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The Fed and a smooth macroeconomic transition to a cleaner U.S. economy

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The transition to a U.S. economy that emits far fewer greenhouse gases (GHGs) has clearly begun. Growth in GHG emissions and growth in gross domestic product (GDP) have been "decoupling" for decades.[1] Huge technological leaps in the price competitiveness of nonemitting energy sources have been made in the past 10 years.[2] Finally, in 2023 a major policy push—the climate change investment provisions in the Inflation Reduction Act (IRA)—will come online.

To minimize human suffering, this transition must occur rapidly, but it must also occur smoothly. Rapidity is necessary because the damaging effects of climate change have already begun, and each year of delay in getting to net zero in GHG emissions will increase the total suffering endured due to climate change in the future. But smoothness is necessary because a climate transition cannot happen in the face of political hostility, and this hostility can be triggered if a push to reduce emissions becomes associated with poor macroeconomic performance.

Concretely, a smooth transition is one that is accomplished with the economy spending most of the time during the transition at full employment and with rising real (inflation-adjusted) incomes. Generally speaking, in the United States this kind of macroeconomic stabilization has been outsourced near-entirely by other policymakers to the Federal Reserve. Recent years have provided plenty of evidence that the Fed at a minimum needs substantial help in meeting these stabilization goals. Further, both the direct effects of climate change and the effects of policy efforts to mitigate GHG emissions will present challenges to macroeconomic stabilization that the Fed almost certainly cannot meet by itself and that it absolutely cannot meet by itself under its current monetary policy framework.

SECTIONS

Executive summary

This report highlights the challenges of maintaining full employment and rising real incomes in the face of climate change and a (needed) rapid transition to a lower-emissions economy. Its key findings are:

- There are many complexities involved in estimation of and communication about the potential economic damage stemming from climate change. When assessing the research literature on this topic, one must understand a number of pitfalls when trying to compare one estimate with another. By far the most important issue in these estimates, however, is that they often fail to include damage to human welfare that is not well-represented by changes in macroeconomic aggregates like gross domestic product. When a broader conception of damages is accounted for, the economic costs of climate change often easily double.
- Two key tasks face macroeconomic policymakers in the transition to a lower-emissions economy. The first concerns *adaptation*—or how full employment and real income growth can be sustained throughout the transition and in the face of climate shocks. The second concerns *mitigation*—or how macroeconomic stabilization policy can best aid the economic changes needed to lower emissions.

Adaptation

In regard to adaptation, we make the following points:

- Too much modeling of the economic damages of climate change treats them as pure supply shocks that do not spill over into demand shortfalls. That is, the implications of these damages for the maintenance of full employment are rarely discussed. But there are plenty of reasons to believe that the economic damage from climate change will come from both damage to the supply side and from the generation of output gaps (shortfalls of aggregate demand) that cause the economy to operate below full employment for potentially extended stretches of time.
- In the post-2008 aftermath of the Great Financial Crisis, a growing literature established that the Federal Reserve's tools were often too weak to ensure a rapid return to full employment following recessions—largely because of the problem of the zero lower bound (ZLB) on interest rates.
    - Going forward, there are reasons to think that the ZLB will bind tightly again in the future, and that both climate change and climate policy can tighten this bind.

- Additionally, there are reasons to think that energy prices are poised to enter a period of substantially greater volatility, which will challenge the Fed's inflation target. Both of these influences argue strongly that constructing a much deeper toolkit for macroeconomic stabilization—both through closing output gaps and through muting inflationary pressures—should be a policy priority. The era of assuming that simply moving the federal funds rate up or down will maximize macroeconomic stability and human welfare should be past.

Mitigation

In regard to mitigation, we make the following points:

- Climate change—perhaps more than any other economic issue—highlights the importance of "real economy" variables and the extreme limitations of financial engineering in meeting its challenges. For example, the federal government can commit large sums of money to subsidize home energy retrofits for efficiency, but not all of the bottlenecks to translating this funding commitment to actually installing the equipment and materials that will boost efficiency are simply financial. Policies that facilitate the mobilization of real resources to needed sectors while maintaining aggregate full employment and fostering broadly shared growth in real incomes will be needed.
- For the Federal Reserve, fostering this mobilization of real resources will likely require some fundamental changes in how it engages in inflation control—and equally importantly, how it communicates to the public about how it engages in inflation control. There are several reasons to think that the effects of climate change—and even some aspects of the policy responses to climate change—will lead inflation to surge above the Fed's current inflation target more often and for more extended periods of time. Given this reality:
    - The Fed's inflation target, at a minimum, should be clarified to apply only to "core" prices—excluding price changes in food and energy.
        - In fact, a new "super-core" price index that accounts for the indirect effects of rising energy prices on inflation should be made the primary inflation target.
    - Even if the clarification about the inflation target applying to core prices is made, and especially if it is not, the Fed should be far more flexible in tolerating large swings of inflation around (and especially above) its target.
- While the Fed—and all macroeconomic policymakers concerned with

fostering a fast and smooth transition to a lower-emissions U.S. economy—will have the most impact on mitigation through policies aiding the mobilization of real (as opposed to financial) resources, its obligations to preserve financial stability will also be affected by climate change. If regulations and financial market interventions by the Fed go beyond fostering financial stability in the face of climate change and actually provide some grease in the wheels of aiding the real resource mobilizations needed to combat climate change (and that's a possibility), that would be an excellent outcome. However, there are strong reasons to think that these financial market interventions will have only modest effects on this mobilization of real resources.

The rest of the paper is organized as follows. Section I highlights some challenges in applying well-known *microeconomic* basics of externalities (like GHG emissions) to *macroeconomic* modeling efforts. Section II provides a brief summary on why empirical macroeconomic estimates of the damage stemming from climate change are often extremely hard to interpret and compare across studies and suggests some better practices for reporting and communicating these results. Section III demonstrates how standard assumptions made in macroeconomic climate models about the long-run constraints on growth (demand vs. supply) can hamper understanding about key issues in adaptation and mitigation. It concludes that models with demand-constrained growth should be a much larger portfolio of thinking about the economic fallout of climate change and climate policy. Section IV highlights that adaptation and mitigation efforts are mostly "real" and not simply financial challenges. It then sketches out how this fact should inform our recommendations about what "greening" central bank behavior should include. Section V provides an overview of how focusing only on the financial challenges of adaptation and mitigation will lead to insufficiently broad recommendations for what central banks can do to meet the challenge of climate change. Section VI argues that climate change highlights convincingly that macroeconomic stabilization efforts in coming decades cannot rest solely on the shoulders of central banks—complementary policies (particularly fiscal) will need to be mobilized even for meeting what were once seen solely as central bank mandates (maintaining stable inflation, for example). Section VII concludes.

I. The economics of climate change: From microeconomic intuition to macroeconomic modeling

The most basic economic insight around GHG emissions is the same as it is around any other pollutant: Their production results in unpriced *externalities,* hence they are overproduced relative to a situation in which their full social cost was accounted for. Externalities simply mean costs (or benefits, if they are positive externalities) incurred from an economic transaction that are borne by parties outside the transaction. So, if I buy electricity to power my home from a power utility that uses coal-fired power plants, the utility and I are the direct parties to the transaction. Some of the costs of the transaction fall on me in the form of fees I have to pay for electricity. But because burning coal to generate electricity results in GHG (and other pollutant) emissions that do damage to people who are *not* direct parties to the transaction, the cost of the transaction (my electricity bill) is inefficiently low and so I will consume too much coal-fired electricity.

The most obvious solution to unpriced externalities is simply to price them: Calculate a full cost of GHG emissions that includes all social costs (including the contribution to global warming) and then add this (say in the form of an ad valorem tax) to the emissions generated by the coal-fired plant.

However, how these microeconomic basics about unpriced externalities should be applied to macroeconomic debates becomes quite complex pretty quickly. This is not even necessarily a climate-specific issue—there is a robust research literature on the complications involved in trying to model macroeconomic behavior as the simple aggregation of microeconomic behavior.[3]

I.1 Are there macroeconomic costs to transitioning to lower-emissions production?

Take one example: Most macroeconomic analyses of climate policy frame mitigation policies as a cost that must be borne to forestall climate change. But this is clearly not true. One reason it is not true stems directly from the microeconomic analysis of unpriced externalities: In the example above, if electricity generated by coal-fired plants is overproduced due to the failure to see the correct social cost of its production, then cutting back on production of coal-fired electricity and ramping up production of something else that is not associated with negative externalities should increase economic efficiency. “Getting prices right” *increases* potential economic output; it does not decrease it.

Of course, part of the problem with translating this broad microeconomic reasoning into macroeconomic terms is that the constructed variables that guide much macroeconomic analysis—like gross domestic product (GDP)—may miss important costs and benefits associated with climate change and mitigation of GHG emissions. For example, in the example above, after correcting the unpriced externality of coal-fired electricity, society may decide to simply consume less electricity and not plough reduced electricity expenditures into some other market good or service that will be reflected in GDP, and instead decide to enjoy more leisure. In this case, climate policy will have reduced GDP. But it will have improved human welfare and the failure of GDP to pick that welfare improvement up is just a statement about GDP’s own limitations as a concept, not a statement about the true economic cost of mitigation policies.

I.2 Must consumption fall to reduce greenhouse gas (GHG) emissions?

Further, the sacrifice often described by economic models of climate policy is often framed in terms of reduced consumption driven by a need to shift resources out of producing consumption goods and into investments in GHG mitigation. But the resources needed to engage in GHG mitigation do not have to be released only by reduced consumption, they can also be released by undertaking less investment in conventional (i.e., nonmitigation) capital. In fact, it is often underestimated how much the current "business as usual" paths of GHG emissions that are so problematic are actually driven by the large inherited stock of conventional capital that will continue to produce in GHG-emitting ways for years to come.[4] Rolling over this inherited stock of conventional capital and replacing it with low-emissions capital is a key challenge for the coming decades.

