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COMMENTARY

MACROECONOMICS AND CLIMATE CHANGE

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Climate change and its consequences are the most important issues affecting the UK economy over the coming century and will present a critical challenge for the UK government moving forward. In particular, the challenge of getting to net zero by 2050 is going to have major ramifications for the macroeconomy. In this commentary, I lay out some of the work that has been done on the implications of climate change and the transition to net zero for the macroeconomy. Economic activity as currently structured involves using fossil fuels as part of the production process. But this releases carbon dioxide into the atmosphere and leads to higher temperatures. I take this as given, simply noting that if this rise in temperature and the change in weather patterns associated with it are going to be stopped, if not reversed, at some point in the future, then we have to move to a 'net zero' (or even 'net negative') economy in which output is produced using only those inputs which do not produce greenhouse gases.

This commentary is structured as follows. Given that climate change is already visible through higher temperatures and different weather patterns, I start by considering the direct effects of climate change on the macroeconomy, that is, 'physical risks'. Climate change can affect the macroeconomy through higher temperatures, more frequent storms, floods and other extreme weather events, and so forth. More generally, an increase in extreme weather events, and so forth, is likely to result in increased volatility in the macroeconomy and I consider what that may mean for macroeconomic policy. Having discussed physical risks, I then consider work looking at 'transition risks', that is, the macroeconomic effects of the transition to net zero. As I said earlier, for climate change to be stopped, the economy must move to net zero.[1] This will mean both explicit government policies aimed at steering the economy towards net zero and private-sector action, in particular investing in green technologies to make the transition happen. I first examine the macroeconomic effects of three government policies: direct regulation, a carbon tax and a 'cap-and-trade' policy.[2] I then examine the effects of the transition on the natural rate of interest, r^*.[3] The final section offers some overall conclusions.

1. Physical risks

The physical effects of climate change are likely to become ever more noticeable and intense. Leaving aside the temperature increase itself, global warming has been shown to result in an increase in the frequency and impact of extreme weather events (see, e.g. Stott, 2016; Stott *et al.*, 2016). Bindoff *et al.* (2013) showed that climate change has already led to an increase in the frequency of daily temperature

[1]Even once the world economy is at net zero, temperatures will still continue to rise for a while as the effects of previous emissions take time to come through.

[2]A 'Cap and trade' scheme is where the government sets the maximum quantity of emissions and allows the market to find the price. An example of such a scheme is the EU Emissions Trading System (ETS).

[3]Here I define the natural real rate of interest as the rate of interest that would clear the market for loanable funds absent financial market or other frictions. That is, at this interest rate, desired savings equals desired investment.

extremes and Diebold and Rudebusch (2022) show how the seasonal pattern of daily temperature ranges across U.S. cities has changed over time. Zhang *et al.* (2013) showed that climate change has led to more intense extremes in daily rainfall. The question for this commentary is what that means for the macroeconomy?

Since climate change is a slow process, it is hard to assess the impact on the macroeconomy. As a result, economists have tended to use weather data as a way of inferring the macroeconomic impact of climate change. This work has identified a number of channels through which changes in, especially, temperature and rainfall can affect macroeconomic aggregates, including the economy's potential growth rate. High temperatures are known to reduce labour productivity given that humans simply cannot work as hard physically and mentally when the temperature is too hot. In fact, Dell *et al.* (2014) report that for each degree Celsius over 25°C productivity in various cognitive tasks falls by around 2 per cent. They also found that a 1°C rise in temperature in a given year in poorer countries reduced the growth rate by 1.3 percentage points in that year. Interestingly though, they did not find the same result for rich countries. Burke *et al.* (2015) found that the growth rate of GDP per head peaks at a temperature of around 13°C, while declining strongly at higher temperatures, and that this was true for both rich and poor countries. And Heal and Park (2015) find that hotter-than-average years are associated with lower output and TFP in hot countries.

There is also some evidence of an effect of higher temperatures on demand. Batten (2018) points out that unusual weather can damage the housing stock and affect consumption through wealth effects. Weather patterns also matter for 'shopping productivity' and for recreation, which can act as a substitute for shopping.[4] In terms of evidence for such an effect, Starr-McCluer (2000) finds a small but significant impact of unusual weather on retail sales, while Roth Tran (2019) finds evidence of long- and short-run adaptation to climate in shopping activities.

