Business Cycles and Environmental Policy: A Primer

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Executive Summary

We study the relationship between business cycles and the design and effects of environmental policies, particularly those with economy-wide significance like climate policies. First, we provide a brief review of the literature related to this topic, from initial explorations using real business-cycle models to New Keynesian extensions, open-economy variations, and issues of monetary policy and financial regulations. Next, we provide a list of the main findings that emerge from this literature that are potentially most relevant to policy makers, including the impacts of policy on volatility and how to design policy to adjust to cycles. Finally, we propose several important remaining research questions.

JEL Codes: Q58, E32

Keywords: fluctuations, climate change, real business cycles, dynamic stochastic general equilibrium, carbon tax, cap-and-trade

I. Introduction

Environmental economists have long strived to identify the "optimal" level of environmental regulation for many pollutants, including, in recent decades, greenhouse gases. This optimal balance between the economy and the environment is usually defined based on efficiency, considering both the marginal benefits and marginal costs of regulation. Optimal

Environmental and Energy Policy and the Economy, volume 3, 2022.

Published by The University of Chicago Press for the NBER. https://doi.org/10.1086/717222

pollution pricing has been one of the main activities of environmental economics as a field, an area where economists have been especially influential in shaping public policy (Hahn 1989; Fourcade, Ollion, and Algan 2015).

Importantly, the costs and benefits of environmental regulation, as well as their distribution, may vary over the course of business cycles. Pollution is highly procyclical and more volatile than gross domestic product (GDP; Doda 2014). For example, the United States generated 11% less greenhouse gas emissions between 2007 and 2013, largely due to the Great Recession (Feng et al. 2015). Recent evidence from the COVID-19 pandemic is even more striking, given the exceptional circumstances of its related recession. Daily global carbon dioxide (CO_2) emissions had already decreased on average by 17% by April 2020 since the beginning of the COVID-19 pandemic (Le Quéré et al. 2020), due to the responses by governments, individuals, and firms, which all contributed to limit economic activity following the outbreak. Overall, global CO_2 emissions decreased by about 7% from 2019 to 2020 (Le Quéré et al. 2021). Because pollution varies with the business cycle, it seems reasonable to conclude that pollution policy ought to adapt to the business cycle as well, following fluctuations in marginal costs and benefits.

Some real-world environmental policies do have automatic adjustment mechanisms that business cycles may trigger. The European Union Emissions Trading System (EU ETS) has created a Market Stability Reserve to insulate the system from allowance supply imbalances linked to business-cycle shocks (Perino et al. 2021). California and Quebec have auction reserve prices, and the Regional Greenhouse Gas Initiative has adopted an emissions containment reserve with price-triggered quantity adjustments. However, most real-world environmental policies—whether market-based policies such as taxes or cap-and-trade, or command-and-control policies—do not explicitly respond to business cycles and instead maintain a constant stringency over cycles. Several reasons may explain this phenomenon.

First, business-cycle adaptations may be seen as of second-order importance in environmental policy, whereas getting the stringency right on average is considered of first-order importance. Environmental policies may be on average too lenient, and fixing this may be seen as more important than making sure policies adjust to business cycles. When policies are too lenient, the economic rationale for adjusting their stringency to the business cycle may be weaker.[1] Many carbon tax proposals, for example, are designed with embedded tax escalators, which may allow them to reach, after several years, a level of stringency that is compatible with the goal of maintaining global temperatures within +1.5–2°C with respect to preindustrial levels (see Stiglitz et al. 2017; IMF 2019). In the meantime, tax rates remain below efficient levels, thus weakening the rationale for business-cycle adjustments. Cap-and-trade programs also struggle with excessive leniency, at least initially. Lacking full information about the costs of regulation, and concerned about price volatility, governments tend to err on the side of avoiding potential high-cost outcomes, and as a result consistently set caps too leniently (Burtraw and Keyes 2018).[2] The fact that allowance prices react endogenously to the business cycle can in principle be a benefit of cap-and-trade schemes.[3] However, evidence suggests that prices in CO_2 trading systems are likely to overreact, because the range of uncertainty over energy demand (and thus baseline emissions) tends to be much larger the range of feasible abatement opportunities, leading to large price swings or trading at administratively set boundaries (Borenstein et al. 2019). Information limitations and political biases can thus pose challenges to ensuring that the average level of stringency is appropriate, much less efficiently adapting to cycles.

A second reason why environmental policy does not adapt to business cycles is a political economy concern: the rationale could be abused by regulators, leading to a persistent weakening of environmental policy. One example is the decisions made by the Trump administration during the COVID-19 recession. By March 2020, the Environmental Protection Agency decided to exempt facilities that release toxic chemicals from reporting their emissions to the Toxic Release Inventory (TRI), which led to an increase in pollution around TRI facilities (Persico and Johnson 2021). Although the decision was motivated mostly by the inability of facilities to meet TRI requirements due to the direct effects of the COVID-19 pandemic, additional rollbacks referred explicitly to the recessionary forces generated by the pandemic.[4] These additional rollbacks often reduced stringency to virtually zero, which is hard to justify as a business-cycle adjustment. A case in point is the regulation of methane, where the federal administration in August 2020 eliminated requirements for oil and gas companies to monitor and repair methane leaks from pipelines, storage facilities, and wells. These requirements, known as Oil and Natural Gas New Source Performance Standards, were recently reinstated by the Biden administration.

A final reason is simply that the literature studying this issue is so recent that it has not yet been able to address the most pressing questions or has not yet been properly communicated to policy makers. The literature on business cycles and environmental policy effectively started just about a decade ago with Fischer and Springborn (2011) and is thus relatively recent.[5] The research has not yet addressed all dimensions of the problem nor all questions that policy makers may have about the implications of tying environmental policy to the business cycle, including distributional effects.

Our goal in this paper is threefold. First, we review the literature on environmental policy and the business cycle, with the goal of summarizing and conveying in a palatable way the economic rationale for business-cycle adjustments to environmental policy, as well as the effects of policy on economic volatility. In this respect, our paper updates early synthesis papers, including Fischer and Heutel (2013). Second, we present an assessment of the main results from this literature that are most relevant for policy makers today. This includes how different types of policy can lead to different volatilities of outcomes, and how policy makers can adapt environmental policy to cycles, ideally ex ante, tying their hands to limit the risk of business-cycle adjustments being abused. Third, we identify areas for future research that have currently been underexplored, with the goal of filling the current knowledge gaps that may contribute to limiting the adoption of business-cycle adjustments in environmental policy. Our general focus is on the climate externality, due to its importance in the current policy landscape, although many of our insights may also carry important implications for other environmental issues. We discuss the importance of considering other pollutants as well, particularly given the fact that greenhouse gases are long-lived stock pollutants, whereas other pollutants such as particulate matter are flow pollutants for which cyclical fluctuations in emissions likely have a larger effect on damages.

We present four main sets of policy-relevant findings from the literature, described in detail in Section IV. First, we discuss how different policies can influence the volatility of outcomes over the business cycle, even when those policies themselves do not vary over the cycle. A main finding here is that policy type matters—a quantity-based instrument such as cap-and-trade leads to overall less volatility, whereas a price-based policy such as a carbon tax leads to more volatility. Second, policy can be designed to vary over the business cycle and these adjustments affect the economy and welfare. Both the dynamically efficient carbon tax rate and the dynamically efficient carbon cap are procyclical—increasing during expansions and decreasing during recessions. However, the magnitude of the welfare advantages of these dynamically efficient policies over static policies remains unclear. Third, policy implications vary depending on the source of the business cycle; that is, the type of shock triggering the business-cycle fluctuation. Almost all of the modeling literature consider aggregate productivity shocks, although some empirical literature suggests that other shocks may contribute more to emissions fluctuations. Productivity shocks may also be sector specific. When productivity shocks are specific to energy-intensive polluting sectors, a tax may have a welfare advantage over a cap, though yielding higher volatility. Fourth and finally, we discuss how environmental policy interacts with other policies or other distortions over the business cycle. Other policies, including monetary policy, and other distortions, including labor market frictions, can affect the efficient cyclicality of policy or its effects on volatility.