I.3 Scale matters in macroeconomic analysis

Another key difficulty in scaling up microeconomic intuition around GHG emissions and their mitigation is the enormous *scale* of the issue. In many cost-benefit analyses done around environmental regulation, key parameters like the economywide interest rates used to discount future costs and benefits can be taken as given. But the scale of investment needed to mitigate GHG emissions is so large that it is impossible to assume the investments themselves would not lead to changes in key economywide parameters like interest rates. The Stern Review: The Economics of Climate Change (Stern 2006), for example, argues that nearly a quarter of total global investment in coming decades will have to be reoriented toward green projects. Interest rates are highly influenced in capital markets precisely by the scale of desired investments. Assuming that these rates can be taken as given regardless of how much GHG mitigation investment is undertaken (or how it is financed) is not realistic.

I.4 How do agents in macro models make decisions in the context of climate change?

The construction of long-run macroeconomic forecasting models used to predict the damages of climate change or the effect of climate policies requires "reference paths" of economywide consumption, savings, and investment. It is not trivial at all to decide how to represent the effects of climate change and the unpriced externality of GHG emissions on these reference paths. In many macroeconomic models of climate change, the reality of the unpriced externality of GHG emissions is represented simply by assuming no mitigation investment occurs. But the economic agents in these models *do* see the marginal cost of emissions and this affects their decisions on savings and investment in conventional capital. As Rezai, Foley, and Taylor (2012) put it:

> On the one hand, the representative agent on this type of path correctly estimates

> the marginal social cost of emissions in making her consumption, investment, and production decisions. On the other hand, she seems to ignore the availability of mitigation technologies, despite this understanding of the marginal social cost of emissions.

This actually leads to overly optimistic reference paths in regard to emissions. To correct this misleadingly optimistic path, Rezai, Foley, and Taylor (2012) offer another approach to constructing the reference paths for "business as usual" in climate models:

> We model the business-as-usual case as an equilibrium of the economy in which global warming is a public bad due to a negative externality. **A state variable is an externality when it has a real impact on the objective function or constraints, but no institutions exist to enforce the social price on individual agent decisions involving it.** Each agent assumes that her decisions will not affect the path of the externality, but when all agents make the same decisions the path of the externality changes.

This approach seems far more relevant to translating the microeconomic intuition of climate change into macroeconomic analyses. But the fact that one must make such subtle distinctions between models based on how they translate the microeconomic intuition of climate change into usable macroeconomic models is often underdiscussed.

I.5 The insurance value of climate change policy

A final slippage between the microeconomic intuition of climate change and how it can be represented in macroeconomic models and analysis is identified in a series of papers by Weitzman (Weitzman 2009 is probably the best overall statement of this issue). Formal microeconomic treatments of an unpriced externality like GHG emissions mostly focus on making decisions at the margin: Ensuring the true social cost of the last dollar of polluting output is set equal to the true social benefit of this output. This sort of reasoning implicitly assumes a relatively smooth and easy-to-identify relationship between an increase in emissions and the social costs imposed. Weitzman (2009), however, highlights that in climate models there are extreme nonlinearities and "tipping point" events that make very large jumps in the social cost of GHG emissions possible at various points along the way to a higher concentration of GHGs in the atmosphere. Obvious examples that have been identified are positive feedback events—such as the thawing of Artic permafrost releasing large amounts of methane gas—which is a powerful GHG and which would cause a large increase in projected warming if this happened.

Because these tipping points and large jumps in potential costs ("climate catastrophes") are near-impossible to identify beforehand, but carry nearly existential downsides should they occur, this implies that the smooth "on the margin" analysis of most microeconomic treatments of pollutants should play a very small role in how we assess the desirability of aggressive GHG mitigations. Weitzman (2009) argues that the primary economic benefit stemming from GHG mitigation should be seen as its "insurance value" in making climate catastrophes less likely.

II. Estimating the macroeconomic costs of climate change

The macroeconomic costs of climate change have been the focus of intense research for well over a decade now, yet many uncertainties remain in basic findings, and many misunderstandings persist in how these costs are communicated to the broader public.

II.1 The importance of assumptions underlying estimated damages

This is well illustrated in an excellent recent review of the economic literature on climate change undertaken by the White House Council of Economic Advisers (CEA). Figure 2 in the CEA paper shows estimates of the physical economic damages in the United States through 2100. The estimates range from 1% of overall gross domestic product (GDP) to 35% of GDP. These radically different estimates are driven by a range of inputs into their construction, most notably: the assumed path of emissions, the assumed sensitivity of global temperatures to emissions, the mapping of global temperature increase onto economic outcomes, and the scope of damages that are considered "economic." Below we say a bit about each of these issues.

II.1.a The assumed path of emissions in macroeconomic models

The Intergovernmental Panel on Climate Change (IPCC) creates a number of potential scenarios regarding the future path of GHG emissions and their effects on temperature. These scenarios are called "Representative Concentration Pathways" (RCPs). At the optimistic end, the IPCC analyzes an RCP that sees relatively low emissions and quick decarbonization. In this scenario, the stock of GHG emissions in the atmosphere peaks at under 500 parts per million (PPM). At the pessimistic end, the IPCC analyzes an RCP that sees high emissions and little decarbonization, resulting in a stock of GHG emissions in the atmosphere closer to 1,400 ppm. It also analyzes two intermediate RCPs. The assumed path of emissions rests on estimates about the pace of technological change as well as the pace of policy efforts to shift production toward lower-emissions techniques.

Forecasting the pace of technological change is obviously extraordinarily difficult. For example, a relatively recent meta-analysis of projected changes in solar installation prices was undertaken by Way et al. (2021). A range of industry experts was asked to forecast the average annual price reductions that would occur over the 2010–2020 period. The average forecast was 2.6% and not a single forecast was as high as 3%, yet the actual annual fall in average prices for solar installation was over 15%. Of course, high-emission energy sources also see technological change and rapid price reductions. The rise of hydraulic fracturing ("fracking") in the United States in the 2010–2020 decade was driven by very large reductions in the cost of this type of extraction.[5]

Forecasting the pace of policy efforts to transition to lower-emissions production is harder still. Over the same 2010–2020 decade that saw rapid reductions in both solar installation prices and the cost of oil extraction through fracking, U.S. policy on renewables was extremely volatile. The Renewable Energy Electricity Tax Credit, for example, was allowed to legislatively lapse three times in that decade, and for wind projects the credit was substantially reduced twice.[6] On the regulatory side, the Clean Power Plan (CPP) announced by the Environmental Protection Agency was set to mandate steep reductions in GHG emissions from power plants but was held up in several legal proceedings and eventually abandoned.[7]

Forecasting the interaction of policy and technology is even harder. For example, many of the techniques that actually led to price reductions in oil extraction through fracking actually cause more emissions (injecting captured carbon dioxide into wells, for example). If policy at any point in the 2010–2020 period had imposed costs that helped internalize the externality of climate emissions, then these technological developments in fracking would not have been profitable and so would not have been undertaken.

II.1.b The assumed sensitivity of global temperatures to emission growth

After estimating an assumed path of GHG emissions, modelers must then use the scientific literature to map this change in emissions into changes in global temperatures. Because this mapping is generally done by climate scientists and not economists, the main role for economists using this mapping is to ensure consistency across models to ensure results are comparable. That is, if estimated economic damages resulting from a pathway that sees the stock of GHG emissions peak at 550 ppm in 2100 differ across studies solely because of different assumed mappings from GHG emissions to global temperatures, this would impose barriers to sensibly collecting useful economic forecasts. And yet far too few studies highlight just how their findings fit into the broader research ranges in this apples-to-apples way.

Additionally, it should be noted that one key source of uncertainty in climate models is the nonlinear responses of global temperature changes to GHG emissions, which were highlighted earlier. For example, if a given temperature change (say, four degrees Celsius) is driven by an increase in GHG emissions, this temperature change itself could spur further increases (say through mechanisms like the melting of Arctic permafrost).

II.1.c Mapping global temperature changes onto economic damages

Much of the variation in estimated damages we highlight above in the White House CEA literature review is explained by assumptions about the severity of climate change (expressed in the graph as the increase in global mean surface temperature). But variation in estimated damages even at quite similar estimates of temperature change remain large. For example, two studies (Kahn et al. 2021 and Burke, Hsiang, and Miguel 2015) assume global mean temperature changes of roughly five degrees Celsius. Yet Kahn et al. (2021)

estimate damages of 10% of GDP by 2100, while Burke, Hsiang, and Miguel (2015) estimate damages of over 35%.

Much of this is due to the vast difficulty in mapping changes in global temperature onto economic damages. The physical risks of climate change that will have potential macroeconomic implications are easy enough to list. For example, climate change could damage productivity and output in agriculture. It could destroy large amounts of productive land, capital, and infrastructure if it results in substantial sea level rise. It could lead to more frequent instances of damaging meteorological events (more and stronger hurricanes, for example). It could make many economic activities (mostly those undertaken outdoors) far harder to undertake and less productive (think of construction workers forced to take much more frequent heat and hydration breaks).

But while easy enough to conceptualize, quantifying the degree of economic damage caused by a given increase in global temperatures is much harder. The attempt to make this quantification has largely followed two paths—"top-down" studies and "bottom-up" studies.

II.2 Top-down and bottom-up estimates

Top-down approaches attempt to directly estimate the effect of past changes in temperature on macroeconomic aggregates like GDP (or employment). These approaches tend to look across countries and examine periods of short-term temperature changes and assess the subsequent behavior of GDP. Bottom-up estimates tend to look at particular economic sectors (agriculture, for example) and examine how output or productivity in the sector is affected by temperature. Sometimes this is done by looking at short-term temperature changes, but often these studies are cross-sectional—relating differences in agricultural productivity between given regions as a function of temperature differences. Often, the results of several bottom-up studies of particular economic sectors are aggregated together to obtain macroeconomic impacts.

Both techniques have their strengths and weaknesses.

The top-down approach is useful because it provides a straightforward mapping of temperature changes onto economic effects. Top-down approaches should also in theory capture "general equilibrium" effects that sector-specific models might miss. For example, economic damage caused by temperature increases in two sectors might not be purely additive and might instead cascade across interconnected systems. For example, rising temperatures and drought might both increase the risk of forest fires and cause stress on water availability. But, in turn, the need to fight increasingly prevalent forest fires might further stress water availability.

