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ORIGINAL PAPER

Greener and cheaper: green monetary policy in the era of inflation and high interest rates

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Abstract

In recent years central bankers have devoted increased attention to the question of whether and how to intervene to address the growing environmental and climate crisis. The climate intervention debate gained momentum during a period of low inflation and loose monetary policy in core economies – a time characterised by near zero interest rates and large asset purchase programmes. Since 2021, however, the macroeconomic context has changed. Against this background, the paper analyses the contradictory and problematic nature of the direction monetary policy has taken in reaction to higher inflation. It argues that higher interest rates delay the green transformation by raising the cost of sustainable investments, and that the resulting delay also hampers prospects for achieving price stability. The paper concludes that the present macroeconomic environment demands a 'greener and cheaper' monetary policy approach designed to address the environmental and climate crisis and also to simultaneously fight inflation.

Keywords Green monetary policy · Central banking · Inflation · Price stability · Interest rates · Environmental and climate risks

JEL Codes E50 · E52 · Q58

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1 Introduction

Growing awareness over the severity of the environmental and climate crisis in recent years has motivated central bankers to focus increased attention on the questions of whether and how they should intervene to tackle climate change (Aguila & Wullweber, 2024). It was during a time of low inflation and loose monetary policy characterised by near-zero interest rates and large asset purchase programmes in core economies that the debate gained traction. In that macroeconomic context, the main conceptual framework for defining the role of the central bank in the climate crisis was based on the argument that environmental and climate risks pose a threat to financial stability. Originally advanced by former governor of the Bank of England (BoE) and chair of the Financial Stability Board (FSB) Mark Carney, the argument was further developed by the Central Banks and Supervisors Network for Greening the Financial System (NGFS) (Carney, 2015; Chenet et al., 2021; Christophers, 2017; NGFS, 2019; Quorning, 2023; Thiemann et al., 2023). Under this perspective, barring a few instances where central bankers did discuss and even implement green monetary policies, including, for example, greening collateral frameworks and tilting corporate bond portfolios by the Bank of England (BoE) and the European Central Bank (ECB), green central banking was primarily considered to be a matter of financial supervision (Dafermos et al., 2022; DiLeo, 2023; Elderson, 2023; Schnabel, 2023).

Since 2021, the macroeconomic context in core economies has undergone dramatic changes. In a matter of months, inflation rates reached levels not seen in more than forty years. Central bankers reacted to the new situation by shifting monetary policy to a contractionary stance. They progressively increased interest rates while at the same time initiating programmes of quantitative tightening (QT). The new macroeconomic environment poses a very different set of challenges for the greening efforts of central banks. Green monetary policies are harder to pursue when central banks adopt a contractionary stance (Schnabel, 2023). The greening of corporate bond portfolios, for example, is possible only in times of quantitative easing (QE). Similarly, policies to lower some interest rates are harder to justify while central banks are increasing policy rates (DiLeo, 2023). To date, very little attention has been given to the systematic analysis and assessment of the challenges related to green central banking in an inflationary context. In this paper, we seek to fill this gap. Based on a systematic review of existing literature, together with an analysis and evaluation of current policies in terms of factors including their challenges and shortcomings, the paper addresses the following questions: What is the effect of contractionary monetary policies (higher interest rates and QT) on the green transformation? What is the relationship between the environmental and climate crisis and inflation? What other policy proposals exist and are these policies capable of addressing the current challenges?

From our findings on the first question, we conclude that the monetary policies currently in place are detrimental to the green transformation. As studies show, the effect of higher interest rates on sustainable investments is greater than on high greenhouse gas-emitting investments considering that the former are more capital-intensive and require larger upfront disbursements that must be financed and thus

require higher leverage (Egli et al., 2018; Polzin et al., 2021; Steffen & Waidelich, 2022). As a consequence, they are more sensitive to cost increases (particularly borrowing costs) than their high-carbon competitors (Monnet & van 't Klooster, 2023; Schmidt et al., 2019). For this reason, interest rate increases tend to disproportionally affect green activities, thus boosting medium-term inflation by delaying the transformation, which, in turn, exposes the economy to additional price increases directly related to climate change while prolonging the inflationary effects of fossil fuel reliance. Moreover, QT has also led to the ending of green-tilted asset purchases. Thus, QT can also slow the pace of the green transformation by reducing the potential of QE to support green investments through easier financing and lower borrowing costs.

With respect to the second question – What is the relationship between the environmental and climate crisis and inflation? – we have found increasing empirical evidence of the impact of these crises on price stability. Scholars identify three different but interrelated types of shock with a potential to affect prices, which ECB board member Isabel Schnabel (2022a) calls climateflation, fossilflation, and greenflation. Climateflation refers to price increases arising from climate-related shocks. Several scholars show that temperature variations due to climate change as well as extreme weather events or severe natural disasters such as hurricanes, droughts, floods, and others have a significant impact on inflation (Beirne et al., 2022; Bremus et al., 2020; Ciccarelli et al., 2023; Faccia et al., 2021; Kotz et al., 2023). Discussion around fossilflation highlights the inflationary cost of fossil fuel dependency in connection with the lack of progress on ecological transformation. Lastly, greenflation refers to the potential inflationary effect that arises when production processes are adapted to lower their carbon footprint. Similarly, policy instruments designed to incentivise the reduction of emissions – carbon taxes or emission trading systems, for instance – can lead to greenflation by increasing the costs of carbon emitting activities. From our review of literature on these aspects we conclude that the present macroeconomic environment demands a monetary policy approach that addresses the environmental and climate crisis while simultaneously fighting inflation, an approach that former ECB board member and current governor of the Bank of Italy Fabio Panetta (2022) calls 'greener and cheaper'. We contend that this is not only necessary for economic and environmental reasons, but that it is also consistent with the primary mandate of central banks. As environmental factors affect inflation, it follows that to achieve price stability, central bankers should pursue green monetary policies.