The remainder of this paper is organized as follows. Section II describes the basics of the environmental dynamic stochastic general equilibrium (E-DSGE) model, the main toolbox to study business cycles in macroeconomics and their relationship to the environment. Section III very briefly summarizes the most important extensions to the basic E-DSGE models, and the companion working paper provides a more thorough literature review (see Annicchiarico et al. 2021). Section IV summarizes what we see as the main findings of the literature most relevant to policy makers. Section V discusses the most promising and most urgent avenues for future research.

II. Description of Basic E-DSGE Model

In this section, we describe the basic DSGE model used in the literature examining environmental policy and business cycles. DSGE models have been frequently used in the literature for decades to study business cycles (Christiano, Eichenbaum, and Trabandt 2018). Models that extend the basic DSGE model to include some aspects of the environment have been called environmental DSGE, or E-DSGE, models (Khan et al. 2019). The workhorse model is based on the real business cycle (RBC) model, where business cycles are fueled by random autocorrelated productivity shocks (Rebelo 2005). Fischer and Springborn (2011), Heutel (2012), and Angelopoulos, Economides, and Philippopoulos (2013) are three early papers that modify the standard RBC model by including pollution and pollution policy. Briefly, the model consists of an aggregate representative agent choosing consumption, labor, and investment to maximize total discounted utility. Capital evolves dynamically based on investment. Pollution arises from production and can negatively affect productivity or utility, but the agent's choices can affect the level of pollution. Given a series of exogenous shocks to productivity, the model can be used to find the efficient level of investment and pollution that maximizes total discounted utility. The model can also analyze pollution policies, such as pollution taxes or cap-and-trade.

We first describe a centralized model, where a representative agent acts the same as a social planner would act. The representative agent chooses consumption c_t, investment i_t, and leisure l_t in each period t to maximize expected discounted lifetime utility. The single-period utility function is $U_t(c_t, l_t)$. The resource constraint is $c_t + i_t = y_t$, where y_t is the level of output or production. A capital stock evolves according to $k_{t+1} = i_t + (1 - \delta)k_t$. Time is normalized to one each period and allocated between labor (n_t) and leisure: $l_t + n_t = 1$. Production is based on the labor and capital inputs along with a productivity shock: $y_t = a_t f(k_t, n_t)$. The productivity shock a_t is exogenous and evolves according to an autoregressive process.

So far, the model described is the standard RBC model. At this point, the model can be modified to include pollution and pollution policy, and there is more than one way to do so. As in Fischer and Springborn (2011), and as is commonly done in computable general equilibrium models, one would modify the production function to also include a polluting input m_t, so that output is $y_t = a_t f(k_t, n_t, m_t)$. The polluting input is costly, so the resource constraint becomes $c_t + i_t + m_t = y_t$. The polluting input is a choice variable and so can be changed in response to economic conditions or policies (described below). An alternative way of modeling pollution, following Heutel (2012) based on the representation in the Dynamic Integrated Climate-Economy (DICE) model (see Nordhaus 1993, 2017), is to let pollution emissions e_t be a byproduct of production that can be reduced through abatement spending z_t. Emissions are $e_t = g(z_t)h(y_t)$, where the increasing function h maps how output creates emissions, holding abatement z_t fixed, and the decreasing function g maps how abatement spending reduces emissions, holding output y_t fixed. The resource constraint under this specification of pollution is $c_t + i_t + z_t = y_t$.

The relationship between emissions in one period e_t and the total stock of pollution x_t can be given by a stock evolution equation. For example, in Heutel (2012), the pollution stock evolves according to $x_{t+1} = \eta x_t + e_t + e_t^{\text{exog}}$, where η is a pollution depreciation rate and e_t^{exog} is the exogenous level of emissions from other economies (e.g., for a global pollutant such as carbon dioxide, this represents emissions from other countries). Another way of incorporating the stock of pollution is done in

Angelopoulos et al. (2013), where the stock variable Q_t represents environmental quality (a good) rather than the pollution stock (a bad). The evolution of environmental quality is $Q_{t+1} = (1 - \delta^q)\underline{Q} + \delta^q Q_t - e_t + \nu z_t$, where $\underline{Q}$ is environmental quality without any pollution and δ^q is a pollution persistence parameter. Emissions e_t negatively affects environmental quality, and abatement spending z_t positively affects environmental quality measured by the parameter ν.

We next describe how damages from pollution can be incorporated into the model. There are two places where pollution damages can enter: Pollution can either negatively affect utility directly, or it can indirectly affect utility by negatively affecting output or productivity. Under the first specification, following Angelopoulos et al. (2013), we can modify the utility function to include the level of environmental quality Q_t: $U_t(c_t, l_t, Q_t)$. Under the second specification, following Heutel (2012), we can modify the production function to include the level of the pollution stock x_t: $y_t = (1 - d(x_t))a_t f(k_t, n_t)$, where d is a damage function that relates the level of the pollution stock to a reduction in output. Several integrated assessment models of climate change, including the DICE model (Nordhaus 1993, 2017, 2018), model carbon pollution as affecting output rather than utility directly.

The centralized model is now complete, and the model can be solved as a social planner's problem, where the damages from pollution are incorporated into the decision-making process. A social planner trades off the benefits of reducing emissions (reducing pollution damages) with its costs (abatement costs). The solution represents the first-best response of all economic variables to exogenous productivity shocks. Solutions can be presented as impulse response functions, which show how all of the variables optimally respond to a one-unit innovation in the productivity shock. Or, solutions can be presented as simulations of business cycles, in which an exogenous series of productivity shocks are drawn and the economy is allowed to optimally respond. Figures 1 and 2 present results from the first-best dynamic policy simulations, based on the model in Heutel (2012), showing impulse response functions and business-cycle simulations, respectively.[6] The model used here is identical to that used in Heutel (2012), though the calibration is updated based on Gibson and Heutel (2020).[7]

Figure 1 shows impulse response functions for the productivity shock (after a one-time innovation in period 0) along with three variables related to the environment: single-period emissions e_t, the pollution stock x_t, and abatement spending z_t. The continuous line shows that the productivity

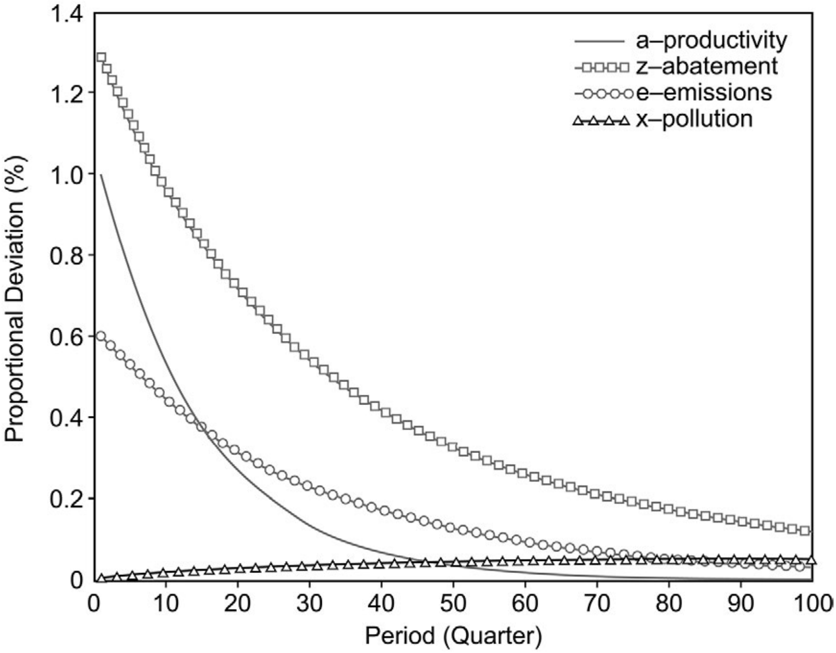

Fig. 1. Impulse response functions—centralized efficient model. Color version available as an online enhancement.