However, top-down approaches have substantial weaknesses as well. For one, they rely on short-term weather variations in the recent historical record. But these might be quite misleading guides to the patterns of climate forced by GHG emissions going forward.

Almost surely the biggest weakness of top-down approaches is that by choosing a specific macroeconomic aggregate to track, they by definition cannot capture costs imposed on human welfare by climate change *that are not reflected in that aggregate*. Take GDP, for example. Two very predictable effects of climate change going forward are that more people will need to spend more money on air conditioning and that health expenditures will rise as tropical diseases have larger areas in which to spread. These are clearly large costs to human welfare, but each serves to actually *boost* measured GDP. When a useful good or service—like comfortable living conditions or maintenance of good health—is moved from universal free availability in the nonmarket realm to the market realm, this registers simply as an increase in GDP, even if it might be quite damaging to human welfare.

Bottom-up studies have tended to focus more attention on quantifying the full range of economic damage that could be caused by climate change. Many have focused on increased health costs or the costs of increased mortality and sickness, representing them (correctly) as detrimental, not as additions to GDP.

One striking example of the importance of accounting for economic damage that cannot be expressed in most macroeconomic aggregates can be found in the first Stern Review on the Economics of Climate Change. In that review, the authors found that the cost of the "business as usual" path of GHG emissions would reach 5% of global per capita consumption if only market-based measures were examined. But if one accounted for the monetized value of increased mortality and morbidity, then this cost more than doubled to 11% of global per capita consumption.

This last point is crucially important. Besides assessing all of the variable *inputs* into estimates of the economic damage of climate change, knowing exactly what the *output* of these estimates is actually measuring is crucial for understanding the proper stakes of climate policy. If one measures the cost of climate change only as the change in market-based measures of GDP estimated in many mainstream models, then these estimates can breed some complacency about the urgency of transitioning to a lower-emissions future.

III. Climate change, demand shocks, and full employment

Most models assessing the economic damage of climate change are focused (appropriately enough) on the long run. An extremely strong convention in long-run economic modeling more generally is to assume the binding constraints on growth are on the economy's supply side. The supply side is the productive capacity of the economy, essentially consisting of the size and quality of its potential labor force; the size and quality of its stock of productive structures, equipment, and software; and its state of technological progress. These supply-side inputs tend to change smoothly and slowly over time.

The economy's demand side (or aggregate demand) is the desired spending of households, businesses, and governments. If this desired spending is too low to ensure the elements of the economy's productive capacity are fully employed, then the economy is said to have productive slack. When this slack becomes too great, economic growth can actually halt or reverse (a recession). However, negative growth is not needed to define the existence of slack—if aggregate demand is below the economy's productive capacity, then it is the demand side, not the supply side, that is the constraint on overall growth, and this shortfall keeps full employment of resources from being attained.

An overemphasis on the supply side was prevalent in the years before the Great Financial Crisis of 2008–2009. That recession, and the extremely slow recovery following it, was clearly the result of chronically slow growth in aggregate demand relative to potential supply. Further, strong feedback effects whereby large demand shortfalls erode the economy's potential supply also seem evident.[8] For example, if a key driver of firms' decisions to invest in productive structures and equipment is to obtain labor cost savings, a long period of depressed wage growth caused by excess unemployment will stunt incentives for this investment. This slower investment, in turn, reduces the growth of the economy's capital stock—a prime contributor to growth in the supply side.[9]

While there has been a resuscitation of research into the extent and causes of demand shortfalls since the Great Recession, this has largely not filtered into much of the research on the macroeconomics of climate change. Instead, this research mostly highlights how climate change can threaten growth in the supply side of the economy. To the degree that climate change could cause slower growth in aggregate demand, this is often framed as resulting from rational economic actors simply forecasting slower income growth in the future and adjusting their spending behavior accordingly, which basically serves to bring demand and supply into closer alignment. Sometimes the increased uncertainty caused by climate change is mentioned as a channel through which it could affect aggregate demand (especially decisions about business sector investment), but this is almost done as an aside.

For example, in a 40-plus page review of "Climate Change and the Macro Economy," Andersson, Baccianti, and Morgan (2020) do include a paragraph on the effect of climate change on demand conditions. But they sum up the research on the macroeconomic effects of climate change by stating: "A significant share of the potentially adverse macroeconomic impacts stems from the effects of climate change on productivity." When they discuss the effects of climate change on future inflation, they write: "In particular, upward price pressures may emerge from a decline in the supply potential of the economy."

In a sense, this incomplete treatment of the problems of demand shortfalls replicates the wider field of macroeconomic research pre-Great Recession. In this wider field of research, the existence of demand shortfalls was always acknowledged, but the implicit assumption was that central banks could be tasked with the job of macroeconomic stabilization and so shortfalls (or even the occasional bout of excess demand growth) could be quickly addressed. The issue of long-run growth was generally held to be much more important than issues of stabilization, and a problem that was largely separable from stabilization.

III.1 Climate change and chronic demand shortfalls

Taylor, Rezai, and Foley (2015) provide what is probably the most complete accounting of how standard modeling choices that present long-run growth as driven by the supply side can mask enormous amounts of potential instability caused by climate change. The details of this accounting are daunting, but a rough summary goes as follows. Supply-driven models assume employment growth is fixed and exogenous—determined by demography and the assumption that the economy always gravitates quickly toward full employment—even if a hard nudge from the Federal Reserve is needed. These supply-driven models also assume that investment spending is a residual—all desired savings by households, businesses, and governments are seamlessly translated into productive investment. Outside of the ZLB constraint on interest rates, there can be no investment shortfall or savings glut keeping the economy from reaching full employment.

Demand-driven models, conversely, represent employment as an endogenous variable—it is the residual of output growth and productivity growth. Investment is influenced by the rate of profit, which is not just a function of central bank interest rate policies, but also of expectations about the future, the relative bargaining strength of capital and labor, and the degree of product market competition.

Given these different assumptions, the channels linking GHG emissions and economic outcomes are much richer in the demand-driven model. In the supply-driven model, GHG emissions generally are modeled as reducing productivity, but the system stays pinned at full employment due to the seamless transmission of desired savings into productive investments (outside the ZLB). In demand-driven models, the economic damage done by GHG emissions can affect the distribution of bargaining strength of workers and capital owners, which in turn can cause sharp shifts in desired investments. The sharp shifts in investment, in turn, can push the economy into recession.

Modeling demand-side implications of climate change is crucial

Taylor, Rezai, and Foley (2015) highlight a number of examples in which a richer modeling treatment of the effects of climate change and climate policy on demand might lead to different predictions than those stemming from models that assume full employment is maintained automatically, both for achieving sustainable full employment but also for GHG mitigation strategies. Below we provide some modest intuition on two of these examples: the effect of productivity reductions stemming from climate change, and the potential for "rebound effects" from efficiency investments.

A macroeconomic ‘rebound effect’

Microeconomic “rebound effects” are quite familiar in the research literature surrounding energy efficiency. The intuition of these is that at least some of the benefits of efficiency investments in terms of reducing energy usage are clawed back by the effect these investments have in making energy cheaper. Imagine a household that installs more energy-efficient air conditioning. If they keep the thermostat at the same level it was on with their previous less-efficient system, then the efficiency investment will reduce energy usage by some amount, and this will be associated with reduced spending on energy. But, if they decide instead to “spend” some of this savings on even-cooler thermostat settings, then the energy reductions spurred by the efficiency investments will be eroded. This response, stemming from increased usage in the face of higher efficiency, is labeled the “rebound effect.”

In demand-driven macroeconomic models, a similar “rebound effect” can occur due to investments in mitigation of GHG emissions. Because output in these models is constrained by aggregate demand, and because investment spending is a key component of aggregate demand, additional investments in GHG mitigation can actually boost economywide output, which will be associated with increased emissions of GHGs.

In short, the outcomes for climate policy of choosing models that assume away demand constraints can be profound, both for the transition path of the economy and also for the effectiveness of mitigation efforts.

Productivity declines

In standard macro models, productivity is a residual. Full employment is guaranteed by the seamless translation of desired savings into planned investments, output is determined by employment and the size of the inherited capital stock, and productivity is simply output divided by employment. In demand-driven models, productivity is endogenous and can be influenced by other economic parameters (such as the state of any gap between aggregate demand and productive capacity). In these demand-driven models, if climate change affects labor productivity directly, this can set off a cascade of effects that leads not just to slower growth of the economy’s productive potential, but to higher unemployment as well.

The case for climate change affecting labor productivity directly is obviously quite plausible. Any activity requiring outdoor exposure could well see the need to incorporate more downtime—extended water and shade breaks, for example—in a world warmed by GHG emissions.

With output determined by the level of aggregate demand and productivity being endogenously determined, it is *employment* that becomes the adjusting variable (with no guarantee that it will be fully employed). For a given level of aggregate demand and reduced productivity, this leads to an increase in employment needed to sustain the demand-determined level of output and a reduction in the share of overall income accounted for by profits. If investment spending is a function of profitability (as much empirical evidence indicates), this could build a series of links whereby climate damage directly causes a reduction in aggregate demand through declining profitability and investments.

III.2 Climate change will severely stress macroeconomic stabilization efforts

Since 2007, the U.S. and global economies have gone through an extended period of stagnation and chronic disinflationary pressures, a pandemic-driven collapse of output, and then a period of the sharpest inflationary pressures experienced in decades. This should make us realize that the pre-2007 macroeconomic consensus positing that the federal funds rate was the only important macroeconomic stabilization tool is completely obsolete.

Macroeconomic stabilization is vitally important, and it is difficult, and it likely requires a whole-of-public-sector approach rather than a simple mandate to the central bank. This recognition needs to find its way into how we think about the challenges of climate change. It's not likely to cause just a smooth reduction in the economy's productive capacity (and that would be quite bad on its own), but is instead likely to cause a recurring set of shocks to both the demand and supply sides of the economy that will need constant amelioration. Some of this same logic also applies to climate transition policy.