As shown in Fernando *et al.* (2021), an increase in the frequency and impact of extreme weather events such as droughts, floods and wildfires, will likely have effects on labour supply, productivity—particularly in the agricultural and electricity generation sectors—and output growth. Leaving aside the potential human cost of such events, an increase in their frequency is also likely to lead to much greater volatility in output. And, as these events become more frequent, it becomes harder for private insurance to cover firms and households against them. This creates a need for more active fiscal and monetary policy to dampen the effects of such shocks.

2. Transition risks from government policy

We can think of classifying government climate policy—which could be set at the national or international level—into three broad types.[5] The first is direct regulation, which we can think of as the most restrictive type since it limits the use of various inputs or mandates specific performance standards. An example would be, say, an outright ban on the use of coal in energy production. The second type of climate policy—'market-based' policy—is based around economic incentives, such as, for example, through pricing carbon. In turn, this could be done using a 'carbon tax'—that is a tax on the use of fossil fuels—or by a 'cap and trade' system. In the case of a carbon tax, the authority fixes the price of carbon, and lets the quantity of emissions be determined endogenously by agents' choices, whereas in a cap-and-trade system, the authority fixed the maximum amount of emissions, with the carbon price generated endogenously. The third type of climate policy is the 'institutional approach'. Here the idea is to internalise the climate externality via the use of, say, voluntary agreements and information programmes.

[4]The idea here is that there is a trade-off between enjoyable leisure and time spent in unpaid activities that we do not necessarily enjoy. For example, the less time we spend shopping (i.e. greater 'shopping productivity') the more time we spend doing enjoyable non-market activities with the result that welfare is increased.

[5]In this commentary, I shall be concentrating on policies to reduce carbon emissions, though clearly 'climate policy' is much broader, taking in such things as policy designed to reduce biodiversity loss and policies to protect food chains and water systems.

2.1. Regulation

Traditionally, stringent environmental policies are considered a burden to economic activity, at least in the short and medium term. However, there is no clear a priori direction of the effects of these policies on macroeconomic variables such as productivity, employment, trade and GDP. The famous 'Porter hypothesis' (Porter, 1991) suggests that well-designed environmental policies might enhance productivity and increase innovation, and therefore deliver direct economic benefits as well as the environmental ones.

Early studies found that environmental regulations hamper productivity but were based on narrowly defined subindustries within the manufacturing sector. Dechezleprêtre and Sato (2017), in a comprehensive review of the literature, found that environmental regulations can lead to statistically significant adverse effects on trade, employment, plant location and productivity in the short run. This was particularly the case for a well-identified subset of pollution- and energy-intensive sectors. But these impacts were small relative to general trends in production. At the same time, there is some evidence that environmental regulation has led to innovation in clean technologies, but it is not clear that the resulting benefits are large enough to outweigh the increase in costs faced by regulated entities.

2.2. Carbon taxes

Economic theory as first laid out in Pigou (1920) suggests that we should deal with externalities, such as global warming arising from carbon emissions, via a tax on the polluters. In the case of global warming, this means a tax on carbon emissions. But what effect would the imposition of such a tax have on the macroeconomy? The answer depends on whether we take a short, medium or long-run perspective.

In the short run, we would expect the imposition of a carbon tax to have a negative effect on output and labour productivity. Put simply, if you increase the cost of a production input then output can be expected to decline. Where this input—energy—is a complement to other factors of production, you would expect the productivity of those other inputs—such as labour—to fall. Estimates of the short-run elasticity of substitution between labour and energy and, indeed, between different sources of energy, suggest that these are complements in the short run. However, over time you would expect the taxed inputs—that is, fossil fuels—to become more easily substitutable with other untaxed inputs, such as labour and clean energy. Hence, in the medium run, the effects on output and productivity are less clear. In the long run, you might expect investment in clean energy to result in technological change that spilled over into other sectors and, so, raised productivity growth more generally.

Given the relative lack of evidence of the effects of carbon taxes, economists have used three approaches: computable general equilibrium (CGE) models, integrated assessment models (IAMs) and purely empirical models. The key to the IAMs is that, in these models, economic activity leads to climate change and climate change affects economic activity. In many respects, the approach is similar to that of CGE models, the difference being that they capture the dynamic effects of climate change in a way that CGE models do not. Against that, CGE models typically consider many sectors and many countries where IAMs tend to be much simpler in this respect.