Notes: The productivity shock *a* increases exogenously in period 0, and all other variables respond endogenously. The *y*-axis units are the percentage deviation from each variable's steady-state value. The simulations are from the E-DSGE model in Heutel (2012) with updated calibration as described in the text.

shock value decays exogenously at a constant rate. In response to that productivity increase, emissions are higher than their steady-state value. During an economic boom, when output increases (not shown in fig. 1), emissions also are allowed to increase. However, figure 1 also shows that abatement spending increases above its steady-state value. Although emissions are increasing during the boom, they are not increasing by as much as they otherwise would if it were not for the efficient response of the economy in increasing abatement spending. The optimal cyclicality of emissions is thus procyclical but less so than they would be absent the dynamically optimal policy.

Figure 2 shows business-cycle simulations for the centralized model without policy, drawn from an arbitrary draw of productivity shocks. Capital is procyclical but less volatile and somewhat lagged from output due to its stock nature. Emissions are strongly procyclical, though not quite as variable as output is. The pollution stock has such a slow decay

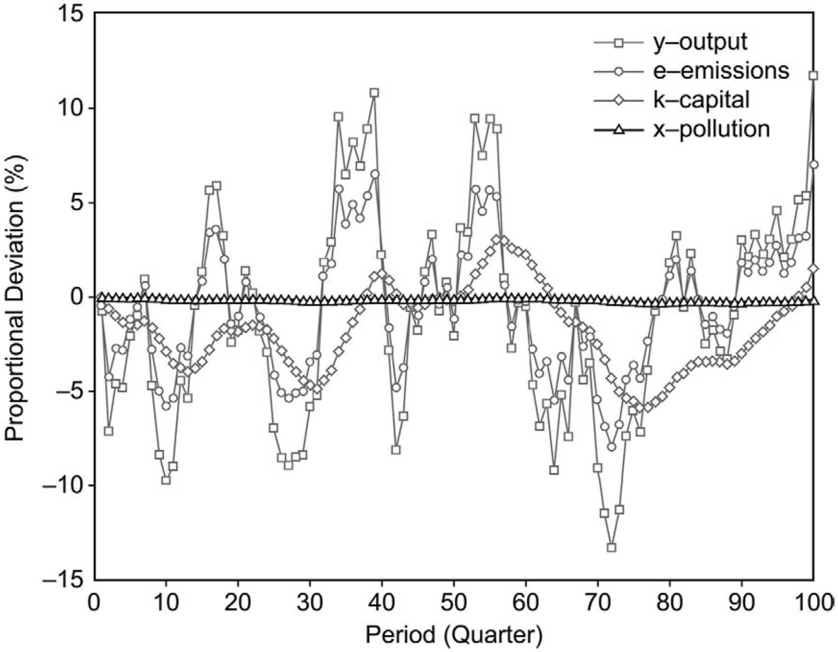

Fig. 2. Business-cycle simulation—centralized efficient model. Color version available as an online enhancement.

Notes: Productivity shocks (not graphed here) are exogenously generated, and all other variables respond endogenously. The *y*-axis units are the percentage deviation from each variable's steady-state value. The simulations are from the E-DSGE model in Heutel (2012) with updated calibration as described in the text.

rate that these business-cycle fluctuations have very limited impact on its value (pollution here is calibrated to carbon dioxide, a stock pollutant that remains in the atmosphere for decades).

Next, we turn to a decentralized model, in which a representative firm maximizes profits and a representative consumer maximizes utility. By assuming that the firm ignores the effect that its pollution has on either productivity or utility, the decentralized model features an externality, so that the decentralized solution will generally not be first best. Either the consumer or the firm can be subject to an environmental policy; for example, a tax on emissions.

The model can also be used to analyze the effect of these policies on various economic outcomes. Fischer and Springborn (2011) analyze the effect of three environmental policies: an emissions tax, an emissions cap, and an intensity standard that fixes the ratio of emissions to output. They generate business-cycle simulations and show how various economic variables respond to the draw of productivity shocks under each of the three policies. We replicate these simulations here in figure 3. In response to an exogenous draw of productivity shocks (identical to the draw in fig. 2), figure 3 plots the response of emissions (panel A) and output (panel B) under each of the three policies: the intensity standard (IT), the emissions cap (Cap), and the emissions tax (Tax).

The three policies are all calibrated to yield the efficient first-best level in steady state, but the policy values do not adjust to the business cycle. Consequently, the three policies yield different cyclical properties. Of course, because the cap is fixed over time, it results in emissions fixed at their steady-state level, whereas the tax and intensity standard result in emissions that vary over the business cycle. Output is slightly less volatile under the cap policy than under the other two policies. This demonstrates that the intensity standard is more accommodating of business cycles due to its flexibility—by restricting emissions per unit output rather than total emissions, it includes a built-in cyclical adaptation.

The decentralized model can also be used to solve for the efficient level of the policy variables that internalizes the pollution externality and reaches the theoretical first best. Such an exercise is performed in Heutel (2012), which includes a specification of external damages from pollution affecting productivity, though unlike Fischer and Springborn (2011) it does not include a labor decision or an intensity standard policy. Results from business-cycle simulations of efficient policy are presented here in figure 4. For the same draw of shocks simulated in figures 2 and 3, figure 4 shows the efficient response of both a tax policy and an emissions cap. Here, the policy values endogenously respond to the draw of the shocks and the changing economy and thus are not fixed over time as in figure 3. Figure 4 shows that both the emissions cap and the emissions tax are procyclical. However, that means the cyclicality of the stringency of each policy is different. During an expansion, the efficient emissions tax increases, which is an increase in stringency, and the efficient emissions cap also increases, which is a decrease in stringency. As also can be seen from figure 4, the efficient emissions tax is more procyclical than the efficient emissions cap.

III. Extensions to the Basic Model

In the more technical working paper (Annicchiarico et al. 2021), we provide an extensive literature review of the state of the E-DSGE literature. Here, we briefly summarize the four broad areas where extensions have