IV. Climate change is mostly a 'real,' not a financial, challenge

Until just a year or two before the COVID-19 pandemic, many of the challenges facing the U.S. economy seemed to point to the power of finance and the primacy of financial constraints. Between 1989 and 2006, household debt as a share of personal income rose by more than 50 percentage points (after rising by less than half of this amount in the 20 years before 1989).[10] This debt became a large drag on the economy after the housing bubble burst. By 2006, the share of the financial sector in total corporate profits was at a historic high even as business investment was lower than the past 40 years' average and mammoth failures in financial sector supervision would soon be revealed.[11] After 2010, fiscal austerity took hold in the U.S., strangling the pace of economic recovery even as interest rates hit historic lows.[12] In short, the decades before the COVID-19 pandemic really did see many economic problems that were mostly about finance—either the failure to regulate and steer private finance into productive uses at a reasonable cost or the failure to properly use the tools of public finance.

But the COVID-19 pandemic highlighted that many crucial challenges are more about the "real economy" than finance. The United States *fiscal* response to the COVID-19 pandemic was among the most ambitious in the world. This response led to the stunning fact that child poverty rates hit their lowest levels ever in 2020 and 2021—years that saw huge struggles in the labor market and wider economy in the midst of the COVID-19 pandemic. It turned out that reducing poverty was mostly a public finance challenge—fiscal transfers simply had to be made larger to pull more people out of poverty.

Conversely, the United States's *public health* response to the COVID-19 pandemic is widely regarded as one of the most ineffective in the world. Despite our resources, the measures of cases, hospitalizations, and deaths per million in the population are clearly worse in the United States compared with the vast majority of our advanced country peers. This public health failure had clear knock-on effects elsewhere. For example, measured "learning loss" by primary school children in the United States over the past two years has been marked. This learning loss is surely driven in large part by the failure to make the investments needed to ensure students and teachers could safely return to in-person instruction as quickly as possible, to surge resources to those students whose educational circumstances suffered disproportionately during the pandemic (say because a caregiver died or their housing situation changed for the worse), and to boost pay to keep staffing at needed levels in the face of pandemic pressures on labor supply in education.

Most of the failures in the COVID-19 public health response were not due to financial constraints. State and local governments currently have healthy budgets and were given extraordinarily generous fiscal aid from the federal government. The federal government (as noted above) spent generously in many areas. But at some point, constraints often stop being strictly financial and start being about the deployment of real resources. In the context of COVID-19 response, this meant ordering sufficient personal protective equipment for front-line workers, installing high-quality indoor ventilation systems in schools, and blanketing vaccine-resistant communities with outreach to boost their rates of vaccine take-up. The precise answers as to why we were so unable to solve these real economy mobilization problems are surely complex and various. But the simple fact that we were not able to solve them should inform how we think about meeting the challenge of climate change.

Put simply, this raises the obvious question of whether or not meeting the challenge of climate change is more like the problem of budget austerity that kept the economy from reaching full employment, or more like the crisis of public health response to COVID-19. In terms of its complexity, and in the simple terms that climate change's main damage is physical, not financial, the public health response to COVID-19 seems like the better model. More and better finance is clearly a necessary condition to aid the transition to a lower-emissions economy, but it is also clearly not a sufficient condition.

One quick example of the need to mobilize real resources for climate change should suffice. The Net-Zero America project at Princeton University has estimated that wind and solar generation capacity will need to rise by at least a factor of four by 2050 in order to reach net zero emissions from the power generation sector.[13] This would require beating the current historical high-water mark for solar and wind capacity additions every year between now and 2050. This also will require mobilizing enormous amounts of physical capital (equipment like solar panels and windmills), labor (both for constructing the generating units but also maintaining them), and even land. As the experience with PPE, air filters, and generalized supply-chain distress since the COVID-19 pandemic began, mobilizing this scale of real resources in a timely and sustained manner is far more difficult than simply financing it.

IV.1 How can the Federal Reserve foster the needed mobilization of real resources for climate change?

The discussion above about the difference between real and financial constraints to transitioning to a lower-emissions economy relates directly to current debates about the role of the Federal Reserve. In recent years, there has been a growing demand to "green" central banks, meaning roughly that these banks should see the clean economy transition as a policy target.

This general demand is admirable. Climate change is a genuine existential threat that should demand a whole-of-government response, and the Federal Reserve is a powerful public institution. However, many of the demands centered around "greening" central banks have focused on the financial regulatory functions of the Federal Reserve, rather than its functions surrounding macroeconomic stabilization. Further, even when "green" demands have focused on Fed functions related to macroeconomic stabilization, they have emphasized new tools (bond purchases of clean energy firms, for example) rather than new frameworks (how the Fed's inflation target or full employment mandate is conceptualized).

Part of this focus on the Fed's financial market tools (regulations and asset purchases) likely reflects the lessons of the decades before the COVID-19 pandemic, when so many of the problems in the U.S. economy really did seem to be mostly financial. This focus also likely reflects the correct perception that the Fed is free of many political constraints in how it chooses to use its policy tools relative to, say, the U.S. Congress. Because the Fed used its policy tools in new and creative ways during the financial crisis, it is often assumed that there are other tools and other creative ways to use them that could solve today's nonfinancial problems.

But in reality, a change in how the Federal Reserve operationalized its monetary policy *framework* for balancing maximum employment and price stability would be far more effective in fostering the mobilization of real resources to fight climate change than would different financial regulatory policies or any new asset purchase program.

Put simply, the most useful thing the Federal Reserve could do in the climate change space is to change how its inflation target is implemented, in three key ways:

- It should clarify that its target applies only to core inflation—it excludes inflation stemming from energy and food price changes.
- It should go even further in purging commodity price effects from its inflation target by constructing a "super-core" measure of inflation that also strips out the indirect effect of energy price increases on the cost of other goods and services as well as inflation effects stemming strictly from exchange rate movements.
- Finally, even if the public clarification of its core price inflation target is made, the Fed should signal clearly that it is willing to tolerate larger swings of inflation around (and especially above) its target during the climate transition.

IV.1.a Clarifying that the inflation target applies to core prices only

In 2012, the Federal Reserve made explicit what had been long assumed about its long-run inflation targets by releasing a statement on "longer-run goals and policy strategy" (see FRB 2012). As many had long suspected, the Fed identified an inflation rate of 2% as its long-run target. Also, as many had long suspected, it put more weight on the price deflator for personal consumption expenditures (PCE) than on the consumer price index (CPI). Surprisingly to some, however, this explicit policy statement did not identify "core" prices as constituting its inflation target. The exact statement it made was,

> The inflation rate over the longer run is primarily determined by monetary policy, and hence the Committee has the ability to specify a longer-run goal for inflation. The Committee judges that inflation at the rate of 2 percent, **as measured by the annual change in the price index for personal consumption expenditures**, is most consistent over the longer run with the Federal Reserve's statutory mandate.

In 2022, after years of consultation with outside researchers, the Federal Reserve released a new statement regarding its monetary policy framework (FRB 2022). The main change was to make explicit that its inflation target should be seen as a long-run average rather than a short-run ceiling. However, the exact target—2% inflation in the price deflator for overall (not core) personal consumption expenditures—was reiterated, stating that,

> The Committee reaffirms its judgment that inflation at the rate of 2 percent, as measured by the annual change in the price index for personal consumption expenditures, is most consistent over the longer run with the Federal Reserve's statutory mandate.

It is often assumed—even by quite-informed observers of the Federal Reserve—that the inflation target really only applies to core inflation. In a Fed working paper providing more context to the revised monetary policy framework of 2022, Federal Reserve Vice-Chair Richard Clarida used core and overall inflation measures generally interchangeably as he discussed the implications and rationale for the new framework (Clarida 2022). For example, when discussing the pre-COVID-19 business cycle, he noted:

> But, at minimum, the failure of actual PCE (personal consumption expenditures) inflation—core or headline—over the 2012–20 period to reach the 2 percent goal on a sustained basis cannot have contributed favorably to keeping inflation expectations anchored at 2 percent.

Tellingly, when providing an assessment of the inflationary environment in the COVID-19 economic recovery, Clarida switched to looking at core inflation exclusively:

> Core PCE inflation since February 2020—a calculation window that smooths out any base effects resulting from 'round trip' declines and rebounds in the price levels of COVID-19-sensitive sectors and, coincidentally, also measures the average rate of core PCE inflation since hitting the ZLB in March 2020—was running at a 3 percent annual pace through October 2021, and that reading is well above what I would consider to be a moderate overshoot of our 2 percent longer-run goal for inflation.

Economic commentary frequently describes the core PCE deflator as being the most "closely watched" measure of inflation by the Fed.[14] This may be true, but it's not what its official inflation target is based on.

Further, the Fed's revealed actions often show that when measures of overall inflation exceed core inflation, it does not simply "look through" the noncore inflation when making policy decisions. The most prominent example of this can be seen in the Fed's actions during 2008. The U.S. economy entered a recession in January 2008. This recession had been seen coming for quite a while—the unemployment rate, for example, had risen from 4.4% in March 2007 to 5.0% by December 2007. Our own institute wrote a report in May 2008 taking as given that the economy was in recession (Bivens and Irons 2008).[15] Yet in September of 2008, after the collapse of Lehman Brothers and with the unemployment rate for August sitting at 6.1%, or nearly two percentage points over its previous trough, the Fed's Open Market Committee (FOMC) met to decide the stance of interest rates. Despite the sharp rise in unemployment over the previous 18 months, the steep fall in home prices over the previous two years, and the collapse of Lehman, the Fed declined to cut interest rates.

The transcripts of the FOMC meeting—released five years later—make clear that it was worry about inflation that drove this stasis. The word "inflation" was mentioned 129 times during the FOMC discussion, while the word "recession" was mentioned five times.[16] In the official FOMC statement released at the end of its meeting, the Fed declared the risks of inflation and recession roughly balanced, judging that "the downside risks to growth and the upside risks to inflation are both significant concerns." (FOMC 2008).

This judgement was near-immediately seen universally as a mistake. By early October 2008 the FOMC convened an emergency meeting to cut interest rates. This mistake, in turn, was driven largely by focusing on overall price inflation rather than core prices. In summer 2008, overall inflation in the CPI had risen to over 5% on a year-over-year basis, up from its average of just over 2% throughout the pre-2008 business cycle. This was a pronounced increase. Yet it was driven near-entirely by commodity prices—and oil in particular. Inflation in the core CPI over that same summer was well under 2.5%. Given that the CPI slightly overstates inflation relative to the PCE deflator, this is essentially exactly in line with the Fed's inflation target.