Results using CGE models suggest that the output costs of a carbon tax may be relatively low. For example, Goulder and Hafstead (2017) found that imposing a $40 tax per ton of CO_2 in the United States in 2020 and letting it rise at 5 per cent in real terms annually left GDP 1 per cent lower in 2035 than it would otherwise have been. Importantly, as shown by Goulder *et al.* (2019), using a CGE model, carbon taxes have distributional effects as they raise the prices of goods and services bought by poorer households by more than those bought by richer households. This suggests that it is important for the government to offset the regressive impact of a carbon tax by recycling the revenues raised. More generally, the overall effects of the tax on the government's fiscal position and the economy more generally will depend to a large degree on whether and how the government recycles the money raised from the tax.

In contrast to the CGE results, some IAMs suggest that the output costs of a carbon tax could be large. For example, using an IAM, Fernando *et al.* (2021) examine the effects of carbon taxes set at a sufficiently high rate in each country to ensure net zero is achieved in all countries in 2050. They find that imposing such a tax results in large output costs varying from around 2 per cent of GDP in the G7 economies to around 8 per cent in OPEC countries and 10 per cent in Russia, relative to a baseline in which there is no tax. Importantly, the costs of the tax vary across sectors as well as across countries and, also, depend to a large degree on whether and how the government recycles the revenue raised from the tax.

In addition, the costs will depend on the extent to which different countries coordinate in setting carbon taxes. If one country imposes a carbon tax and their trading partners do not, then the country will suffer a competitive disadvantage. Domestic households will switch from relatively more expensive domestic production, which is subject to the tax, towards imports, which are not. Indeed, it could be argued that this has already happened as Western economies have reduced their carbon emissions by allowing high carbon emitting heavy manufacturing industry to migrate to developing economies. One way of dealing with this is the imposition of a carbon border adjustment (CBA), which taxes the carbon content of imports in line with the domestic tax. Arshad *et al.* (2022) examine the consequences of both a coordinated increase in carbon taxes across the world and a trade war resulting from a 'green club' of countries imposing a carbon tax on their domestic production as well as a CBA tax on imports. They find that a sudden and sharp coordinated rise in carbon prices from 2021 to 2025 of between \$130 and \$700 per tonne of CO_2 (depending on the country) leads to a fall in GDP growth of between 1 and 4 per cent in the first 2 years of the simulation. The effects of only a subset of countries imposing the carbon tax depend heavily on the extent to which the 'non-green club' countries impose retaliatory tariffs on the 'green club' as well as how the governments within 'green club' countries use the revenues raised from the carbon tax.

The long-run effects of a carbon tax will depend on the extent to which it encourages substitution to low-carbon technology and whether this switch has spillover effects that lead to faster technical change across the whole economy. Acemoglu *et al.* (2012) show in an endogenous growth model that a carbon tax (i.e. a tax on 'dirty' inputs or equivalently the flow of carbon emissions) can be used to redirect technical change and that such a tax, if combined with research subsidies and as long as the 'dirty' and 'clean' inputs are sufficiently substitutable, can achieve environmental goals without sacrificing much if any long-run growth.

Given the assumptions necessary for the modelling approach, it can be argued that a purely empirical approach might be a better way of assessing the effects of a carbon tax. Metcalf and Stock (2020) suggest that there are plenty of data from countries and regions that have implemented carbon taxes that could be used to do this. In their paper, they use data from 31 European countries and find essentially no evidence that carbon taxes have had a negative effect on GDP growth or employment. Dechezleprêtre *et al.* (2014) found that knowledge spillovers—measured by patent citations—are significantly greater for 'clean' technologies than for 'dirty' technologies and that 'clean' patents tend to be cited by more prominent patents. This provides some empirical support for the Acemoglu *et al.* (2012) results.

2.3. Cap-and-trade

While keeping to the 'market-based' approach, instead of setting the price of carbon emissions via a carbon tax, governments can instead set the quantity of carbon emissions. In a 'Cap and trade' scheme the government sets the maximum quantity of emissions and allows the market to find the price. The EU ETS is the world's first and largest multilateral cap-and-trade system for emissions, setting a cap on total emissions by the installations covered by the system, with the cap being reduced over time.[6] The installations themselves buy, receive and trade emission allowances with each other.

[6]The idea was to set the initial cap at a level slightly below total emissions in the European Union at the time the cap was introduced. However, in the absence of reliable emissions data, the cap was set based on estimates. As a result, the total amount

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The effects on output of such a scheme are likely to be similar to those of a carbon tax. Känzig (2022) finds that higher carbon prices in the EU ETS led to a temporary but substantial fall in economic activity while Känzig and Konradt (2023) find that the economic costs of the EU ETS are larger than those of carbon taxes. Against this, however, there is likely to be a positive effect over time on innovation in green technology. Indeed, Calel and Dechezleprêtre (2016) found evidence that the ETS has increased low-carbon innovation among regulated firms by as much as 10 per cent.