This leads us to the third question: What other monetary policy instruments exist and are they capable of combining a green monetary approach with price-stabilising policies? Examples of such policy instruments include green quantitative easing, green lending policies, green financial regulation, and green direct credit allocation. The results of our systematic review and analysis of the proposed policy alternatives show that while not all of these approaches serve to tackle inflation and the environmental and climate crisis at the same time, some are, indeed, capable of shaping monetary policy that is both green and anti-inflationary.

The remainder of the paper is structured as follows. Section 2 reviews the literature on the the consequences of higher interest rates and QT for the green transformation. Section 3 explores the literature on the impact of the environmental and climate crisis on price stability. Section 4 outlines monetary policy alternatives for accelerat-

ing the green transformation and discusses the extent to which they are also capable of controlling inflation. The final section summarises our arguments and points out possible avenues for further research.

2 The consequences of contractionary monetary policy for the green transformation

Both scholars and central bankers argue that higher interest rates can delay the green transformation by raising the cost of sustainable investments (Ferguson & Storm, 2023; Kedward, 2022; Monnet & van 't Klooster, 2023; Schnabel, 2023; Van Doorslaer, 2023; Voldsgaard et al., 2022). In comparison to fossil fuels, for example, renewable energy projects are more capital-intensive (Hirth & Steckel, 2016). For this reason, they require larger upfront investments that need to be financed (Egli et al., 2018; Polzin et al., 2021; Steffen & Waidelich, 2022). As a result, clean energy firms are much more leveraged than those reliant on fossil fuels (Kleintop, 2023). High leverage, however, imposes long-term constraints due to debt service obligations requiring a larger share of revenue that could otherwise be invested in inputs or new capacity (Voldsgaard et al., 2022).

Factors such as these make renewable energies as opposed to traditional energy sources more sensitive in terms of economic viability to the cost of capital increases, one of the most important determinants of which is interest rates (Đukan & Kitzing, 2021; Hirth & Steckel, 2016; Schnabel, 2023; Steffen & Waidelich, 2022). Estimates show that when the cost of capital is increased from 5 to 10%, the cost of electricity from offshore wind increases by 47%. For large-scale solar photovoltaics (PV), costs increase by 52–54%, and for rooftop solar, 60%. In contrast hereto, the same hike in the cost of capital would amount to an increase of only 8% in the cost of gas-fired electricity (Voldsgaard et al., 2022). An alternative estimation suggests that in the case of gas an increase in interest rates from 3 to 7% would raise the levelised costs of electricity (LCOE), that is, the net present cost of producing energy over the lifetime of a generator, by only 4%, while the same interest rate increase in the case of offshore wind power and large-scale solar PV would boost the LCOE by more than 30% (Ferguson & Storm, 2023). An estimate for Germany shows that an increase in interest rates to pre-Great Financial Crisis levels would elevate the LCOE of large-scale solar PV systems and onshore wind investments by 11 and 25% respectively over a period of five years, thus sharply reducing their viability (Schmidt et al., 2019).

The sensitivity of renewable energies to the cost of capital also explains differences in their incorporation across time and space. According to Egli et al. (2018), between 2000 and 2017 in the German solar PV and onshore wind power markets, a decline in the interest rate had a substantial effect on the economic attractiveness of these technologies. They estimate that lower financing costs explain 41% of total solar PV LCOE reductions and 40% of onshore wind LCOE. Polzin et al. (2021) argue that in Europe capital-intensive renewables tend to cluster in countries with low costs of capital despite the fact that countries with higher capital costs often have favourable natural conditions, as is the case with Greece for solar PV systems (Polzin et al., 2021).

These effects would be further compounded if prices of energy were to fall while interest rates remained high. What is more, higher interest rates tend to increase risks for renewable energy investments to a greater degree than for fossil fuel investments. For this reason, renewable energy projects are required to pledge more collateral. Moreover, higher interest rates also tend to have a greater negative impact on the value of green energy stocks than on the value of carbon-intensive stocks. As a consequence, high interest rates shield carbon-intensive industries from new renewable energy competitors (Ferguson & Storm, 2023).

Finally, higher interest rates also increase the cost of borrowing for households and governments (Batsaikhan, 2022). When household budgets become tighter, homeowners and landlords grow more reluctant to change existing non-sustainable energy systems (such as gas boilers and oil furnaces) for more sustainable options (such as photovoltaic systems and heat pumps). Higher interest rates also make it more expensive for governments to borrow money in order to finance green investments (Van Doorslaer, 2023).

In connection with higher interest rates, quantitative tightening (QT), i.e. the reduction of central bank balance sheets by the rolling back of asset purchase programmes, has ambiguous effects on the environment. On the one hand, by reducing market liquidity QT can make a positive contribution toward decarbonisation considering that central bank asset purchase programmes are biased towards carbon-intensive sectors (Battiston & Monasterolo, 2019; Dafermos, Gabor, Nikolaidi, Pawloff et al., 2020; Dafermos, Gabor, Nikolaidi, and Van Lerven, 2020; Matikainen et al., 2017). On the other hand, it can also impede the green transformation by reducing the potential that green QE policies, such as the tilting of the central bank's corporate bond portfolio, would otherwise have to support green investments through easier financing and lower borrowing costs (DiLeo, 2023).