In short, the Fed's failure to react to the slowing economy in 2008 was entirely caused by failing to look through commodity price increases and rely on core prices as the correct measure of inflationary pressures building in the economy. Additionally, this is not a new mistake. Bernanke, Gertler, and Watson (1997) found that the Fed in the past consistently responded to rising oil prices with interest rate increases, and that these increases were a primary reason why rising oil prices led to slower economic growth in the U.S.

In short, casting the inflation target in terms of overall, not core, inflation had real and severe consequences. Perhaps it has learned its lesson and this mistake will not be made again even if there is no formal change to Fed frameworks, but given the stakes involved, more clarity on this would be hugely useful.

IV.1.b Creating a 'super-core' that purges all effect of commodity price inflation

The low-hanging fruit in changing Federal Reserve frameworks to foster full employment through a period of increasingly volatile energy prices is focusing firmly on core inflation to guide monetary policy. But it is well known that even focusing only on core prices does not completely purge the inflationary effects of commodity price increases from policymakers' view. Commodities—particularly energy—are used as inputs in goods and services that appear in the core personal consumption expenditures deflator. When the price of inputs rise, this puts upward pressure on these other core goods and services *even with no change in the underlying state of macroeconomic balance*. The obvious example—seen clearly over the past year—is the strong link between higher oil prices and higher airline fares. Fuel costs are an enormous part of airline operating expenses, so when oil prices spike, there is pronounced upward pressure on these expenses, which airlines often try to pass through to customers.

Given the Fed's large research capability and the existence of quite detailed input-output tables from the Bureau of Economic Analysis (BEA), it would not be particularly difficult to construct a measure of inflation in core goods and services that was purged of the effect of rising commodity prices. If, say, fuel costs are 20% of total airline expenses, and these costs rise by 40% over a year, this would imply an 8% increase in total expenses. There would be strong pressure to protect profit margins by passing these increases onto customers. The Fed could construct a price index that measured the rise in costs for industries that purged the rise in commodity costs (by assuming they rose at historically average rates, for example).

This kind of "super-core" index would not, obviously, be the only price measure examined by the Fed to make policy decisions, but it could certainly provide useful information. In 2008, for example, airline fare inflation hit 15% and greater in the summer as oil prices spiked. The passthrough of commodity price inflation into core inflation is easy to see in an industry that depends so heavily on fuel as an input, but this general effect was likely replicated all across the economy. It is not hard to imagine that a measure of "super-core" inflation accounting for this bleeding over of commodity price inflation into core inflation would have actually been *falling* as the Fed met in September 2008 and could have provided valuable information that could have kept it from making its mistake.

The benefit of purging inflation measures used to set monetary policy from commodity price swings is obviously relevant to issues of climate change and the transition to a lower-emissions economy. A key cost that climate change is likely to impose on the global economy in coming years is commodity price volatility. Climate change will make agricultural output more volatile and more steadily expensive over the medium term. Extreme weather events are likely to cause large spikes in fossil fuel prices by destroying the infrastructure of extraction and distribution. For example, a hurricane that hit the Houston shipping canal would have profound consequences for oil and gasoline prices globally for an extended period of time. This canal is a key distribution node from the massive agglomeration of oil refineries. If a hurricane damaged the ability of ships to pass through it, the source of more than a third of oil shipments to the rest of the country would be compromised and the result would be a very sharp spike in oil and gasoline prices.[17]

None of these climate-related price shocks should necessarily be met by interest rate increases from the Fed. They may well happen when overall measures of overall slack are tame—or even highlighting the need for higher aggregate demand. Ensuring that the Fed does not respond to shocks like these with inappropriate monetary tightening is extremely important.

Similar concerns can be raised about the effects of climate policy seeking to transition the economy to a lower-emissions future. The linchpin of such "decarbonization" strategies is an enormous change in the energy mix used by U.S. households and industry, moving from fossil fuel energy to electricity powered by renewable sources. The scale of this endeavor is large and the time span short. In just the electricity-generating sector, the amount of energy supplied today by coal and natural gas electrical plants (still the majority of the nation's electricity) needs to be completely replaced by renewable sources by 2050 to meet most climate goals. Then, the entire new renewable electricity grid needs to expand by another 50% to handle the electrification of activities that used to be powered directly by fossil fuels (replacing internal combustion engine vehicles with electric vehicles and replacing natural gas home heating systems with electric heat pumps).

It is highly unlikely that such a large transition will happen seamlessly. Most estimates of what such a transition is likely to mean for energy prices show some manageable increase in prices in the near to medium term followed by a longer-run reduction. The near-term increase in these prices—whether driven by the inherent volatility of energy markets or even by some policy imperatives—should not threaten efforts to maintain full employment by sparking interest rate increases. Moving to a monetary policy framework that explicitly looks through these price increases when assessing the state of inflationary pressures building in the economy would be very helpful.

IV.1.c Accounting for imports in the 'super-core'

The same logic that calls for strictly ignoring the role of inflation in noncore items when setting the stance of monetary policy actually holds as well for inflation driven by the rising cost of imports. If, for example, the dollar loses value relative to currencies of other trading partners, this should all else equal lead to more expensive imports over time. But these higher import prices do not tell us anything about the state of macroeconomic slack—or how close we are to full employment—in the United States. As such, these higher import prices and the spell of inflation that will lead to them should not necessarily be met by more contractionary monetary policy.

Despite the fact that the United States remains a relatively closed economy compared with its advanced country peers, this concern about the effect of import prices on wider inflation trends is not academic. Taylor and Barbosa-Filho (2021), for example, find that import price changes are highly predictive of U.S. core inflation. Storm (2022) provides further evidence on this relationship. Crucially, this holds even when oil and other energy imports are excluded.

As with the discussion about commodity prices, the importance of this can be seen in a past historical episode that led to a large monetary policy mistake. Following the Volcker shock of the early 1980s, unemployment began falling—rapidly first and then more gradually—throughout the rest of the decade. After peaking at just under 11% at the end of 1982, the unemployment rate stood at just under 6.5% in the first quarter of 1987.[18] Inflation in the overall CPI began moving upward in early 1987, and this prompted the FOMC to begin a steady increase in the federal funds rate in that year, a round of increases that continued through the beginning of 1989.[19] By early 1990, the economy had entered recession. That recession is not *fully* explained solely by this monetary tightening, but nearly all accounts of the recession's origins include these years of steadily rising interest rates.

Unlike the 2008 episode, the inflation that began in 1987 was largely in core measures. But, crucially, the value of the U.S. dollar had fallen by roughly 40% between 1985 and 1987 against our major trading partners.[20] Given standard estimates of the lag between exchange rate movements and import price changes, this fall in the dollar's value surely explained a very large part of the post-1986 uptick in core inflation. This dollar depreciation was hardly an obscure event—it was the outcome of a multilateral negotiated agreement (sometimes known as the "Plaza Accord").[21] Yet even today the episode of the late 1980s and the balancing of rising inflation and low unemployment very rarely mentions the effect of the falling dollar.

A similar effect followed the Fukushima earthquake of 2011 in Japan.[22] Fukushima is near a locus of plants deeply important to the supply-chain for Japanese automakers' global production. The earthquake and associated events (such as the crisis it caused at a nearby nuclear plant) caused huge disruptions to this supply chain. The effects rippled to the United States, leading U.S.-based plants owned by Japanese automakers to sharply cut back production for almost a year. The CPI for new and used cars in the United States saw steady and large declines from 2010 through 2017—except for one year of noticeable inflation increases in 2011, potentially driven by the supply shortages stemming from this Fukushima effect. Given the backdrop of steadily declining new and used car prices and a deeply depressed U.S. macroeconomy, this 2011 effect did not feed through in any meaningful way to the overall CPI, but it shows clearly that traumatic international events can feed through trade flows to U.S. economic outcomes. The Fukushima disruption was not climate-driven—it was an earthquake. But it is hardly a stretch to imagine the same kind of disruption stemming from a hurricane or typhoon, which are forecast to become more common and more intense in the future due to climate change.

It would not be particularly onerous for central banks to construct measures of core inflation that purge effects of import price changes unrelated to the state of domestic demand slack. Input-output models can be used to map what share of the final demand for each industry is satisfied by imports from a given country. The effect of changes in a given country-industry import price can then be estimated and removed from the final goods price. Again, this would not be used as the sole price index for making monetary policy decisions, but if this import-purged index showed substantially different inflation dynamics than other indices, this would be important information for the purposes of macroeconomic stabilization.

The need to account for commodity price changes in the face of climate change and climate policy is perhaps more intuitive than accounting for import price changes. But while the direct impact of many effects from climate change may be strongly regional, these can then be transmitted to the rest of the global economy through trade flows. For instance, in the example above about a hurricane shutting down transport of refined oil from the Houston refinery complex, the immediate effect of this would mostly be on U.S. prices. But if more expensive domestic oil prices pushed up the costs of production of U.S. exports (like automobile or airplane parts), this would transmit inflation to our trading partners by pushing up the price of their imports (or U.S. exports).

Accounting for sharp movements in import prices is not just generalized good practice for monetary policymakers; it is also likely to be particularly relevant to the coming era when the effects of both climate change and climate policy loom large.

IV.1.d Inflation will be more volatile—and will need to be higher for stretches—due to climate change

Even if the Federal Reserve changes its monetary policy framework to target inflation measures that have been purged of volatile commodity price movements, climate change and many climate policies will require much greater flexibility from the Fed about how its inflation target is maintained. Put briefly, climate change and climate policy will require substantial reallocation of resources across sectors in the U.S. economy—particularly in the next two decades. For the purposes of fighting the worst effects of climate change, it is vital that this reallocation happen quickly. For the purposes of maintaining high levels of welfare, it is vital that this reallocation happen mostly in the context of full employment. To meet both goals, the Fed will need to allow significant periods of time when inflation is exceeding its overall inflation target.