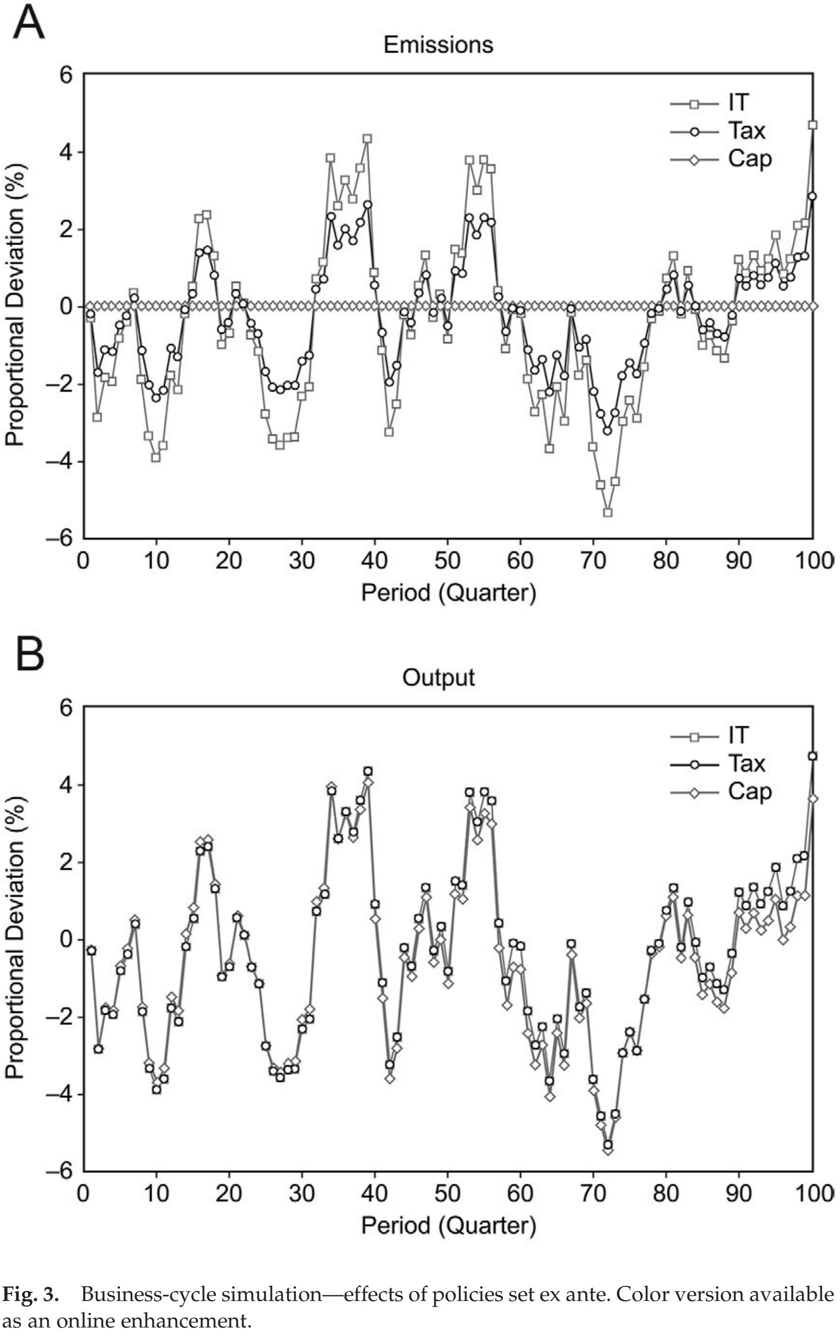

Fig. 3. Business-cycle simulation—effects of policies set ex ante. Color version available as an online enhancement.

Notes: Productivity shocks (not graphed here, identical to those in fig. 2) are exogenously generated, and all other variables respond endogenously. The top panel plots emissions, and the bottom panel plots output, both in percentage deviation from each variable's steady-state value. IT, Cap, and Tax denote the intensity standard, the emissions cap, and the emissions tax, respectively.

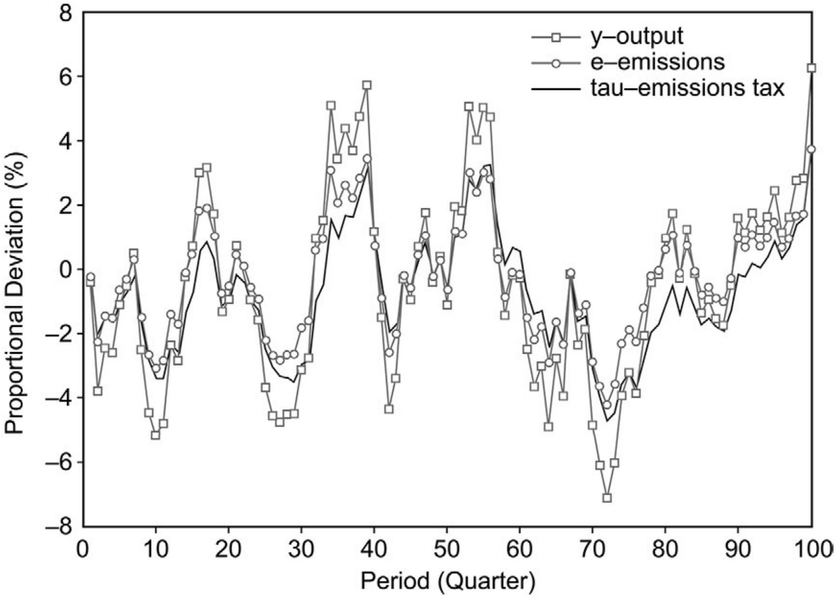

Fig. 4. Business-cycle simulations—efficient policy. Color version available as an online enhancement.

Notes: Productivity shocks (not graphed here, identical to those in fig. 2) are exogenously generated, and all other variables respond endogenously. The y-axis units are the percentage deviation from each variable's steady-state value. The simulations are from the E-DSGE model in Heutel (2012) with updated calibration as described in the text.

been made in the literature: (i) extensions that maintain the RBC framework, (ii) New Keynesian extensions, (iii) open-economy extensions, and (iv) extensions incorporating credit market imperfections, financial regulation, and unconventional monetary policy. Although the details of the individual studies are relegated to the working paper, the results of these extensions will inform our discussion in the following section of the most policy-relevant findings that we identified in the literature.

Several studies maintain the RBC framework of cycles produced through autocorrelated productivity shocks but add more complications. One such study (Dissou and Karnizova 2016) develops a multisector economy, where shocks can be sector specific, including shocks arising to emissions-intensive industries such as the fossil fuel sector. Other papers consider different types of productivity shocks, including anticipated versus unanticipated shocks and investment-specific shocks (Khan et al. 2019), or frictions arising from other sources such as the labor market (Gibson and Heutel 2020). These variations influence the interactions between business cycle and emissions volatility.

The second set of extensions includes New Keynesian (NK) elements. The heart of the NK framework includes imperfect competition, nominal rigidities, and nonneutral monetary policy. For instance, Annicchiarico and Di Dio (2015) modify the E-DSGE model to include imperfect price adjustments and an interest-rate rule governing monetary policy. They explore how the optimal design of the carbon tax (including its cyclicality) depends on the degree of price stickiness and on monetary policy. Several other extensions in this vein explore related issues under alternative modeling assumptions. For example, Economides and Xepapadeas (2018) study the challenges climate change poses to monetary policy and the potential inflationary effects of carbon pricing, which are among the main concerns for central banks (NGFS 2021).

The third variant of the literature uses open-economy versions of E-DSGE models to look at cross-country pollution and policy spillovers and international environmental agreements. Several of these papers also incorporate some elements of the NK approach, including nominal rigidities and imperfect competition. For example, Annicchiarico and Diluiso (2019) develop a two-country model to explore how real and monetary policy shocks propagate across borders, and how this propagation is influenced by environmental regulation.

Finally, the fourth set of extensions considers credit market imperfections, financial regulation, and unconventional monetary policy. This strand of the literature is motivated by the concerns that climate-related risks may represent a threat to financial and macroeconomic stability. A debate exists about whether and to what extent financial regulators can or should address climate change; for example, by creating new tools like green-biased regulations to encourage the transition to a low-carbon economy. A related concern is that of the transition risk that arises from an abrupt implementation of ambitious climate policy in an economy where leveraged banks have a large stake in affected industries and assets like those related to fossil fuels and other carbon-intensive industries. In this case, climate policy could create stranded assets, which may trigger financial instability risks. Several recent studies explore these and other related issues. Two concurrent studies in this literature are by Diluiso et al. (2020) and Carattini, Heutel, and Melkadze (2021), which combine a multisector E-DSGE model with a model of financial frictions and study how unconventional monetary policy such as green quantitative easing (in Diluiso et al. 2020) or green-biased capital requirements (in

Carattini et al. 2021) can stabilize the economy in response to a potential crisis brought about by asset stranding in the context of a gradual (in Diluiso et al. 2020) or abrupt (in Carattini et al. 2021) implementation of ambitious climate policy.

IV. Policy-Relevant Findings from the Literature

In this section, we provide a brief overview of the main findings from the literature that are most relevant to policy makers, who may seek either to design policies to accommodate business cycles or to assess the impacts of business cycles on policy effectiveness or pollution. The first two subsections describe positive findings from the literature about the effect of policy on economic volatility and the design of policy over the business cycle. The last two subsections discuss caveats to these findings, pointing out that the source of fluctuations matters and that other macroeconomic market failures or distortions interact with environmental policy.