Not only is monetary policy that serves to delay the green transformation shortsighted; it is also detrimental to the prospects of achieving price stability. In the next section, we review the growing evidence of the relationship between the environmental and climate crisis and inflation. This evidence is what led Schnabel (2023) to argue that interest rate increases could paradoxically also be seen as contributing to medium-term inflation by delaying the transformation and thus exposing the economy to climateflation and fossilflation.[1] Monnet and van t' Klooster (2023) similarly argue that contractionary monetary policy makes the economy more vulnerable to inflation driven by geopolitical or environmental events.

3 The environmental and climate crisis and price stability

Only recently have scholars and policymakers begun to focus their attention on the relationship between the environmental and cliamte crisis and inflation. ECB presidentChristine Lagarde (2020, p. 3) argues that 'bringing climate change more funda-

[1] Despite recognising the pernicious effects of higher interest rates on green investments, Schnabel (2023) defends hiking rates on the argument that price stability is a precondition for the sustainable transformation.

mentally into our analysis and strategy is not "mission creep": climate change is also a price stability risk'. She points out that 'climate change has consequences for us as a central bank pursuing our primary mandate of price stability, and our other areas of competence, including financial stability and banking supervision' (Lagarde, 2021, p. 1). Several central bankers at the ECB (Elderson, 2023; Schnabel, 2023) and the BoE (Mann, 2023) have followed up on Legarde's comments with similar remarks. As yet, however, central banks continue to rely on macroeconomic models that fail to include variables related to the environmental and climate crisis (Boneva & Ferrucci, 2022).

Businesses have also expressed concern about this connection. In an ECB survey on the impact of climate change and climate policies, nearly 80% of the 90 multinational firms interviewed said that their input costs had already risen. Close to 50% reported that they have had to increase their selling prices as a consequence. Nearly 60% of the respondents cited the costs of low-carbon alternatives along with cost pressures caused by rising prices of clean energy or necessary investments as one of the main challenges arising from the transition to a net-zero economy (Kuik et al., 2022).

Schnabel (2022a) outlines the most comprehensive framework for understanding the consequences of the environmental and climate crises on price stability. Using the neologisms climateflation, fossilflation, and greenflation, she distinguishes between three different types of environment and climate-related shock that can drive inflation. Climateflation describes inflationary pressures arising from climate-related shocks such as droughts and heatwaves that reduce crops and increase food prices; hurricanes and floods that destroy production capacity and raise prices; climate migration that affects labour supply and thus wages; disasters that require reconstruction which could increase the price of construction goods; and changes in the energy mix that impact relative prices and create the risk of destabilising inflation expectations (Batten et al., 2016; Beirne et al., 2022; Bremus et al., 2020; Ciccarelli et al., 2023; Cœuré, 2018; van Tilburg & Simić, 2021). All such events can also indirectly impact transport infrastructures (a drought in the region of the Panama Canal that reduces the number of ship crossings, for instance) and consequently decrease supply by impeding import activities and making it difficult to provide markets with goods (Parker, 2018). Moreover, climate disasters can also disrupt exports and fuel capital outflows, leading to a fall in foreign exchange reserves (Bortz & Toftum, 2023). This, in turn, can force a devaluation, leading to inflation through an increase in the prices of imports or goods denominated in foreign currency. At the same time, however, severe climate events can induce deflationary pressures by destroying assets and reducing income and thereby negatively affecting household consumption and firm investments (Beirne et al., 2022; Bremus et al., 2020; Ciccarelli & Marotta, 2024).

Research demonstrates that extreme temperatures due to climate change are a source of inflation. Empirical estimates for a variety of countries show that extreme temperatures lead to increases in food prices ranging from 0.38 to 3.23 percentage points (Bandara & Cai, 2014; Faccia et al., 2021; Iliyasu et al., 2023; Kotz et al., 2023; Yusifzada, 2023). This impact is heterogeneous depending on the goods considered, the season, and the characteristics of the country under analysis, including its monetary policy regime. The literature also shows that climate change has an impact on headline inflation, estimating the effect to lie between 0.3 and 2.6 percentage

points (Ciccarelli et al., 2023; Iliyasu et al., 2023; Kabundi et al., 2022; Kotz et al., 2023; Mukherjee & Ouattara, 2021). According to findings by Natoli (2022) there is a small and at times non-significant deflationary effect of surprise temperature shocks on inflation in the U.S. A study by Cevik and Tovar Jalles (2023) conducted over the period from 1970 to 2020, and based on a sample of 173 countries, is the only example of an estimate that extreme temperatures result in lower headline inflation (a cumulative 3.5 percentage points over four years). Depending on the period and country under analysis, however, their findings show differences between headline prices and food prices.

Extreme weather events, or severe natural disasters such as hurricanes, droughts, floods, earthquakes, and wildfires, have also been pointed to as sources of inflation. Estimates show that the price effects of such events can be significant, with marked differences depending on the type and intensity of the event, the country under analysis, and the commodities in consideration. Research studies broadly agree that the inflationary impact of storms and floods merits particular attention due to the relative frequency of these events. Most studies show some degree of impact although estimates vary on the size and persistence thereof (Heinen et al., 2019; Kabundi et al., 2022; Moessner, 2022b; Parker, 2018). There is more consensus in the literature on the significant effects of drought on consumer prices (Moessner, 2022b; Parker, 2018). Hurricanes have likewise been shown to have a large effect on the cost of food and housing (Heinen et al., 2019). Findings on earthquakes, on the other hand, reveal no significant effect on prices (Cavallo et al., 2014; Parker, 2018).