Probably the best statement of this argument comes from Guerrieri et al. (2021). This paper is framed around the structural reallocations caused by COVID-19, but the case that the economy will need permanent reallocations of resources across sectors is actually far more compelling for climate change. Much of the economic fallout of COVID-19—like the switch to durable goods spending as face-to-face services collapsed or the burst of demand for real estate in the wake of a widespread shift to working from home—may well reverse as the virus's salience falls or will just be a one-time event. But climate change and policy-induced efforts to restructure production to reduce emissions will cause permanent ramping down of some industries and a radical increase in others.

The insight of the Guerrieri et al. (2021) paper is that optimal monetary policy in response to shocks depends on how symmetric the shocks are in their effect on different sectors, and how persistent the demand shock is. When the shock is highly asymmetric and persistent, this means productive resources have to be moved between sectors. In the case of climate change and climate policy, obvious examples could include the need for more resources in construction and engineering jobs and public transit and fewer resources in fossil-fuel-based power generation. A key signal for moving resources between sectors is changing relative wages. To attract resources into expanding sectors, relative wages must rise there.

A key impediment to changing relative wages is downward nominal wage rigidity—the empirical fact that U.S. employers seem highly reluctant to cut nominal wages.[23] When nominal wages cannot fall in the contracting sector, a period of above-trend inflation can lead to a change in the relative wages between contracting and expanding sectors without the need for nominal wage cuts. If, instead of tolerating a period of above-trend inflation to facilitate the resource reallocation between sectors, the Federal Reserve tightened monetary policy, this would mute nominal wage growth in the expanding sector and would keep a temporary period of higher inflation from greasing the wheels of labor market adjustment by cutting into real pay in the contracting sector.

IV.1.e Stagnation does not foster reallocation

This finding that more expansionary monetary policy—even to the degree that it raises the optimal inflation target—fosters needed reallocations is vitally important. The history of economics has often seen the precise reverse argument—that recessions and periods of slow growth are "necessary" to foster economic restructuring. This view—sometimes called the "liquidationist" view—is perhaps most strongly associated with Schumpeter and Hayek. For example, Schumpeter (1934) wrote: "[D]epressions are not simply evils, which we might attempt to suppress, but…forms of something that has to be done, namely, adjustment to…change."

This view that labor market reallocations are stronger during recessionary periods extended into modern times. However, over the past few decades, a growing body of research finds the exact opposite—economic restructuring actually tends to happen more rapidly during periods of faster growth. Caballero and Hammour (2005) find what they label a "reverse-liquidationist" effect of recessions relative to periods of growth: Recessions actually block needed restructuring of the economy.

IV.1.f Reallocation is less painful during periods of more rapid growth

Aside from the question of whether or not reallocation is *fostered* by rapid growth is the question of whether or not reallocation causes *less damage to welfare* during periods of rapid growth. Chodorow-Reich and Wieland (2020) look at exogenous measures of labor reallocation in economic history. They find that in local areas undergoing labor reallocation, a strong national economy allows this to happen without causing higher unemployment locally. But if local labor reallocations instead happen during periods of national slumps, then reallocations do cause local labor market distress.

Given that adjustments to climate change will essentially be a cascade of overlapping and nonsynchronized local reallocations, the maintenance of strong aggregate demand nationally will be highly important in ensuring these do not cause local labor market damage.

V. The Fed's financial market policies cannot be relied upon to aid substantial resource reallocation

Since the financial crisis and Great Recession of 2008–2009, the Federal Reserve has essentially taken on a third unofficial mandate beyond its statutorily granted tasks of maximizing employment and fostering price stability: financial stability. It was widely recognized that the housing-bubble burst and the associated financial crisis were aided by regulatory gridlock stemming from too many agencies having partial jurisdiction over key parts of the financial system, which allowed for regulatory arbitrage on the part of banks looking to take on higher risks. The Dodd–Frank legislation passed in 2010 made the Federal Reserve the linchpin of the financial regulatory system in the United States.

Its role as the key financial regulator means that the Fed will have to confront the fallout of climate change on one important dimension: its effect on the balance sheet health of key financial institutions. Climate change and climate policy will have profound effects on the value of key economic assets, and these assets are often financialized and consist of large parts of the balance sheets of financial intermediaries. One obvious example includes coastal real estate. The value of seafront housing in the United States is enormous, and banks and other financial institutions hold residential mortgages as a key asset on their balance sheets. Absent the effects of climate change, these assets can appear quite safe because they are well collateralized—should mortgage holders be unable to make payments, the banks can take ownership of the underlying real asset. But if the value of the underlying real asset is itself imperiled by rising sea levels, then the financial health of the bank will be clearly damaged.

A similar set of reasoning concerns fossil-fuel-based assets and the prospects for climate policy that will force a reset of these assets' prices stemming from an internalization of the greenhouse gas externality. If, say, a measure that raises the price of greenhouse gas emissions is ever passed (a carbon tax, for example), this will reduce the demand for goods and services whose production emits GHGs (household heating oil or gasoline for passenger vehicles) and this will in turn reduce the value of assets used in the production of these goods and services (oil fields or refineries, for example). Financial institutions holding either equity or debt in firms that own these fossil-fuel-intensive assets will see their value substantially marked down, and this would affect these institutions' underlying solvency.

In theory, it is in financial institutions' own interest to account for the increased risk that climate change and climate policy poses to assets on their balance sheets. In practice, of course, this kind of self-interest has not proved sufficient to keep financial markets stable, for a whole host of reasons.[24] Given this, perhaps the single most common demand from those asking for "greener" central banks is regulation forcing financial institutions to assess the sensitivity of their balance sheets' risks (both assets and liabilities) to climate change and climate policy.[25] If a financial institution has a high share of its balance sheet assets in investments that might be severely impacted by climate change and climate policy, the risk weights for these assets should be increased and these institutions ought to be required to hold more safe capital ("safe" both in conventional ways but also remote from climate risks).

This is eminently sensible. Robust financial regulation requires assessing new and emerging threats to the underlying health of assets held by many financial institutions, and it is completely clear that climate change and climate policy may well present such risks. It would be a clear failure of financial regulation to not account for this.

Some have gone further and argued that mandating increased risk weights for climate-sensitive assets—or imposing other mechanisms that discourage financial institutions from holding these assets—might actually be affirmatively helpful in the reallocation of real resources needed to fight climate change. The reasoning is that if it becomes more expensive for financial institutions to hold climate-sensitive assets, then demand for these assets would fall. This fall in demand for climate-safe assets would hence raise user costs of capital for firms engaging in the underlying activity. So if financing a new oil well with debt became more expensive because financial regulation forces banks to charge a premium on the interest rate charged on this debt, then few oil wells might be built.

Some have gone even further still and argued that the user cost of capital for assets backed by fossil-fuel-emitting activities could be raised, and the cost of capital for green activities reduced, by the Federal Reserve's balance sheet operations even outside its regulatory functions. That is, instead of just raising the cost of capital for assets backed by fossil fuel activities (the debt of oil companies, for example) by forcing banks to hold more safe capital for each increment of climate-sensitive capital, this cost of capital could also be increased by the Federal Reserve refusing to buy fossil-fuel-backed assets when it engages in asset purchases like its so-called "quantitative easing" (QE) programs.[26] Further, the cost of capital for assets backed by green activities (construction of solar farms, for example) could be reduced by having the Fed disproportionately buy these assets when undertaking quantitative easing.

The theory behind the recommendation for the Fed to purchase assets backed by green activities and not purchase assets backed for fossil fuel activities makes sense. If real investment in these activities was constrained by the availability of finance, then this pattern of Fed asset purchases could put a thumb on the scale that hastened a transition to a lower-emissions economy. However, the empirical heft of this proposed policy in terms of hastening this transition is likely to be small.

V.1 The limits of Fed financial engineering in driving climate investments

There are three main reasons for pessimism on why “green quantitative easing” is likely to have limited traction. First, it fails to address what is by far the biggest impediment to moving resources out of GHG-emitting activities and into greener ones—the implicit (and enormous) subsidy of unpriced emissions. Second, Fed balance sheet policies have historically only operated on debt. But other forms of firm finance—like equity and internal funds—would likely be sufficient to overcome any disadvantage in debt markets arising from Fed purchases. Third, the empirical research on how earlier rounds of quantitative easing worked to spur economywide aggregate demand seem to show most of the effective transmission channels were not necessarily through narrow market segments. Instead, much of the effect occurred through household wealth effects and bank balance sheet effects. In short, quantitative easing did seem to boost economywide spending over the past decade, but the ability to focus this effect on particular sectors in an attempt to meet narrow industrial policy goals seems potentially limited.

V.1.a Financial engineering does not address the unpriced externality of GHG emissions

Resources for the Future (RFF) has an online tool that allows users to translate the impact of a given carbon tax into fuel cost increases. A $50.00 carbon tax (per metric ton of carbon dioxide) translates into gasoline and home heating fuel increases of between 22% and 46%. More recently, a team of authors (several also affiliated with RFF) found that the “social cost of carbon” was likely around $180.00 per metric ton.[27] The “social cost of carbon” is a measure that accounts for the various unpriced external costs of carbon emissions, including both local health effects and also the economic damage associated with climate change. To fully price-in this external cost, an equivalent carbon tax would have to be levied.

What all of this means is that the failure so far to fully price-in the external cost of greenhouse gas emissions constitutes an *enormous* subsidy to continued fossil fuel usage. The size of this advantage stemming from the unpriced externality would likely dwarf any conceivable cost advantage for greener activities that might stem from even an aggressive Federal Reserve policy aimed at lowering the financial costs of issuing debt for these activities. The size of this subsidy can also be seen in recent analyses of the climate provisions in the Inflation Reduction Act (IRA). The IRA allocates hundreds of billions of dollars in subsidies for nonemitting sources of energy. As welcome as the IRA is, most models show it cuts only about two-thirds of the gap between current trajectories of GHG emissions and international targets for these cuts (as specified, for example, in the Paris commitments) by 2050.

