypothesis, using an interpolated PMR indicator (columns 1 and 2), the initial PMR indicator (columns 3 and 4) and a dummy that takes value one if the product market regulation indicator is above the sample median of the given year (columns 5 and 6). Last, a disaggregate product market regulation indicator provides tentative evidence that barriers to international trade and investment could have an important role in hindering productivity gains (columns 7 and 8).

Table A4.3. **Interaction between environment protection stringency and overall product market regulation stringency**

Dependent variable: Mfp growth	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Interpolated PMR	**yes**	**yes**	**no**	**no**	**no**	**no**	**no**	**no**
PMR dummy	**no**	**no**	**no**	**no**	**yes**	**yes**	**no**	**no**
Leader MFP growth	0.17***	0.13***	0.31***	0.37***	0.31***	0.37***	0.31***	0.37***
	(0.033)	(0.033)	(0.10)	(0.099)	(0.10)	(0.098)	(0.10)	(0.100)
Distance to frontier	0.22***	0.10***	0.16***	0.11***	0.15***	0.11***	0.15***	0.11***
(lagged)	(0.029)	(0.016)	(0.049)	(0.030)	(0.048)	(0.029)	(0.049)	(0.029)
EPS tightening (MA)	0.63***	0.48***	0.96**	0.80*	0.42***	0.27**	0.86**	0.67*
	(0.19)	(0.15)	(0.44)	(0.41)	(0.13)	(0.11)	(0.42)	(0.38)
Effect of gap on EPS tightening (MA)	-0.16	-0.18**	-0.71**	-0.43	-0.67**	-0.40	-0.79**	-0.49*
	(0.12)	(0.087)	(0.29)	(0.28)	(0.30)	(0.28)	(0.32)	(0.27)
PMR (t-1)* EPS	**-0.31*** **	**-0.22***	**-0.41***	**-0.40***	**-0.29*** **	**-0.26*** **		
tightening (MA)	**(0.10)**	**(0.089)**	**(0.22)**	**(0.22)**	**(0.087)**	**(0.082)**		
State control (t-1) *							-0.061	-0.037
EPI (MA) (t-1)							(0.12)	(0.11)
Barriers to entr. (t-1)							-0.073	-0.084
* EPI (MA) (t-1)							(0.23)	(0.099)
Barriers to trade and							-0.39	-0.37**
inv. (t-1) * EPI (MA) (t-1)							(0.45)	(0.15)
PMR (t-1)	0.058***	0.030	0.069	0.070	0.028*	0.031*		
	(0.022)	(0.021)	(0.055)	(0.054)	(0.017)	(0.017)		
State control (t-1)							0.0099	0.010
							(0.027)	(0.025)
Barriers to entrepre-							0.0090	0.0094
neurship (t-1)							(0.034)	(0.030)
Barriers to trade and							0.10	0.10*
investment (t-1)							(0.074)	(0.059)
Fixed effects								
Country*Industry	Yes	No	Yes	No	Yes	No	Yes	No
Country	No	Yes	No	Yes	No	Yes	No	Yes
Industry	No	Yes	No	Yes	No	Yes	No	Yes
N	1.541	1.541	366	366	366	366	366	366
adj. R2	0.17	0.18	0.25	0.23	0.25	0.23	0.25	0.23

Note: Robust standard errors in parentheses and they are clustered at country-industry level; *** denotes statistical significance at the 1% level, ** significance at 5% level, * significance at 10% level. (MA): denotes the moving average of the EPS change over three-years-lags. Changes in a country's EPS are interacted with pre-sample industry environmental dependence. All specifications include the following controls: output gap, dummy for crisis and year trend, employment protection legislation (OECD EPL), and country's degree of capital account openness (Chinn-Ito Index).

Simulation inputs for the modelling

Under a number of simplifying assumptions,[6] the effect of energy prices on PMR on manufacturing investment as a share of GDP can be simulated as follows:

$$effect_t^{v0} = (\beta_1 * \Delta EPI_{ct-1} + \beta_3 * \mathrm{PMR}_c \Delta EPI_{ct-1}) * (\frac{I}{GDP})/(\frac{I}{K})$$

where β_1 and β_3 are the coefficients estimated in the sixth column of Table A4.1, ΔEPI_{ct-1} is a country level change in end-user energy price for the manufacturing sector used in the scenarios, PMR_c is the PMR level in 2013 (2008 in Indonesia), the investment to capital ratio is the average over 2009-11 observed in the firm-level database used for the regressions (from Worldscope), and the manufacturing investment to GDP ratio is reported in national accounts. For countries for which the manufacturing investment data is not available, the manufacturing investment to GDP ratio is taken from the GTAP8 database. This computation can cover 17 out of the G20 countries.