Scholars have also estimated the joint effects of extreme weather on inflation. Kim et al. (2022) show that in the United States between 1963 and 2019 severe weather shocks (including very high and very low temperatures, heavy precipitation, droughts, high winds, and changes in sea level) had a positive impact on energy and food prices, although not on core inflation. Based on their research on data from 19 euro area countries over the period from 1999 to 2021, Beirne et al. (2022) estimate that headline inflation (mainly explained by food and beverage prices) increases by 0.1 percentage points in response to a disaster and subsequently declines. Findings from a study conducted by Kunawotor et al. (2022) on the impact of extreme weather events on prices in 52 African countries between 1990 and 2017, demonstrate that large and severe weather events, depending on their severity, have a direct impact of between 0.075 and 0.123 percentage points on headline consumer price inflation. Finally, from their research using a panel data set of 24 OECD countries covering the period from 1990 to 2019, Ciccarelli and Marotta (2024) conclude that physical risks (calculated as the costs of premature deaths from exposure to environmental risks and GHG emissions, and thus excluding extreme weather events or natural disasters) have an ambiguous effect on prices, depending on whether supply side or demand side factors prevail. They also show that the effects differ across sectors, and therefore across countries, depending on their sectoral composition.

The second type of shock, the inflationary cost of dependency on fossil fuels, which Schnabel (2022a) calls fossilflation, highlights the lack of progress on the ecological transformation as a cause of inflation. An increase in oil and gas prices is inflationary due to the lack of green alternatives to replace fossil fuels. As Schnabel warns, while price increases could incentivise the production of greener sources of

energy, a long time frame for the transformation process might result in persistent inflation (Schnabel, 2022b).[2] The inflation rate for 2021 and 2022 was largely of this nature (Kedward, 2022; Van Doorslaer, 2023), considering that it was driven by energy price increases attributed to the Russian invasion of Ukraine and Europe's dependence on fossil fuels (Panetta, 2022; Schnabel, 2022a) from which oil firms derived record profits (Weber, 2022).

Lastly, a potential inflationary effect can arise when production processes are adapted to lower their carbon footprint (Schnabel, 2022a). This so-called greenflation can occur, for example, when the production of electric vehicles or wind plants leads to an increase in demand for the limited supply of metals and minerals, which in turn fuels inflation. Greenflation can also result from policy instruments such as carbon taxes or emission trading systems that are designed to incentivise the reduction of emissions (Konradt & Weder Di Mauro, 2023).

The effect of such policies on prices, however, is a matter of controversy in the literature. On the one hand, as several scholars have found, although these policies do affect energy prices, they have only moderate or even negative effects on inflation (Ferrari & Nispi Landi, 2022; Konradt & Weder Di Mauro, 2023; Moessner, 2022a). Ciccarelli and Marotta (2024) argue that while carbon taxes have an impact on energy prices, this does not lead to higher increases in core prices. Moreover, they show that core prices increase more in countries without carbon taxes. At the same time, they claim that transition risks (proxied using the OECD indicator of environmental policy stringency) have a positive impact on sectoral prices. Känzig (2023), on the other hand, shows that in the EU Emissions Trading System (ETS), a carbon pricing shock leads to a significant increase of about 0.2% in consumer prices and 1.6% in energy prices at peak. Moreover, he provides evidence that higher prices have a heterogeneous effect on households, leading to a significant decrease in consumption by low-income households, but only marginal decreases for high-income households. Furthermore, Känzig and Konradt (2023) provide further evidence of a differential effect with respect to carbon pricing policies. They show that while higher ETS prices lead to a significant increase in consumer and producer prices, European carbon taxes do not. Concerning oil prices in particular, their findings indicate a persistent increase from higher ETS prices but no significant effect, and even a decline, as a result of European carbon taxes. Following an approach similar to that of Känzig and Konradt, Berthold et al. (2023) conclude that in the EU a one-standard deviation carbon pricing shock leads to an increase in consumer prices of 0.05%. According to their findings, the rise in prices is largely explained by the increase in the prices of dirty goods resulting from the increase in their input costs. Mann (2023) similarly argues that carbon price shocks could have a persistent effect on inflation and that the effect might be higher for an ETS system in relation to a carbon tax. Del Negro et al. (2023) hold an intermediate position. They develop a New Keynesian model showing that when prices are fully flexible taxes on dirty sectors are not inflationary and subsidies on green sectors are not deflationary. If central bank policy is aimed at closing the output gap, however, the effect of nominal rigidities in dirty sectors might be inflationary and in green sectors deflationary.

[2] By reducing profitability, low fossil fuel prices could potentially disincentivise green investments.

4 Towards an anti-inflationary green monetary policy framework

As demonstrated in the foregoing sections, current monetary policies not only serve to delay the green transformation by raising the cost of borrowing; they also fail to tackle the environmental sources of inflation. What the current macroeconomic scenario requires instead are monetary policies designed to counter the environmental and climate crisis while at the same time controlling inflation. Former ECB board member and current governor of the Bank of Italy Panetta (2022) suggests the possibility of a 'divine coincidence' in the form of monetary policies capable of shaping economies in a greener but also cheaper direction. In this section, we examine various alternative options for developing a greener monetary policy approach and then discuss the extent to which they are also capable of controlling inflation.