One benchmark example of how effective a program of "green QE" might be in spurring mitigation investments concerns the standard QE programs undertaken in response to the Great Recession and financial crisis of 2008–2009. Most evaluations of these programs since 2008 find the first program—"QE1"—to have had the largest effect of any of the three waves of QE.[28] Besides its effect on Treasury interest rates, the biggest effect of QE1 was on mortgage-backed securities (MBS), as the Fed targeted the mortgage market specifically for stabilization. Estimates of the effect of QE1 on the MBS market indicate that interest rates were lowered by roughly 0.5–1 percentage points. In one sense, this is evidence of success—the mortgage market is large enough that this level of interest rate decline has expansionary macroeconomic effects. But the effect of lower interest rates on the actual act of building new homes (residential investment) is just one channel linking mortgage rate declines and real economic activity. Further, it is a weak channel in this sector, with asymmetric effects that mean lower rates do little to spark more investment.[29] The small effect of interest rate declines on real investment is a common theme across most studies examining the determinants of macroeconomic investment.

V.1.b Changes in debt market alone can be undone by other forms of finance

Given the huge advantage fossil fuels have currently due to the unpriced externalities associated with their use, financial engineering focused on raising the cost of just one source of investment finance (the debt of either fossil fuel or green companies) is easy for financial markets to undo. The Modigliani–Miller theorem (Modigliani and Miller 1958) in finance argues that the capital structure of a firm (the share of its balance sheet liabilities that are equity vs. debt) cannot affect the firm's underlying value. There are plenty of reasons why the strict Modigliani–Miller theorem is wrong, but its essential insight that financial engineering cannot turn an otherwise competitive company noncompetitive or vice versa is useful to keep in mind. Eventually, it is the end-product price, not the cost of one form of investment finance, that must change to tilt market share away from GHG-emitting production techniques and toward cleaner ones.

Take the example of two firms competing to supply home heating services in a given area. One sells natural gas systems that emit GHGs and the other sells electric heat pumps that are nonemitting. If the unpriced GHG externality gives natural gas systems a cost advantage in this area, this will be hard to reverse with financial engineering. If Fed policy raises the cost of issuing debt to the natural gas company, this company can then turn to equity financing. As long as this company has the cost advantage in servicing the region, equity investors should be forthcoming—and in fact the cost to the firm of raising equity investments will be lower now than it was before the Fed debt policy began.

Finally, the capacity of many parts of the economy that are the heaviest GHG emitters to self-finance new investment out of internal funds is likely large.

V.1.c How has quantitative easing worked in the past?

The relative success of past rounds of quantitative easing is a contested topic in macroeconomics. The perceived success of it, however, has led many to think it could have substantial power in boosting real investment in needed climate change investments. But even the research literature highlighting the effectiveness of quantitative easing actually has discouraging findings for hopes that it can mobilize new investments.

Probably the best documented piece arguing for the success of quantitative easing is Gagnon (2016). He finds that the large-scale asset purchases of quantitative easing measurably lowered interest rates. In many textbook presentations of how interest rate reductions are supposed to boost aggregate demand, the role of business investment is often stressed. But, in more recent empirical investigations of the role of interest rate reductions in boosting aggregate demand, channels outside of business investment are often more important.

For example, lower mortgage interest rates can spur mortgage refinancing, which boosts the balance sheets and spending power of households. This has real macroeconomic effects, but it does not really target any specific sector.

Christensen and Krogstrup (2016) document that a substantial part of the effect of quantitative easing actually stems not from the asset purchases, but from the creation of reserves that are needed to finance the asset purchases. As they note, "reserve-induced effects are *independent of the particular assets the central bank purchases* [emphasis added]."

Chodorow-Reich (2014) and Rodnyansky and Darmouni (2017) highlight that quantitative easing has the potential to raise the value of a bank's assets if the Fed purchases assets already held by the bank. So banks with large amounts of mortgage-backed securities (MBS) on their balance sheets saw the value of these assets rise as QE1 led to large purchases of MBS. This enhanced value of banks' assets strengthened their balance sheets and allowed them to lend on a larger scale, potentially providing some macroeconomic boost. Crucially, however, this increased lending was not *targeted* at any particular sector, it simply came about because the entire value of the banks' balance sheets had been improved by quantitative easing.

VI. Ensuring a smooth transition to a cleaner economy will take more than monetary policy

The debate over the Fed's role in the transition to a cleaner economy often echoes the debate about the Fed's role during the too-slow recovery from the Great Recession of 2008. Often in that earlier debate, frustrations over political decisions regarding fiscal policy led many to demand the Fed—seen as far less constrained by politics than fiscal policymakers—undertake more ambitious efforts to restore full employment. But too often, the demands either settled on measures that would be largely ineffective or which the Fed actually had neither the legal authority nor the substantive ability to undertake.

For example, it was widely recognized that austerity from state and local governments following the 2010 elections was a prime reason why economic growth was so slow in the following years.[30] This austerity was clearly a political choice, not a situation forced upon state policymakers. In response, many observers and advocates began demanding that the Federal Reserve do something to reverse this state and local fiscal austerity. Often a demand was made that the Fed should extend credit directly to state and local governments.[31] Having a generous credit line made available to these governments was a fine idea, but it would not have made a substantial dent in austerity. The point of Fed credit lines or asset purchases is to reduce borrowing costs. But borrowing costs in the 2010–2015 period for state and local governments were already among the lowest in history. It is just not credible that state policymakers like Sam Brownback or Scott Walker would have reversed their austerity policies if the Fed somehow engineered another 50-basis-point reduction in state borrowing costs.

Beyond advocacy of these types of largely ineffective moves, the Fed was also often implicitly criticized for not undertaking policies that it had neither the legal authority nor the substantive ability to undertake. The clearest example were often-vague demands that the Fed engage in "helicopter money" or "quantitative easing for the people."[32] In practice, these are demands for cash transfers made directly to households. Because both "helicopter money" and "quantitative easing" are terms associated with central banking, they sounded to many like policy initiatives the Fed really could undertake. But they are not. The Fed has no legal authority to transfer money directly to households. An objection to this reasoning is that the Fed did not have legal authority to undertake many of its financial rescue operations during the 2007–2009 financial crisis. But this is far from obvious. The Fed went into the crisis with broad legal authority to undertake lender-of-last-resort functions. And far from ignoring any potential legal constraint on its powers, one of the most consequential decisions made by the Fed—the decision in 2008 to not bail out Lehman Brothers—was quite likely driven by the Fed's judgement that because Lehman was insolvent the Fed was barred from loaning it money.[33]

But even if an activist Fed decided to ignore potential legal constraints and try to transfer cash directly to households, *it has no means of doing this*. When the broad cash transfers legislated as a fiscal response to COVID-19 were implemented, they were feasible because the legislation directed the Internal Revenue Service (IRS) to identify taxpayers and send them the checks. But the Fed is not allowed to demand the IRS hand over its list of taxpayers and addresses. In short, "helicopter money" requires *fiscal* policymakers to act, not just the Fed.[34]

The real lesson of the anemic recovery from the Great Recession should have been that the Fed has very limited powers to ensure macroeconomic stabilization on its own. This lesson will almost surely be proved again in the coming decades in the context of the climate debate.

VI.1 Climate change will prove that the Fed needs assistance even away from the zero lower bound (ZLB)

During the recovery from the Great Recession, the Fed's need for assistance from other policymakers—particularly fiscal policymakers—was thought to be asymmetric and driven by the ZLB on interest rates. The common metaphor was that the Fed could not "push on a string"—meaning that it could not force households and businesses to spend more simply by making it cheaper to borrow and spend. The flipside of this thinking was that "pulling on the string" would work just fine; when the economy ever threatened to overheat and generate excess inflation, interest rate increases would reliably restrain spending growth.

There is a lot of wisdom in the pushing/pulling on a string metaphor. Rigorous empirical work demonstrates conclusively that there is a major asymmetry in the effect of monetary policy on aggregate demand: Rate increases quite reliably reduce aggregate demand while rate cuts provide only a very weak boost.[35]

However, lots of this reasoning starts from an assumption that containing inflation—one of the Fed's two major planks—is always and everywhere a task of keeping aggregate demand restrained. In this view, restraining inflation can and should be accomplished simply by raising policy interest rates. But as the experience of the past year should signal loudly, this is not necessarily true. The inflation of 2021–2022 has very few of the data signatures of a labor market "overheating." Real wages have fallen over the much of the period, and the labor share of income has fallen as well.[36]

The inflation instead looks like a series of exogenous shocks that then set off large ripple effects driven by distributional conflict. When the various pandemic shocks led to skyrocketing prices of goods, for example, this in turn led economic actors to try to protect their real incomes by demanding higher incomes. Workers demanded raises and firms refused to allow profit margins to contract to absorb higher input costs (and even opportunistically fattened these margins).

For most of the post-1979 period, workers' ability to demand higher nominal wages in the face of sharp inflationary shocks was quite limited. But workers' bargaining power in the 2021 labor market was buoyed by a number of sui generis factors. Unemployment insurance was temporarily made extraordinarily generous for most of the year, giving workers a much-enhanced fallback position should employers not offer decent pay. Further, huge swaths of the economy that had shut down for much of 2020 were simultaneously reopening. This led to a historically rapid surge of job openings. This historically unprecedented scramble for workers—particularly in low-wage sectors like leisure and hospitality—led to greatly enhanced bargaining power for those willing to work. Finally, virus fears (or inconveniences) kept labor force participation depressed among many swaths of workers—particularly older workers. For those willing to work in the face of degraded working conditions, bargaining power was in long supply.

Between the sui generis aspects of the 2021 labor market and the continuing cascade of shocks, inflation proved far more persistent than many had hoped. But as bad as the shocks were and as unusually large as the ripple effects might have been, the most important ripples never threatened to amplify the shocks' initial effects. Wage growth, for example, has consistently dampened, not amplified, the initial shocks.[37]

There is worry that the faster pace of wage growth that has accompanied the shocks might not relent absent a large increase in the unemployment rate. This fear is often expressed with reference to "hot" labor markets. But, again, it seems odd to flatly label the labor market as "hot" or "overheated" when real wage growth is falling and the labor share of income is falling. In reality, it seems like many are arguing that an inflation set off and sustained by a series of shocks and ripple effects can only be reined back in by engineering a rapid drawdown of aggregate demand.

This dynamic becomes obviously problematic when looking at what the next 10–20 years holds for the U.S. and the prospects for undergoing the clean economy transition while spending most of that time at full employment.