3. Transition risks from investment

The transition to a net-zero carbon economy will require near-full electrification of economic activities and a move from using high carbon-emitting capital to low or zero carbon-emitting (green) capital. In turn, this will require large amounts of investment. For example, the UK government (HM Treasury, 2021) calculates that to achieve their net zero ambition, additional investment needs to reach around £50–60 billion per year in the late 2030s, equivalent to a total additional investment amount of around £660–791 billion to the end of 2037. In this section, I consider the effects on the macroeconomy that are likely to arise from this large increase in investment.

Increased investment, in and of itself, should have positive effects on output. And this is particularly important in the United Kingdom, where business investment has been low relative to similar countries for many years. To the extent that low business investment has been one of the causes of low UK productivity growth, we might expect that the increase in investment resulting from the need to 'green' the economy will help to bring us back to more reasonable rates of productivity growth. Of course, as discussed above, in the short run it may be that the investment will be in technology that is relatively inefficient compared with existing technologies based on fossil fuel usage, in which case it will take a while for any increase in productivity growth to appear.

From the point of view of monetary policymakers, though, perhaps the key issue is what effect this investment might have on the natural rate of interest, r^*. Intuitively, we might expect r^* to rise, at least in the short run, as we need to reduce consumption today relative to the future to free up the funds required for investment. Against that, however, we might expect the return on existing capital, powered by fossil fuels, to fall as using such fuels becomes more costly (as a result of a tax or 'cap-and-trade' scheme). We also might expect a temporary slowdown in growth—which acts to reduce r^*—given the negative effects on output caused by the increased cost of inputs discussed above. Which of these effects outweighs the other will depend on how fast the carbon-emitting capital becomes obsolete, how negative are the output effects in the short and medium run, and how fast the new investment can be put in place. It also depends on the extent to which changes in the relationship between investment and savings in the United Kingdom can affect the global real interest rate. For a small open economy, r^* will depend on the relationship between investment and savings at the global level. Of course, if all (or at least most) countries are moving towards net zero, then the effects described above will carry through into r^* at a global level.

In the long run, the effect on global r^* will depend on whether investment in green technology results in spillovers that affect the productivity of other sectors of the world economy. As argued above, there is some evidence for green investment leading to higher growth via spillovers. In this case, we would also expect to see a long-run rise in r^*. If growth were not higher in the long run, then neither would be r^*.

4. Conclusions

In this commentary, I have discussed the implications of climate change and the transition to net zero for the macroeconomy. I considered both physical risks and transition risks, as well as important policy

of allowances issued exceeded emissions and, with supply significantly exceeding demand, in 2007 the price of allowances fell to zero.

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questions around the effects of a carbon tax on GDP and the effects of investment in green technology on the natural rate of interest. I should note, though, that the area of climate and the macroeconomy is huge and, for reasons of space, there is much that I did not cover. In particular, I did not consider the issues of climate-induced migration and the possible conflicts and instability that could result. Nor did I consider the issue of biodiversity loss, which is linked to climate change and is likely to amplify its effects, for example, via threatening food chains and water systems.

I found that higher temperatures and more extreme weather events are likely to lead to lower, and more volatile, output. These results provide a strong incentive for governments to move as quickly as possible to net zero. That said, I also found that the transition itself is likely to negatively affect output, at least in the short run where it is hard for firms to switch out of using fossil fuels and into greener technologies. Looking over the medium to longer run, a large increase in investment in new green technologies could lead to higher output and possibly, depending on the degree of spillover from this investment to productivity in other sectors, to higher future output growth.

For this to happen in the United Kingdom, though, investment—both public and private—needs to start increasing, and sooner rather than later. So, maybe the key question for fiscal policymakers is how to finance the required public investment while ensuring that the public finances remain sustainable. One answer is to use the revenue raised via carbon taxes to finance the investment. Alternatively, they will need to raise taxes elsewhere or increase debt (with possible implications for fiscal sustainability) or both. Policymakers at the Bank of England need to consider the implications for financial stability of increased volatility, increased claims on the insurance industry and the possibility of 'stranded assets', as well as the effects of climate change and policy on growth and r^*.

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