4.1 Alternative approaches to green monetary policy

Scholars have only recently begun to focus closer attention on the role of green monetary policy in an anti-inflationary strategy (Monnet & van 't Klooster, 2023; Van Doorslaer, 2023; Van 't Klooster, 2022). While not explicitly concerned with the anti-inflationary consequences of green monetary policy, the relevant literature has made substantial contributions that can help to shed light on this issue by extension.

4.1.1 Green asset purchase programmes

Given the bias of existing QE portfolios towards carbon-intensive assets, a large body of literature has developed around proposals for a greener approach to QE (Battiston & Monasterolo, 2019; Dafermos, Gabor, Nikolaidi, Pawloff et al., 2020; Dafermos, Gabor, Nikolaidi and Van Lerven, 2020; Matikainen et al., 2017). Under this approach, central banks would purchase bonds (including corporate bonds, national and local government bonds, and investment bank bonds) to finance green investments (Anderson, 2015). In this way, funding would be provided for green investments at lower interest rates. Proposals for a further feature of a green QE programme include a ban on the purchase of bonds from carbon-intensive sectors unless specifically intended for financing green projects (Dafermos, Gabor, Nikolaidi, Pawloff et al., 2020).

4.1.2 Lending policies

Interest rate policies for secured lending belong to the classical set of monetary tools. Proposals for greening such tools include measures to differentiate central bank interest rates according to green lending volume. This would provide cheaper funding to banks that excel at green lending (van 't Klooster & van Tilburg, 2020). The Bangladesh Bank has already initiated several green refinancing schemes with lower interest rates for green loans (Dikau & Ryan-Collins, 2017). Long-term refinancing operation windows that already exist in some countries can facilitate the implementation of such proposals (Krebel & Van Lerven, 2022). The ECB is accordingly considering

greening its targeted longer-term refinancing operations facility (TLTROs) (Elderson, 2023; Schnabel, 2023).

Another way in which central banks could foster the green transformation would be by changing their collateral framework (Dafermos et al., 2021; Gabor et al., 2019; Schoenmaker, 2021). To meet current eligibility criteria for collateral, assets must be of high quality. Current collateral frameworks fail to take climate risks into account (Gabor et al., 2019; van Lerven et al., 2020). This constitutes a built-in bias against green assets which tends to mobilise credit in the direction of carbon-intensive activities. According to estimates, 59% of the corporate bonds accepted as collateral by the ECB are issued by carbon-intensive companies (Dafermos et al., 2021). As current practice shows, it is indeed possible for central banks to change eligibility requirements so as to ban dirty securities or accept green assets as collateral. The People's Bank of China (PBoC), the ECB, and the Bank of Japan (BoE) are already accepting various green bonds as collateral in credit facilities (Bank of Japan, 2021; Barmes & Livingstone, 2021). Although less ambitious, another approach would be for central banks to impose higher haircuts and margin requirements for non-green assets.

4.1.3 Financial regulation

Central banks and other financial regulators have several tools to encourage banks to increase sustainable lending and discourage lending to finance carbon-intensive activities. They can increase the reserve requirement for carbon-intensive activities to decrease high-carbon lending capacity, and/or reduce the reserve ratio for green investments to increase the amount of funds available for environmentally sustainable lending. Lebanon's Banque du Liban is one example of a central bank that has reduced reserve requirements for loans to finance environmentally friendly projects (Barmes & Livingstone, 2021). In general, the literature on green finance agrees that raising the reserve requirement is more effective than lowering it. Many high-income countries do not require banks to hold minimum reserves. But even if they did, it might not constrain high-carbon bank lending, given the excess liquidity that exists in money markets (Campiglio, 2016). What is more, by encouraging some institutions to take excessive risks, a lower reserve ratio could lead to financial instability (D'Orazio & Popoyan, 2019). Another option related to reserve requirement adjustments involves differentiating between interest rates on reserves. The People's Bank of China (PBoC), example given, pays a higher interest rate on required reserves for banks with better green financing performance (Barmes & Livingstone, 2021). In a similar fashion, banks borrowing from the Bank of Japan's green lending facility are allowed to shift their reserves from a lower-paying to a higher-paying rate (Bank of Japan, 2021). Another incentive that central banks can use to spur the market for carbon certificates is to accept such assets as part of legal bank reserves (Volz, 2017).

Revising capital adequacy rules would be a further possibility for central banks and financial regulators to contribute toward meeting climate commitments (Dafermos & Nikolaidi, 2021). Risk-weights, for example, which are currently biased against green assets due to their longer pay-back period (D'Orazio & Popoyan, 2019), could be modified so as to include those that reflect the degree to which assets are green or carbon intensive (Esposito et al., 2019; Gabor et al., 2019; Schoenmaker & van

Tilburg, 2016). It would also be possible to require higher capital requirements for banks that lend money to finance dirty activities ("dirty penalising factor") and/or lower capital requirements for green lending practices ("green supporting factor") (Campiglio, 2016). As in the case of liquidity requirements, the former is the preferable option due to concerns over the financial stability implications of the latter. Estimates show at any rate that the impact of green capital requirements is quantitatively small (Dafermos & Nikolaidi, 2021). In a similar fashion, countercyclical capital buffers have been proposed as a way to help foster a greener financial system. This strategy could be implemented by banks to build a buffer during periods of carbon-intensive credit growth. Doing so would increase their resilience both by setting aside a certain amount of capital not to be used for the further expansion of credit as well as by providing a capital base to absorb losses in the event of a cycle reverse or a climate-related shock that might leave assets stranded (D'Orazio & Popoyan, 2019).