The resulting simulated effect is a change in manufacturing investment relative to a baseline scenario, expressed as a share of GDP. This is included in the modelling as an additional investment shock, reflecting the path of energy price of the scenario.

Notes

1. A moving average specification has been used by Albrizio, Koźluk and Zipperer (2017) and builds on the argument that investment is usually planned ahead; a reaction to energy prices may thus take some time.
2. This analysis is not performed at the firm level because of limited country coverage: Albrizio, Koźluk and Zipperer (2017) firm level estimations cover 12 countries. Lack of cross-country information is a particular concern here because the product market regulation is observed at the country level.
3. Industry environmental dependence is an index of industry pollution intensity ranging from 0 to 1 and is used to proxy for industries' exposure to environmental regulation. Pre-sample observations are used to ensure exogeneity (see Albrizio, Koźluk and Zipperer, 2017).
4. Adding an additional lag of the energy price inflation does not lead to any identification of a bounce back effect either.
5. Insignificance can also be due to the inherent uncertainty surrounding such detailed estimates, and selection results can vary if the selection method is modified. For instance, regulatory protection of incumbents would be identified as strongly significant is a similar exercise with interpolated PMR data, and this can reflect the interest of incumbents in deterring transitions.
6. In particular, the control variables used in the regression are assumed to be held constant in the future, and the coefficient estimates derived from the Worldscope sample are assumed to hold for the whole manufacturing sector.

References

Albrizio, S., T. Koźluk and V. Zipperer (2017), "Environmental Policies and Productivity Growth: Evidence across Industries and Firms", *Journal of Environmental Economics and Management*, Vol. 81, Elsevier, Amsterdam, pp. 209-226, https://doi.org/10.1016/j.jeem.2016.06.002.

Bas, M., et al. (2016), "The effects of input tariffs on productivity: panel data evidence for OECD countries", *Review of World Economics*, Springer Nature, Vol. 152/2, pp. 401-424, http://doi.org/10.1007/s10290-016-0247-z.

Botta, E. and T. Koźluk (2014), "Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach", *OECD Economics Department Working Papers*, No. 1177, OECD Publishing, Paris, http://dx.doi.org/10.1787/5jxrjnc45gvg-en.

Dlugosch, D. and T. Kozluk (2017), "Energy prices, environmental policies and investment: Evidence from listed firms", *OECD Economics Department Working Papers*, No. 1378, OECD Publishing, Paris, http://dx.doi.org/10.1787/ef6c01c6-en.

Gabaix, X. (2011), "The Granular Origins of Aggregate Fluctuations", *Econometrica*, Vol. 79/3, Wiley, Hoboken, pp. 733-722, http://doi.org/10.3982/ECTA8769.

Johansson, Å., et al. (2008), "Taxation and Economic Growth", *OECD Economics Department Working Papers*, No. 620, OECD Publishing, Paris, http://dx.doi.org/10.1787/241216205486.

Koske, I. et al. (2015), "The 2013 update of the OECD's database on product market regulation: Policy insights for OECD and non-OECD countries", *OECD Economics Department Working Papers*, No. 1200, OECD Publishing, Paris, http://dx.doi.org/10.1787/5js3f5d3n2vl-en.

Nicoletti, G., S. Scarpetta and O. Boylaud (2000), "Summary Indicators of Product Market Regulation with an Extension to Employment Protection Legislation", *OECD Economics Department Working Papers*, No. 226, OECD Publishing, Paris.DOI: http://dx.doi.org/10.1787/215182844604.

Porter, M. (1991), "America's green strategy", *Scientific American*, Vol. 264/4, Springer Nature, London.

Porter, M. E. and C. van der Linde (1995), "Toward a New Conception of the Environment Competitiveness Relationship", *Journal of Economic Perspectives*, American Economic Association, Pittsburgh, Vol. 9/4, pp. 97-118, http://doi.org/10.1257/jep.9.4.97.

Sato, M. et al. (2015), "International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency", Grantham Research Institute on Climate Change and the Environment, London School of Economics, London.

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