A. Policy Effects on Volatility

Emissions are a byproduct of production and are thus naturally procyclical. Empirical evidence suggests that emissions are even more volatile than GDP, indicating they arise from sectors more vulnerable to business-cycle variations (Doda 2014). The flip side of this relationship is that policies to control emissions will also influence the response of other macroeconomic factors to exogenous shocks.

A cap on emissions has a built-in dampening effect on the business cycle. A positive productivity shock will expand output and demand for emissions, but the cap will require further efforts to limit polluting inputs or abate emissions, manifesting in an increase in the emissions price. With a negative productivity shock, the cap becomes less constraining; emissions prices fall with demand, and less abatement effort is required in a downturn. Because one means of reducing emissions is reducing output, less of this output-related abatement is needed in a downturn. As a result, an emissions cap limits volatility of other macroeconomic variables. This effect becomes even more pronounced when prices are more difficult to adjust, because these rigidities tend to exacerbate business cycles (Annicchiarico and Di Dio 2015). However, the stabilizing properties of a cap are mitigated when wages are sticky, because the effects of uncertainty on employment are greater (Jaimes 2020). In contrast, the procyclical response of emissions prices under cap-and-trade system could exacerbate inflation volatility, so monetary policy interactions matter too (Annicchiarico and Di Dio 2017).

An emissions tax, by contrast, fixes the price of emissions and allows the quantity of emissions to respond. Investment and production decisions take the emissions price into account, but a positive productivity shock will cause output and emissions to expand. A tax does little to deter this response to the business cycle, and may even exacerbate volatility by making investment more sensitive to productivity shocks (Fischer and Springborn 2011). A carbon tax is also likely to allow greater transmission of business cycles across borders (Annicchiarico and Diluiso 2019).

An emissions intensity standard—fixing emissions per unit of output—offers a road in between a tax or a cap. A positive productivity shock increases demand for emissions, but an increase in output also loosens the emissions constraint, which is set per unit of output. As a result, the emissions price rises, but to a lesser extent than with a fixed cap. The output-based allocation of emission allowances implicit in intensity targets also provides a general incentive boost to output, leading to higher levels of investment and output than a cap or tax. However, in terms of volatility, an intensity target does little to change how the macroeconomy responds to business cycles, compared with no policy (Fischer and Springborn 2011).

The above comparisons are largely based on stark policy choices. In practice, many emissions trading systems adopt provisions with banking and borrowing that will allow emissions price responses to macroeconomic shocks to be spread over time (e.g., Kollenberg and Taschini 2019). Recognizing that the economy is composed of many sectors with different emissions intensities, the influence of climate policy on macroeconomic volatility may depend on the source of business-cycle variation. For example, shocks related to the energy sector are more likely to interact with climate policies than other productivity shocks (Dissou and Karnizova 2016).

Besides the pollution policies discussed above, macroprudential financial regulations, designed to align environmental and financial stability objectives, are also shown to influence the transmission of the business cycle. Green-biased regulations may bring down the volatility of business-cycle fluctuations, while favoring green investments and reducing the exposure of financial intermediaries to assets at risk of stranding (Punzi 2019; Benmir and Roman 2020; Diluiso et al. 2020; Carattini et al. 2021).

B. *Dynamically Optimal Policies and Welfare*

Allowing policy variables to vary along with the business cycle gives more flexibility for the policy to address market imperfections and improve welfare. Some policies, such as unemployment insurance, are clearly designed so that their intensity or stringency responds to business cycles. For an environmental policy such as a pollution tax or cap-and-trade system, the goal would be to design it so that the stringency of the policy (the tax rate, or the level of the cap) can vary in ways that keep emissions prices better aligned with marginal environmental damages over the business cycle. However, in practice, for adaptive policies to do more good than harm relative to fixed policies, not only must the adjustments be well targeted but the efficiency advantages from the policy's variance over the cycle must also outweigh any costs that might be incurred by allowing it to vary. These costs could include administrative costs of the cyclical adjustments, costs arising from households' or firms' uncertainties about policy values, increased trading frictions or transaction costs, or even higher political economy barriers to implementation. We return below to the question of how policy makers can introduce simple rules requiring limited information to mimic "optimal" cyclical adjustments.

Designing a policy such as a tax so that its values in each period efficiently respond to business-cycle conditions is often called the Ramsey problem (Chari, Christiano, and Kehoe 1994). Heutel (2012) solves the Ramsey problem for both an emissions tax and cap-and-trade system, calibrated to the US economy and carbon dioxide emissions. As we showed in figure 4 (using an updated calibration of that earlier model), both the Ramsey-optimal carbon tax and the Ramsey-optimal carbon emissions cap are procyclical, increasing during expansions and decreasing during recessions. This implies that a carbon tax becomes more stringent during expansions and less stringent during recessions, whereas a cap-and-trade system becomes less stringent during expansions and more stringent during recessions.[8] This pattern may provide a political economy advantage for taxes over cap-and-trade, given that tax relief can be communicated to the public during recessions, rather than a cap adjustment that would increase prices. However, under this calibration the Ramsey-optimal carbon tax is more volatile than the Ramsey-optimal cap, which may be a disadvantage of it.[9]

To consider specifically how to design policy to adjust to the business cycle, Heutel (2012) provides something close to "rules-of-thumb" based on GDP. Ideally, as mentioned in our introductory paragraphs, business-cycle adjustments should be a policy feature that is introduced from the start and operates according to a clear and transparent rule. Rules-based adjustments would allow timely responses, avoiding the delay of passing new legislation or promulgating amendments to regulations. They also would tie the hands of policy makers and avoid arbitrary decisions once a shock materializes. If the regulator can set the policy stringency as a function of lagged GDP (or its deviation from trend), then what is the function mapping GDP into the efficient policy? Heutel (2012) finds that the efficient carbon tax rate increases by about 142% of the deviation of output; for example, if output is 10% higher than trend in a particular quarter, then the efficient carbon tax rate is 14.2% higher than trend in the following quarter. For the efficient emissions cap, the response is 66% of the deviation of output; if output is 10% higher than trend in a particular quarter, then the efficient carbon cap is 6.6% higher than trend in the following quarter.[10] In addition to or instead of GDP, regulators may use leading indicators to forecast shocks. In the United States, for instance, prominent leading indicators are the Purchasing Managers Index and the Consumer Confidence Index.[11]

How important are the business-cycle adjustments for welfare? Lintunen and Vilmi (2013) compare the Ramsey-optimal emissions tax with a constant tax (they do not consider cap-and-trade) and find slight differences in emissions but negligible overall economic effects. Heutel (2012) notes that the welfare comparison can depend on the shock values (see following subsection). Both papers are calibrated to greenhouse gas pollutants for which the accumulated stock matters rather than the flow of emissions in any period. For flow pollutants, business-cycle policy adjustments may have larger welfare impacts than for stock pollutants, as we discuss in Subsection V.D. Likewise, the question of whether a tax or a cap is more efficient in response to business cycles can also depend on shock values, and the answer may differ for stock versus flow pollutants.

C. Source of Shocks

Most of the papers that we have reviewed here use an RBC model, where cycles are fueled by exogenous shocks to aggregate productivity. Whether or not productivity shocks are in fact a predominant driver of real-world business cycles is a question up for debate in the broader macroeconomic literature.[12] More specifically, two recent papers investigate the source of emissions fluctuations over the business cycle, and both find that other types of shocks besides productivity shocks—such as shocks to energy efficiency, specific technologies, or nonenvironmental policies—are important drivers.