A still further proposal involves the modification of liquidity requirements such as the Net Stable Funding Ratio (NSFR) or the Liquidity Coverage Ratio (LCR). Regulations requiring financial institutions to increase their holdings in high-quality liquid assets (cash, sovereign bonds, high rating corporate bonds, etc.) and to match long-term assets with more expensive long-term liabilities have the adverse effect of biasing them against investment in green assets, which are typically long term and less liquid (Barmes & Livingstone, 2021; Campiglio, 2016; D'Orazio & Popoyan, 2019; Gabor et al., 2019). Lowering the requirements for green assets or increasing them for dirty investments could eliminate that bias or even shift it towards green funding.

Additional proposals to promote a greener banking sector include the imposition of limits on large exposures to prevent financial institutions from becoming overexposed to carbon-intensive counterparties (Barmes & Livingstone, 2021; D'Orazio & Popoyan, 2019; Schoenmaker & van Tilburg, 2016); penalising global systemically important banks (G-SIBs) that fund polluting activities (Gabor et al., 2019); introducing sectoral leverage requirements to limit overleveraged positions towards green sectors (D'Orazio & Popoyan, 2019); creating caps on loan-to-value (LTV), debt-to-income (DTI), or loan-to-income (LTI) ratios to limit lending to greenhouse gas intensive companies (D'Orazio & Popoyan, 2019); and setting restrictions on profit distribution (Campiglio, 2016).

Finally, a proposal that has grown in prominence lately involves the potential of prudential transition plans. The idea became popularised following a speech by European Central Bank (ECB) board member and chair of the Network for Greening the Financial System (NGFS) Frank Elderson in which he argued that banks were falling short of supervisory expectations and were setting carbon emission goals without any concrete actions to achieve them (Elderson, 2021). For this reason, his argument goes, banks should adopt clear and legally binding plans detailing the intermediate steps they intend to take to achieve carbon neutrality. Formulating these plans would require banks to assess their climate and environmental risk exposure and to develop a mitigation strategy accordingly (Després & Miller, 2023; Dikau et al., 2022). Supervisors would have the authority to set expectations, assess the plans, and impose appropriate measures if the targets are not met.

4.1.4 Direct credit allocation

Another proposal discussed in the literature is that central banks pursue a more proactive approach toward the implementation of direct credit allocation policies, formerly a common strategy in advanced economies that is still used today in some developing countries (Barmes & Livingstone, 2021; Bezemer et al., 2018; Campiglio, 2016). To steer credit allocation in a green direction, central banks can use a variety of different measures. First, they can impose much stricter regulations on the banking sector. This can be done by requiring banks to set different interest rates for financing activities, depending on whether and to what degree they are greenhouse gas intensive (Barmes & Livingstone, 2021; Monnet & van 't Klooster, 2023). The People's Bank of China, for example, used to exert "soft pressure" on the banking system ("window guidance") by holding regular meetings to ensure that credit was reallocated from carbon-intensive borrowers to investors in green activities (Dikau & Volz, 2021). A more aggressive approach involves limiting the financing of greenhouse gas intensive activities via quantitative restrictions on lending, or banning investment and financing altogether in certain sectors (Barmes & Livingstone, 2021; Chenet et al., 2019). Following this strategy, the Banco do Brasil has imposed restrictions on lending in certain environmentally sensitive areas of the Amazon (Dikau & Ryan-Collins, 2017). Similarly, central banks can impose quantitative minimums on green lending. The Bangladesh Bank is an example of a central bank that uses this option by requiring financial institutions to allocate 5% of their portfolios to green sectors (Dikau & Ryan-Collins, 2017). Another example is the Reserve Bank of India, which requires commercial banks to lend a certain proportion of loanable funds to priority sectors, including renewable energy (Campiglio et al., 2018).

To exert influence on lending to the non-financial sector, central banks can cap the level of financing for carbon-intensive firms (Chenet et al., 2019). In a bolder approach, central banks can finance companies directly (Grauwe, 2019), a strategy already followed by a number of central banks in response to the Covid-19 pandemic. By the same token, monetary authorities can purchase equity to capitalise green firms. They can even exert shareholder rights in companies in which they own stock, thereby influencing investment decisions.

Central banks could also resort to the capitalisation or purchase of bonds issued by development banks or green investment banks. This option would serve to increase the credit supply for activities currently not privately financed because they are considered too risky, too long term, or unprofitable (Campiglio, 2016; Dikau & Ryan-Collins, 2017; Gabor et al., 2019; Geddes et al., 2018; Grauwe, 2019; Semieniuk & Mazzucato, 2019). Finally, fiscal policies designed to promote ecological transformation could be directly financed by central banks. A variety of instruments, including the purchase of green treasury bonds, would serve this purpose (Galvin, 2020). But there are also other direct mechanisms that would allow central banks to grant loans to their treasuries or ministries of finance, or to overdraft their accounts to finance green investments. The use of such direct lending mechanisms to finance fiscal policies was already a practice employed by several central banks during the pandemic.

4.2 Discussion

Table 1 provides an overview of the green and potentially anti-inflationary monetary policies discussed above.

In the following we discuss the potential of these alternative monetary policies to address the climate and environmental crisis, and their implications for price stability.