If it is true that much of the U.S. inflation problem of the past two years has largely been a problem of shocks and ripple effects, policies that provide buffers against shocks and quickly muffle ripple effects would have been far more useful than across-the-board reductions in aggregate demand (like those engineered by the sharp interest rate increases from the Fed).

Two examples of policy targets to address the types of shocks that led to the 2021–2022 inflationary episode are supply-chain resilience and energy price stability.

V.1.a Supply-chain resilience

It's hard to imagine that global supply chains in manufacturing goods are likely to be as stressed going forward as they were during the COVID-19 pandemic, but climate change could well put enormous pressure on these networks in the near future. Coastal ports are obviously vulnerable to extreme weather events, and these events will become more numerous and more severe in coming years. Policies to aid supply-chain resilience would include incentives for stockpiling key intermediate goods or for sourcing them from diversified origins. Further, there is likely much room for policies aimed at supply-chain information monitoring to avoid bottlenecks. Many of these policies are included in recent legislation passed in the United States, such as the Infrastructure Investment and Jobs Act (IIJA) and the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act.

V.1.b Energy price stability

Besides durable goods price shocks stemming from stressed supply chains, the other large inflationary shocks in the past two years have come from energy prices. It remains the case that much energy consumed in the U.S. today is fossil fuel based, and in the longer run it is vital that we see the *relative* price of fossil-fuel-based energy rise considerably relative to renewable energy. However, it does not follow from this reasoning that large and sudden spikes in the prices of oil and gas are useful for long-run climate change goals.

For one, large spikes in oil and gas are extremely unpopular politically. Political leaders hoping to foster policies to move the U.S. economy to a lower-emissions path will not survive long in office if the price of oil and gas spike up. More substantively, until the marginal unit of energy in the U.S. economy is produced by renewables, a large spike in oil and gas prices may well lead to a substitution toward energy derived from coal—and coal is far more GHG-intensive than even other fossil fuels.

Finally, while large upward movements in the price of oil and gas are highly damaging politically, large downward movements do not carry much political benefit, but they do lead to great reluctance in the energy sector to invest more resources in oil and gas extraction and refining.

Given these considerations, it seems like it would be *highly* strategic to orient policy around bringing more stability to the price of oil and gas in the United States. Policymakers can decide the desired path for how much the *relative* price of oil- and gas-based energy should rise relative to renewables over the long run, and then orient policy to minimize variation around that path. In the recent inflationary episode, drawdowns from the Strategic Petroleum Reserve (SPR) have been associated with putting a brake on upward movements in gasoline prices. But historically, this type of SPR release has been extremely ad hoc, and so has done little to bring long-run stability or predictability to these markets.

Further, a fall in oil and gas prices leads rather quickly to changed U.S. consumer habits around autos—they switch quickly to larger and higher gas-consuming vehicles. Falling prices also sow the seeds for the next sharp rise, as it tends to lead to a sharp contraction in oil and gas investment.

Williams, Datta, and Amarnath (2022) have released a plan calling for the SPR, along with the Treasury Department's Exchange Stabilization Fund (ESF) and the Defense Production Act (DPA), to target much greater price stability in the oil and gas sector. The broad outlines of the plan are that the SPR should release oil when prices are high to tamp down price pressures but should use the ESF to precommit to purchasing oil for refilling the SPR when prices hit a given floor. Finally, if firms that want to undertake investments in extraction and refining at the new more stabilized price find themselves less able to do so, then the DPA could be used to ensure that key inputs are made available to them.

Such plans will strike many on first blush as inconsistent with climate change goals. But, again, the desired long-run trajectory of rising relative prices of fossil-fuel-based energy can be set with even quite stringent emissions reductions in mind. The point of stabilization is to minimize price volatility around this longer-run trend.

This price volatility has been highly damaging to U.S. households in the past couple of years, and it likely sparked a good part of the rise in nominal wage growth that gave the initial inflationary sparks a bit more persistence than many thought would happen. The job of maintaining full employment with reasonably stable inflation would be much easier to attain if these kinds of sector-specific pressures on inflation could be addressed more directly with a broader toolkit than just interest rate increases.

VII. Macroeconomic stabilization in the face of climate change will be hard and central banks will have to show great flexibility

Climate change and climate policy will add quite a bit of volatility to macroeconomic performance in coming decades. At the same time, the stance of macroeconomic policy is likely to be quite important in determining how rapidly and smoothly the transition to a lower-emissions economy can happen.

By far the biggest contribution monetary policymakers will make to greening the economy will be figuring out the parts of this volatility that should be dampened (keeping real supply shocks from setting off demand shocks through financial market effects) and which parts should be allowed (more frequent above-target inflationary episodes if they allow better reallocation of resources toward greener sectors). This is actually a key part of their current mandate—and it is clarifying the operational specifics of this mandate and implanting them in a flexible and modern way that will be vital to making the climate transition both rapid and smooth.

Strangely, so far, most discussions about the "greening" of central banks spend far less time on these issues and instead focus on new and more exotic tools that central banks should embrace. But these suggested new tools would be quite weak generally, while core issues like how much inflation should be tolerated and how to purge inflation targets of volatility that cannot be addressed through aggregate demand management will be vital. There should be more debates on these kinds of "meat and potatoes" issues about how policymakers in charge of macroeconomic stabilization reply to climate shocks and try to smooth the resource reallocation needed to mitigate the worst of climate change. Hopefully this paper can be a part of starting this debate.

Notes

1. For evidence on the extent of global decoupling, see Hubacek et al. 2021. The supplementary material online accompanying the article provides estimates of national-level decoupling.

2. On the rapidly falling costs of renewable energy, see IRENA 2022.

3. Carroll 2001 is one good example of this literature. He points out that macroeconomic consumption spending will depend not just on the average level of income and wealth, but on its distribution. The reasoning is that households with low wealth will have a "precautionary savings" motive to self-insure against future risks to individual negative income shocks. In the aggregate, negative and positive individual shocks to income might neutralize each other, but because there are limited institutions allowing individuals to insure against negative shocks, savings will be

higher if a larger fraction of the population has lower wealth.

4. On the importance of the inherited stock of conventional capital in driving projections of GHG emissions, see Kemp-Benedict 2019.

5. On the rise of shale oil production driven by technologically induced reductions in the cost of hydraulic fracturing, see Killian 2015.

6. See CRS 2021 for an extended overview of the legislative history of renewable energy tax credits.

7. See Jordan 2019 for a discussion of the Clean Power Plan and its eventual demise. Bivens (2015) provides an assessment of the likely employment effects of the CPP, including issues related to demand-constrained growth.

8. For evidence of this feedback from chronic demand shortfalls leading to macroeconomic "scarring," see Ball 2014.

9. For evidence of these effects, see Bivens 2017.

10. This rise in household debt is often cited as a key hallmark of the "financialization" of the U.S. economy. For trends in household debt as a share of GDP, see https://fred.stlouisfed.org/series/HDTGPDUSQ163N.

11. For the finance sector's rising economic footprint over time, see Bivens and Blair 2017. For evidence on investment as a share of GDP, see https://fred.stlouisfed.org/graph/?g=UQDq.

12. See Bivens 2016 for evidence on austerity.

13. See the Net-Zero America project (Larsen et al. 2021) for these numbers. Essentially, the report highlights that total electricity demand will more than double across all pathways toward decarbonization. But given that today's nonemitting electricity generation is under 40% of the total, this implies meeting all electricity demand in 2050 with nonemitting sources requires this base to rise by at least four.

14. Just one example might suffice: A headline from CNBC in July 2022 was "Inflation Figure That the Fed Follows Closely Hits Highest Level Since January 1982" (Cox 2022).

15. In that piece, originally released in May 2008, the very first sentence was: "Evidence is mounting that the U.S. economy is in a recession."

16. These numbers come from an analysis by Appelbaum (2014).

17. See Holley 2020 for an extended discussion of the vulnerability of the Houston shipping canal to hurricanes, and the large nationwide ripple effects that would result from the canal being struck.

18. For these unemployment trends, see https://fred.stlouisfed.org/graph/?g=USI0.

19. For developments in inflation and the federal funds rate, see https://fred.stlouisfed.org/graph/?g=USlt.

20. For dollar movements, see https://fred.stlouisfed.org/series/TWEXBPA.

21. See Frankel 2015 for a good history of the Plaza Accord.

22. See Carvalho et al. 2021 for a good overview of the economic effects of the Fukushima earthquake's disruption to global supply chains.

23. See, for example, Fallick, Lettau, and Wascher 2015.

24. See Duffie 2019 for a mainstream view on why underregulated financial markets are prone to crises.

25. See Bolton et al. 2020 for a detailed overview of how this type of green financial regulation might work.

26. See Dafermos, Nikolaidi, and Galanis 2018 for an overview of how a green QE could work.

27. See Rennert et al. 2022 for this updated social cost of carbon calculation.

28. See Gertler and Karadi 2012 for an explicit ranking of various programs of large-scale asset purchases.

29. On the weakness of interest rate cuts in spurring residential investment, see Kohlscheen, Mehrotra, and Mihaljek 2018.

30. See Bivens 2016 for documentation of the role of state and local spending in dragging down aggregate demand growth in that period.

31. See Brown 2011 for an overview of this demand.

32. For an overview of what is meant by “helicopter money” in this regard, see Blyth and Lonergan 2014.

33. See Cline and Gagnon 2013 for the case that Lehman’s insolvency was the primary reason why the Fed did not offer a bailout.

34. Some of those arguing for “helicopter money” explicitly recognize some of the legal and/or logistical challenges to this. But very few go as far as suggesting concrete fixes for these (like the establishment of individual accounts at the Fed, which would allow “helicopter money” to be undertaken). One reason why legal challenges are often glossed over in these accounts is that they are often touting the virtues of “helicopter money” precisely because it could allow the Fed to act and not be hamstrung by dysfunctional congressional politics. But if instituting helicopter money requires legislative action to change the law, this obviously makes the whole argument fall apart.

35. See Angrist, Jorda, and Kuersteiner 2016 for this evidence.

36. See Bivens 2022a for this evidence and how it pertains to claims of economic overheating.

37. See Bivens 2022b for evidence of the dampening effect of wage growth.

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