Khan et al. (2019) empirically study the drivers of emissions variation in the United States, including monetary and government spending shocks as additional sources of uncertainty. They consider six different shocks—anticipated and unanticipated neutral technology (TFP) shocks, anticipated and unanticipated investment-specific technology shocks, government spending policy shocks, and monetary policy shocks—and find empirically that the largest impact on pollution among these shocks comes from the anticipated investment-specific technology shock. Jo and Karnizova (2021) provide a similar analysis, including shocks to energy efficiency that can cause a negative correlation between output and emissions. Jo and Karnizova (2021) identify shocks that can cause emissions and output to be negatively rather than positively correlated with each other, and they find that these types of shocks explain almost half of the overall volatility of emissions. They argue that shocks to energy efficiency are the primary example of these negative-correlation shocks. Because other types of shocks may have different implications for the relationship between business cycles and emissions and, as Jo and Karnizova (2021) suggest, some shocks cause emissions and output to move in opposite directions, then it is likely that the optimal response of policy to these shocks is different than the optimal response to productivity shocks. Unfortunately, as of today, the literature has little to say about how policy can respond to these types of shocks, so more research is needed to shed light on this question.

In the context of E-DSGE models, some initial indication of the importance of the source of shocks is given by Dissou and Karnizova (2016), who study sector-specific productivity shocks. Their main finding is that under productivity shocks localized to energy sectors, a carbon tax outperforms a cap in welfare terms, although it leads to higher volatility of macroeconomic aggregates. However, for shocks to sectors other than energy-intensive sectors, a tax and a cap (even in the absence of intertemporal considerations such as banking) have statistically equivalent welfare implications. This result indicates that including flexibility mechanisms may be more important for quantity-based policies, especially when energy sector volatility is a primary issue.

D. Interaction with Other Policies or Distortions

Policies targeting pollutants that are widespread throughout the economy, such as carbon dioxide emissions, are likely to give rise to equally pervasive effects on macroeconomic responses to other policies and market distortions. Carbon prices and regulations influence a range of household and producer behavior, which may have nontrivial implications for the frequency and severity of business cycles.

Climate change is not the only policy issue of macroeconomic importance. Policy makers must grapple with market power and barriers to competition, frictions in labor markets that result in excess unemployment, regulations or behavioral practices that impede the adjustment of prices and wages, and financial market imperfections that may elevate the cost of borrowing and limit the amount of credit. The literature has pointed out that simultaneously addressing environmental issues and other market failures is particularly challenging in the presence of different sources of uncertainty. From this perspective, the literature on environmental policy and business cycles has drawn attention toward the interactions between environmental regulations and other policies, especially those aimed at stabilizing the economy over the business cycle, such as monetary policy, financial regulations, and labor market policies.

The underlying monetary policy affects optimal environmental policy design in response to exogenous shocks. Depending on the degree to which monetary policy reacts to the level of economic activity and stabilizes the economy, the optimal carbon price may be more or less procyclical, relative to what one would expect without monetary accommodation (see Annicchiarico and Di Dio 2015, 2017). The interaction also goes both ways: the stronger the negative environmental externality, the less accommodative—and so the more stringent—the optimal monetary policy should be to avoid excess expansion and emissions. In addition, an ambitious greening policy may produce large fluctuations in consumer prices. In this sense, unanticipated and abrupt climate actions may potentially represent a challenge for monetary stability (e.g., Economides and Xepapadeas 2018; Carattini et al. 2021).

Some unconventional monetary policies aim at changing the composition of central banks' balance sheets toward green assets. Early studies on the effects of such green-biased quantitative easing programs point to a very limited scope of these policies in greening the economy, as well as little difference in their effectiveness in reviving the economy following an adverse shock as compared with market-neutral quantitative easing programs (see Benmir and Roman 2020; Diluiso et al. 2020; and Ferrari and Nispi Landi 2020). However, emerging analyses of the effects of the introduction of nonneutral financial regulatory schemes, such as green-supporting and/or brown-penalizing regulations (see

D'Orazio and Popoyan 2019), suggest that by inducing a portfolio reallocation of financial intermediaries toward green investments, these schemes encourage the greening process and reduce the exposure of banks to climate-sensitive assets, mitigating the financial effects of stranded assets (see Punzi 2019; Benmir and Roman 2020; Diluiso et al. 2020; Carattini et al. 2021).

Finally, labor market frictions—such as the costs of searching for employment, relocating for a job, or finding suitable employees—also affect environmental policy over the business cycle. Such frictions are often represented as congestion problems: Adding an unemployed worker to the pool of job seekers reduces everyone else's probability of finding a job, but raises the probability for hiring firms of finding a good match. Similarly, more job vacancies make it harder for firms but easier for unemployed workers to find a match. Depending on how these balance out, the level of employment may be inefficiently high (too many vacancies) or low (too many job seekers). Economic efficiency then requires combining a pollution policy (e.g., carbon tax) with a labor market policy (e.g., a tax or subsidy on job creation), so as to jointly address the environmental externality and labor market imperfections. However, when the labor market instrument is unavailable, the optimal design of the emission tax is more challenging: The optimal carbon tax will be less or more procyclical depending on whether the market delivers an inefficiently high or low employment level. Gibson and Heutel (2020) find in their preferred calibration that the procyclicality of the efficient carbon tax is only half as high once labor market frictions are accounted for. The existence of labor frictions and unemployment would then provide a further rationale, based on equity as well as efficiency, for designing a state-contingent environmental policy.

V. Remaining Questions

A number of important questions related to environmental policies and business cycles remain to be addressed. In this section, we categorize some promising directions for future research.

A. Heterogeneous Agents and Distribution of Impacts

Over the recent decades, building on the work of Hopenhayn (1992) and Aiyagari (1994), DSGE models have gone beyond the representative firm and household assumptions to incorporate micro-level heterogeneity.

This incorporation has broadened the range of problems that can be studied in business-cycle analysis. The attention is no longer on the study of aggregate dynamics, but rather on the analysis of the evolution of the distribution of heterogeneous agents in response to aggregate and/or idiosyncratic shocks.[13]

On the production side, firms can differ in terms of size, efficiency, products, production processes, access to credit, and innovation ability. The entry and exit of heterogeneous firms shape the aggregate fluctuations in economic activity and the associated creation and destruction of jobs. Firms can also differ in their abatement capacity, can be more or less polluting, or can differ in their innovation in clean technologies. In this context, aggregate dynamics and the performance of pollution policies will also be influenced by composition effects, due to the reallocation of market shares among heterogeneous firms. The underlying environmental regulation is likely to affect firm dynamics and eventually aggregate productivity, GDP, and employment. In contrast, the changing composition of the production structure in response to shocks may affect policy effectiveness and optimal design.

Households, meanwhile, can differ in terms of age, wealth, skills, income, occupation, portfolio composition, access to credit, and expectations. All these dimensions matter for many of households' economic decisions and can be relevant for the propagation mechanisms of shocks and for the impact of policies falling in various domains. Incorporating heterogeneous households in an environmental business-cycle model may open up, for instance, questions about the impact of pollution policies on inequality and on wealth reallocation.

The literature to date has largely avoided issues of equity, but existing results have important implications for the two main observations that follow. First, the models demonstrate that efficient emissions are less procyclical than they would be in laissez-faire. The efficient level of climate policy's stringency (e.g., the carbon tax rate) is lower in recessions than in expansions. This conclusion, however, neglects the distributional implications of policy, including carbon tax revenues. Redistributing revenues in a lump-sum way, as "carbon dividends," would be progressive (Cronin, Fullerton, and Sexton 2018). The federal carbon tax of Canada, for instance, makes about 70% of Canadians financially better off, disproportionately improving the livelihood of low-income households (PBO 2019). It is not obvious, then, how reducing a carbon tax in times of recession, and thus the size of carbon dividends to households, would affect equity, especially when accounting for the fact that utility from dividends may decrease with income, so that a disproportionate impact on low-income households would disproportionally affect overall utility, even assuming a homogeneous effect of the recession on households. Such a research question could be addressed by introducing heterogeneous households (for instance, to reflect income distribution) and several ways of redistributing tax revenues or revenues from auctioning permits. Such ways may also include the possibility of shifting part of the dividends over time (i.e., from good times to bad times), although this solution would also need to be defined ex ante to avoid any arbitrariness and ensure that citizens' trust in the government is not eroded.