4.2.1 Green asset purchase policies

Although green QE can make an important contribution toward a greener economy, it will not suffice on its own to address the environmental and climate crisis. Estimates show that if central banks were to purchase 25% of the total amount of green bonds and maintain that share over time, the resulting volume of green investments would still fall far short of what is required to meet official sustainability goals (Dafermos et al., 2018). This is because the incentives for green financing under green QE cannot possibly increase investments to the level required. Moreover, considering that since 2022, QE has largely been replaced by QT, proposals for green QE programmes have lost much of their appeal (DiLeo, 2023; Schnabel, 2023). An alternative would be for central banks to adopt a green QT policy according to which they would sell dirty assets while keeping green assets in their portfolios. Such a policy, however, offers far weaker steering options. This, on the one hand, is because as long as the demand for dirty assets remains high, any lack of demand on the part of central banks would in all likelihood be offset by private demand. And, on the other hand, in line with contractionary policy there would be little to no additional purchase of green assets. The mere retention of green assets already in central bank portfolios, however, does not offer much possibility for steering the economy in a green direction.

4.2.2 Lending policies

The adoption of greener collateral frameworks would support the green transformation by facilitating loans at more favourable terms to parties holding green assets. This would reduce the cost of financing sustainable assets while increasing costs for dirty ones. At the same time, it would allow central banks to protect their own balance sheets by freeing themselves of assets subject to climate risks (Oustry et al., 2020). Creating greener collateral frameworks offers the added advantage of serving not only traditional banks but also shadow banks which fund a large part of their operations with repos. Additional proposals specifically geared to the operations of shadow institutions include the imposition of a financial transaction tax (FTT) on dirty assets and offering investors shares in a selection of environmentally oriented exchange-traded funds (ETF) (Gabor et al., 2019). With regard to the implications these proposals have for controlling inflation, lending policies could help to finance the investments necessary to mitigate climateflation, fossilflation, and greenflation, at least to some extent. As Van ‘t Klooster (2022) shows, measures to differentiate interest rates so as to offer lower rates to projects geared to advancing renewable energy, energy-efficient housing, and other green projects, can contribute to medium-term price stability.

Table 1 Green central banking approaches

Green Central Banking Approaches	Aims and Objectives
Asset Purchase policies	To purchase green assets (green QE), thereby providing funding and lowering the cost of borrowing; to sell dirty assets (green QT)
Lending policies	To make green borrowing cheaper or dirty borrowing more expensive as an incentive to facilitate green loans while discouraging dirty lending
Differentiation of interest rates	To foster green Longer-Term Refinancing Operations (LTRO) that provide cheaper funding to banks that favour green lending
Green collateral frameworks for secured lending	To impose higher haircuts and margin requirements for non-green assets while banning the use of dirty securities as collateral, and accepting green assets as collateral
Financial regulation	To revise the regulatory framework to encourage green lending and discourage dirty lending
Green reserve requirements	To increase the reserve ratio requirement for banks that lend to carbon-intensive activities or reduce the reserve ratio for banks that lend to green investments
Green capital requirements	To adopt risk weights that reflect the degree to which assets are green or carbon intensive while setting higher capital requirements for banks that finance dirty activities and lower capital requirements for green lending practices
Green countercyclical capital buffers	To build a buffer during periods of credit growth and thereby set aside a certain amount of funds that can serve as a capital base for absorbing losses in the event of cycle reversal or climate-related shocks
Green liquidity requirements	To lower the Net Stable Funding Ratio (NSFR) or Liquidity Coverage Ratio (LCR) for banks that lend to green activities and/or increase these ratios for dirty investments
Transition plans	To ask banks to adopt detailed legally binding plans stating the intermediate steps that they are going to take to achieve carbon neutrality, and periodically assess them against supervisory expectations and achievement of the targets.
Other policy measures	To impose limits on large exposures to prevent financial institutions from becoming overexposed to carbon-intensive counterparties; to penalise G-SIBs that fund polluting activities; to introduce green sectoral leverage requirements, creating caps on loan-to-value (LTV), debt-to-income (DTI), or loan-to-income (LTI) ratios; and to set restrictions on profit distribution
Direct credit allocation	To provide credit guidance for the redirection of capital from dirty to green sectors
Policies via the financial sector	To require banks to set different interest rates for green and dirty lending; quantitative restrictions on lending; banning investment and financing in certain sectors; and impose quantitative minimums on green lending
Policies via non financial corporations	To set caps on the level of financing for carbon-intensive firms; provide guarantees for green projects; purchase bonds or grant loans to firms; purchase equity to capitalise green firms; and ensure the exercise of shareholder rights to direct investment
Financing green or development banks	To capitalise or purchase bonds issued by development banks or green investment banks
Financing fiscal policies	To purchase green treasury bonds, and to grant loans or overdrafts to treasuries

Source: Authors' elaboration

4.2.3 Financial regulation

Monetary authorities have a variety of regulatory instruments at their disposal to encourage banks to increase sustainable lending and discourage lending to finance carbon-intensive activities. The option that plays a crucial role in this respect is the

power that financial regulators have to adjust requirements that they impose on banks in connection with reserves, capital, and liquidity. These policies can have an anti-inflationary impact by incentivising banks to increase lending to sustainable investments and thereby increasing the supply of renewable energies and other green goods. They can also constrain the potentially inflationary consequences that the increase in credit might have by simultaneously reducing credit provision to dirty sectors. However, the overall effect is probably too small in itself to incentivise strong shifts in financial flows towards sustainable investments.

4.2.4 Direct credit allocation

Credit guidance policies allow the state to have a greater degree of control over the direction of credit. This can have a strong positive effect by redirecting capital away from dirty sectors to green initiatives, a process that typically requires considerable coordination between the central bank, the treasury, and other government organisations (Chenet et al., 2019). Depending on how direct credit allocation is structured, it can strongly encourage both private and public green industrial investments. Regarding the question of price stability, credit guidance policies have been successfully used in the past to fight inflation. Monnet and van 't Klooster (2023) show that in the 1970 and 1980 s central banks such as the Bundesbank and the Banque de France increased interest rates but exempted key sectors from monetary tightening. They continued to provide export credit or credit to certain industrial projects at former rates, for example, (and, in the case of France, without a limit on credit growth) in order to help maintain price and exchange rate stability. In this way, policies that differentiate between the general interest rate and that offered to critical sectors, even in the context of an interest rate increase, avoid the negative consequences that would result from undifferentiated increases in sectors relevant to the economy and the inflationary outlook.

5 Conclusion

The current macroeconomic scenario is characterised by growing environmental and climate risks and higher rates of inflation. Against this backdrop, central banks in core economies have been increasing interest rates to fight inflation, notwithstanding the negative repercussions of higher interest rates for the green transformation. In this paper, we argue that this approach is problematic not only due to the catastrophic consequences of delaying the green transformation, but also because of its implications for price stability. Growing evidence in the relevant literature confirms that the environmental and climate crisis are a source of inflationary pressures that can lead to price volatility.

Our analysis of empirical studies shows that climate-related shocks typically exert positive effects on prices to varying degrees, depending on a variety of factors including the nature of extreme weather events concerned (hurricanes, extreme temperatures, floods and droughts, etc.), the country in which the event occurs, the type of price in question (food prices, consumer prices, headline inflation, etc.), and the

period under study. Moreover, findings suggest the presence of important nonlinearities, meaning the more extreme the events are, the greater their effect is on prices. Considering the rising incidence of climate related shocks, we argue the need for an approach to monetary policy that serves to counteract these effects. The relevant literature reveals a wide range of possibilities for central banks to create conditions necessary for achieving the vision referred to by Panetta (2022) as a 'divine coincidence' between decarbonisation and price stability in a transition process that is both 'greener and cheaper'.

In our review of the different proposals discussed in the literature, we examine options for shaping and implementing a monetary policy framework that is both green and anti-inflationary. On the whole, we conclude that monetary policy can, indeed, contribute to a greener economy without jeopardising price stability by providing more and cheaper funding for green projects and less, at higher interest rates, for dirty ones. As borrowing costs are a main determinant of investment costs in green projects such as the development of renewables, lower financing rates would also contribute to lowering prices. Moreover, the reduced cost of borrowing would serve as an incentive for further green investment (Schoenmaker, 2021). The resulting investments could then increase the supply of green goods, and the increased supply would, in turn, lower their prices. In the case of renewable energy sources designed to replace fossil fuels, for example, lowering their borrowing costs and thus their prices would reduce the inflationary effect resulting from continued dependence in our economies on non-renewable resources (Van 't Klooster, 2022; Weber, 2022). Additionally, larger investments tend to encourage innovation, spurring productivity gains that can lower costs and, in turn, prices. Furthermore, green investments can contribute to mitigating climate change and adapting the economy to its impacts, thereby diminishing inflationary environmental and climate-related shocks and increasing resilience to the risks associated with changes in climate conditions.

It merits mention that central banks would be able to implement some of the proposals discussed above within their existing monetary policy frameworks without substantially altering the workings of the financial system (Aguila & Wullweber, 2024). In view of the extensive challenges that the worsening climate crisis poses to financing structures, however, it can be assumed that the sustainable transformation will require a much broader and deeper socio-economic transformation (Dziwok & Jäger, 2021; Svartzman et al., 2019). The fundamental question here is whether shifting profit and risk considerations alone can provide sufficient motivation to bring about the green transformatin. So far non-financial green investments have not been more profitable than carbon-intensive investments (Bolton & Kacperczyk, 2021; Christophers, 2022). Whether market mechanisms will suffice to change this is questionable, especially considering the complexity of the challenges involved. Compared with traditional investments, green investments are typically higher risk, longer term, smaller in scale and confined to more local areas (Gabor et al., 2019; Kedward et al., 2020).

As a result, merely changing the incentive structure within the same framework is bound to fall short of what will actually be required to mobilise the volume of resources necessary for the green transformation. To advance sustainable transformation processes and stimulate innovation so as to achieve the level of productivity

gains that can lower costs and therefore prices, the state will very likely have to assume a much stronger role in shaping rather than just fixing the market (Chenet et al., 2021). Transformation of the state and the financial system, however, would require central banks themselves to take bolder measures as agents of change (Aguila, Haufe & Wullweber, forthcoming; Wullweber, forthcoming). If they were to adopt such a role, central banks would be capable of steering credit toward low or zero carbon investments.

With the worsening of the environmental and climate crises, it is becoming all the more urgent to accelerate the green transformation towards a more sustainable future. It is only recently that scholars and economists have begun to focus closer attention on the correlations between green monetary policies and inflation. Consequently, our paper offers an early evaluation of empirical findings and proposals in this context. Much more research will be needed in order to determine which of the policies would be most conducive to a green transformation in an economic environment of price stability. Empirical investigation must be an ongoing process to keep pace with the rapidly-changing macroeconomic landscape of today's world, especially considering that research on the phenomena discussed in our paper is in its early stages. In particular, while the phenomenon of climateflation has gained increasing attention in empirical studies, the implications of fossilflation and greenflation remain less understood and need more in-depth study. Another aspect that requires closer theoretical and empirical examination involves the sensitivity of green investments to changes in interest rates and credit supply. Systematic research in these areas is crucial to inform monetary policy development and enable decision makers and regulators to more effectively respond to the climate and environmental challenges of today's world.

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Declarations

Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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