Second, the efficient level of regulation, which accounts for the business cycle, implies both lower emissions and lower employment than the unregulated equilibrium (Gibson and Heutel 2020). If labor market frictions imply that vacancies are too high, then the environmental policy creates an additional efficiency benefit by reducing the labor market distortion. However, accounting for distributional effects on who is employed and who is not in a recession may lead to different policy implications, in particular if low-income households, which derive a higher utility from their salaries, would be more affected by layoffs driven by recessionary forces. The standard framework could thus be extended to include distributional effects in job creation and destruction, as well as interactions with other policies, including policies aimed at fostering economic recovery (e.g., stimulus packages) or redirecting the economy toward cleaner production modes (e.g., Green New Deal). Also in this case, part of the revenues could be banked during good times to fund Green New Deals in bad times, with the abovementioned condition about embedding such mechanism in the design of the policy since the outset to avoid arbitrariness still applying.

B. Interaction between Environmental and Other Public Policies

Environmental policies are not the only ones that respond to market changes over the business cycle. Many topics related to the interaction between environmental and other policies remain either unexplored or still in early stages. Prime targets for further research on environmental policy interactions are fiscal policy, trade policy, monetary policy, and financial regulation.

Fiscal policy leads that list because tax policies and government spending tend to be countercyclical themselves (at least at the federal level in the United States). Furthermore, environmental priorities are increasingly being incorporated into fiscal responses. At present, many postpandemic recovery plans around the world include green stimulus packages to both restart the economy and favor transition to a cleaner and more sustainable path, including the Recovery Plan for Europe, the American Rescue Plan, and the proposed American Jobs Plan. Such fiscal responses are likely to influence the optimal adjustment of stringency of carbon pricing regulations, for example. These issues could be addressed by modeling the public sector in more detail, accounting for the composition of public spending (capital spending and current spending) and for different tax instruments.[14]

Trade policy can be intertwined with climate policy, with important business-cycle implications. The most obvious example is represented by carbon border adjustments, which are currently receiving serious consideration from the European Commission in the context of the Green Deal, at least for trialing in selected sectors covered by the EU ETS. Besides the direct effects that the introduction of such a policy may have on border prices and trade flows, one may expect it to have an influence on the international propagation of the business cycle. The study of this issue requires the use of fully fledged open-economy models in which countries are interlinked with each other and where the different steps of the production process are located across different countries. Furthermore, the fact that different countries may be on different points of the business cycle may or may not justify deviations from an equal carbon price for domestic and foreign production. The same logic would apply to a global carbon tax or system of harmonized carbon taxes, which have both attracted substantial attention in recent times by scholars (Hoel 1992; Thalmann 2013; Weitzman 2014; Nordhaus 2015; Cramton et al. 2017; Stiglitz et al. 2017; Weitzman 2017; Carattini, Kallbekken, and Orlov 2019; IMF 2019) and policy makers, with for instance the International Monetary Fund pushing for a minimum carbon price among large emitters covering about 80% of global greenhouse gas emissions. In this case, the reference price (and escalator) may include some room for idiosyncratic business-cycle adjustments, so that countries can adjust to the business cycle without leaving a carbon pricing coalition. Of course, it is also important in this case that the business-cycle argument is not abused by domestic or foreign vested interests.

Regarding the implications for monetary policy, future research should address the challenges posed by physical and transition risks to different monetary policy regimes and study how different carbon pricing policies are likely to affect inflation dynamics. Central banks and financial regulatory authorities are increasingly interested in climate-related issues (e.g., Carney 2015; Vermeulen et al. 2018; Rudebusch 2021). The debate revolves around the need to enrich their mandate by opening the door to climate challenges in the conduct of monetary policy and in the design of the financial regulatory framework (see Campiglio et al. 2018; D'Orazio and Popoyan 2019). Hence, future research should also explore more in depth the possibility of incorporating climate objectives in the mandate of central banks. This would mainly imply giving up market neutrality in asset buying and would enlarge the area of activity of central banks and their tools.

Concerning financial regulation, the literature on climate-related financial system risks is still nascent; further studies could contribute to move the frontier further and shed additional light on how to design a macroprudential regulatory framework able to favor green investments, reduce climate-related financial risk, and possibly also preserve financial stability. Numerous green macroprudential tools have been proposed (e.g., brown-penalizing and green-supporting capital requirements, green-biased liquidity regulation, and differentiated reserves requirements), calling for further research investigating their potential ability to align environmental and financial objectives.

C. Suboptimal Policy Stringency and Nonpricing Policies

The E-DSGE literature tends to assume that environmental policy's stringency can be set to balance marginal costs and benefits in its steady state, from which it should fluctuate "optimally" in response to productivity shocks. As discussed in the introduction to this paper, important constraints can prevent environmental policies from reaching their optimal level, much less adjusting with the business cycle.

In the case of climate change in particular, although economists have yet to agree on the optimal level of carbon pricing—for instance, exactly how high the social cost of carbon is—a general consensus has formed that it should be well above current levels (Howard and Sylvan 2015). Carbon pricing remains the favorite policy tool of economists to tackle climate change (see, e.g., Goulder and Parry 2008; Aldy et al. 2010; Baranzini et al. 2017; Stiglitz et al. 2017). In the decade since 2010, when it covered about 5% of global greenhouse gas emissions, carbon pricing has expanded rapidly and currently covers about 22.5% of global greenhouse gas emissions; however, only for a few schemes do they exceed \$50 per ton of CO_2 (World Bank 2020).

Hence, an important question that the literature has arguably yet to tackle is whether, or to what extent, environmental policies that are set at a "suboptimally" low level of stringency should also adjust to the business cycle. In this context, three possible scenarios merit investigation: (1) a scenario in which the policy does not adjust to the business cycle, (2) a scenario in which the policy does adjust to the business cycle, and (3) a scenario in which the policy adjusts upward during economic booms but does not adjust downward during recessions. Furthermore, the uncertainty surrounding climate damages may call for more price certainty than would otherwise be the case. Business-cycle adjustments may also be embedded in a price trajectory that accounts for learning as in Bayesian models (Kelly and Kolstad 1999; Kelly and Tan 2015).

Additional attention should be paid to the design of environmental policies—particularly banking and borrowing provisions in cap-and-trade systems—and how they respond to business cycles. Pizer and Prest (2020) show in a micro model that when governments optimally adjust policies to shocks, quantity regulation with intertemporal allowance trading can have advantages over price regulation, due to the intertemporal transmission of expectations into prices. Lintunen and Kuusela (2018) incorporate such expectations into a business-cycle model, with a regulator that sets the periodic cap so that the number of banked allowances together with the new ones equals the desired cap level. Expected future permit prices create an effective floor for current prices, allowing the regulator room to increase the emission cap when needed to avoid the risk of undesirably high prices. The result of active allowance supply management is less volatile permit prices and less buildup of banked allowances in a downturn than without banking.

Pizer and Prest (2020) caution that if governments set policy inefficiently or firms imperfectly anticipate policy changes, taxes have advantages again. In this respect, Aldy and Armitage (2020) study how cap-and-trade systems lead to price uncertainty, because shocks can affect how a given cap is priced. When the investment in pollution abatement is irreversible, excessive volatility in the allowance prices can increase the effective cost of achieving a given mitigation target. In contrast, this price uncertainty can also have a dampening effect on irreversible investments in new capital goods. These issues should be explored in macro models. More generally, most of the literature to date has made stark policy comparisons between taxes and caps, but in practice many design features—such as free allocation, alternative compliance options, and international linking, as well as certain built-in adjustment mechanisms such as price floors, safety valves, and quantity-based triggers—are increasingly included and may have macroeconomic implications.

Another aspect of suboptimal policy design recognizes that a great number of environmental policies do not price carbon explicitly or even implicitly. Clean energy standards or market share mandates for renewable generation, biofuels, or zero-emission vehicles are common tools in transition policy portfolios. Although they may impose an implicit tax on sources that do not qualify as clean, they do not distinguish among the carbon intensity of nonqualifying sources. Similarly, mandatory phase-outs of coal-fired generation or internal combustion engine vehicles do not differentiate among the carbon profiles of nonprohibited sources. However, these types of target-based approaches do impose constraints on the economy, and the shadow values of those constraints will respond to business cycles. The Green New Deal proposal framework in the United States (H.R. 109, 116th Cong.), for instance, does not even mention carbon pricing. Incorporating nonpricing mechanisms—and especially multiple and overlapping ones—into macroeconomic models is challenging, but a worthy area for future research. Finally, the issue of enforcement or imperfect monitoring may be importantly related to business cycles. For example, as state revenues fluctuate, the resources devoted to enforcement may also fluctuate, and how optimal policy or optimal enforcement responds to those fluctuations remains to be explored. That is, it is possible that the cyclicality of enforcement affects the cyclicality of emissions, beyond what is usually considered in analyses of optimal tax rates or caps.

D. Non-GHG Pollutants

Most of the literature has focused on climate policy rather than policies for other environmental issues and pollutants. This view is understandable, because the broader environmental policy literature is increasingly focused on climate change and greenhouse gases (GHG). Hence, the focus of our paper is also mostly on climate change.

However, the relationship between business cycles and environmental policy may be equally or more important for non-GHG pollutants. Most GHGs, for instance carbon dioxide, are long-lived stock pollutants that stay in the atmosphere for decades. Business-cycle-level fluctuations in emissions have little effect on the aggregate stock of atmospheric carbon, which is what affects climate change. This can be seen in figure 2—over the business cycle the pollution stock (x) stays nearly constant though quarterly emissions (e) vary considerably. For this reason, the marginal benefits of climate mitigation stay relatively stable.

Many other pollutants are primarily flow pollutants, remaining in the environment and affecting the economy only for a short period. For these pollutants, business-cycle fluctuations in emissions can have serious effects on their damages. For example, ozone damages can vary considerably even over the course of a single day (Adler and Severnini 2020). As we discussed in Subsection IV.B., this may mean that the welfare benefit of policies that dynamically adjust to business cycles is higher for non-greenhouse-gas policy, because the cyclical adjustments in the policy values are able to respond to the cyclicality of damages. E-DSGE models solving for optimal policy or evaluating the effects of policy over the business cycle should study flow pollutants such as ozone or sulfur dioxide. Furthermore, even for analyses of climate policy, the cobenefits of reduced emissions of flow pollutants represent a substantial fraction of the social cost of carbon (Parry, Veung, and Heine 2015), meaning that incorporation of these benefits in business-cycle models is crucial. Finally, regulation of pollutants other than greenhouse gases may be more likely to be closer to what economists tend to consider the appropriate level of stringency (e.g., Shapiro and Walker 2020).

However, it is not certain that business-cycle considerations are always more important for non-GHG flow pollutants than for GHG stock pollutants. Because a stock pollutant accumulates, the effect on damages of a cyclical increase in emissions (from a business-cycle expansionary period) will last longer, as will the effect from a cyclical decrease in emissions. If policy fails to account for these cycles, then this variation in damages will extend over a longer period than it would under flow pollutants. It is thus an open empirical question as to whether or not cycles are more important in policy design for stock and flow pollutants, and so studying this question is crucial.

VI. Conclusion

To explore the relationship between business cycles and environmental policy, we have reviewed the growing literature using dynamic stochastic general equilibrium (DSGE) models to study the effects of policy over business cycles and the response of optimal policy to cyclical fluctuations. The majority of this literature focused on price-based climate policies, including carbon taxes and cap-and-trade, with additional economic features such as NK price rigidities. We highlight several important findings from this literature that are most relevant to policy makers, who may seek to craft policy to respond to business cycles. We also offer suggestions for important policy-relevant questions that remain unanswered, to guide the future of the literature.

Endnotes

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1. Environmental policies may be too lenient for several reasons. First, due to uncertainties arising from difficulties in estimating costs and benefits properly (e.g., Pindyck 2013), leading standard economic analysis such as integrated assessment models (e.g., Nordhaus 1993) to provide estimates of optimal stringency that may be the source of important debates (e.g., Stern 2007; Pindyck 2013; Stern and Stiglitz 2021). Second, due to a consistent tendency of policy makers to overweight or overestimate costs versus benefits (Harrington, Morgenstern, and Nelson 2000). Third, due to similar information asymmetries between experts and citizens, leading them to overestimate drawbacks and underestimate benefits of market-based instruments for environmental policy (Carattini, Carvalho, and Fankhauser 2018; Dal Bó, Dal Bó, and Eyster 2018). Finally, economic efficiency or other economics-based optimization criteria may not be the primary consideration in policy design.

2. An example is the European Union Emissions Trading System (EU ETS), in which allowance prices collapsed early on and remained persistently low for nearly a decade (EC 2012). Although such low price outcomes were largely due to an overallocation of permits (Martin et al. 2014), the Great Recession also contributed to depress prices (Koch et al. 2014).

3. Some commentators, however, do not seem to have been able or willing to disentangle the two elements, overallocation of permits and effect of the business cycle, in their critique of the EU ETS. Fortunately, in a cap-and-trade system, the appropriate response to either price-depressing element is to tighten the cap, which recent reforms have done (see Hepburn et al. 2016), but it remains far from clear whether the accompanying reforms are sufficient to address future shocks (Fischer et al. 2020).

4. With the executive order "Accelerating the Nation's Economic Recovery From the COVID-19 Emergency by Expediting Infrastructure Investments and Other Activities" of June 2020, the Trump administration instructed agencies to waive long-standing environmental laws given that "Unnecessary regulatory delays will deny our citizens opportunities for jobs and economic security, keeping millions of Americans out of work and hindering our economic recovery from the national emergency."

5. Of course, there is a much larger and older literature on business cycles more generally, which is beyond this scope of this paper to discuss.

6. These graphs update figs. 4 and 5 in Heutel (2012). This model (like the model in Angelopoulos et al. 2013 but unlike the model in Fischer and Springborn 2011) omits labor and leisure.

7. This updated calibration is based both on the most recently available version of the DICE model's damage function, and emissions elasticity estimated from monthly emissions and GDP data through 2019. See details in Gibson and Heutel (2020).

8. The efficient carbon tax is procyclical despite the fact that the pollution stock is almost entirely unchanged over the business cycle. This is because damages from pollution (calibrated from DICE) are expressed as a fraction of gross output. Over the business cycle, that fraction does not change much because the pollution stock does not change much, but gross output changes, and so therefore the marginal damages from pollution change, justifying the procyclical efficient tax.

9. Gibson and Heutel (2020) and Carattini et al. (2021) also solve for Ramsey-efficient carbon taxes in response to RBC shocks, with other market failures in their DSGE models.

10. Karp and Traeger (2021) consider a similar exercise, where the cap in a cap-and-trade scheme can endogenously adjust to macroeconomic and technology shocks, though not in a DSGE context.

11. Additional indicators that may be relevant for this exercise and could be examined in future research include jobless claims and unemployment rates, yield curves—for instance for the 10-year Treasury bond—or stock market returns. It is an open normative question whether environmental policy should be tied to GDP, rather than jobs or the unemployment rate of the most disadvantaged members of society.

12. For example, see Christiano, Eichenbaum, and Vigfusson (2003), Galí and Rabanal (2004), and Angeletos, Collard, and Dellas (2020).

13. See, e.g., Heathcote, Storesletten, and Violante (2009), Clementi and Palazzo (2016), and Kaplan, Moll, and Violante (2018).

14. As an example, the design of the optimal dynamic carbon tax should be made in conjunction with other preexisting tax instruments, as recently shown by Barrage (2020).

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