

Modelling policy coordination and ecological transition policy

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ABSTRACT

Ecological transition calls for ecological structural change requiring smart and coordinated macroeconomic policies, and this article proposes macroeconomic modelling to provide a baseline analytical framework to tackle this issue. We can define “ecological policies” as all macroeconomic policies aimed at enhancing green productivity by increasing green sectors’ share and green productivity in all sectors, as well as by changing the components of aggregate demand according to green instances. Ecological policy coordination entails integrating traditional monetary and fiscal policies with typical industrial policies. This paper introduces an Eco 3-equation model, showing ecological macroeconomic policies’ positive role in promoting win-win strategies concerning environmental and social sustainability by examining a case study pertaining to energy inflation. This phenomenon is particularly relevant due to recent inflation caused by the hike in energy prices generated by the Ukraine war, which can potentially influence the economy adversely, involving complex monetary and fiscal policy responses.

1. Introduction

Two of the most pressing issues currently, environmental degradation and unemployment, have highlighted the need to analyse the relationship between sustainable development’s environmental and social dimensions (Chen et al., 2022). Focusing on sustainable development, ecological macroeconomics explicitly acknowledges the essential reliance of economic activities on the materials and energy derived from the planet by integrating various aspects of the real economy, the financial economy, and natural systems, offering a crucial conceptual framework for examining the aggregate macroeconomic impacts of sustainability policies (Victor, 2023). Defined in this paper as nations’ strategies for reducing CO₂ and other GHG emissions (Wan et al., 2022), the ecological transition to a low-carbon economy represents a shift towards enhanced energy efficiency, reduced greenhouse gas emissions, and the pursuit of a harmonious balance between economic progress and ecological well-being (Umar and Safi, 2023). It

necessitates the implementation of diverse climate policies, substantial technological advancements, investments in green technologies, and the initiation of significant socioeconomic transformations (Roy, 2024). Therefore, the ecological macroeconomics objective is to elucidate the interconnections among these dimensions and factors and develop sustainable and equitable policy responses for them (Rezai and Stagl, 2016).

While Daly (1991) argued the need to incorporate environmental issues into the macroeconomic frameworks used to analyse and propose consistent policies due to possible trade-offs between environmental and social goals, Jackson (2009), preceded by Victor & Rosenbluth (2007), highlighted explicitly the “need for an ecological macroeconomics” approach, then, the literature on ecological macroeconomic models has grown rapidly (Hardt and O’Neill, 2017, p. 199), attributing an essential role to policies and institutions. The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) define green growth as “a policy focus that emphasises “environmentally sustainable economic

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progress to foster low-carbon, socially inclusive development” (UNECE, 2011, p. 3). The crucial components of any green growth policy should include a strong green investment strategy, employment policies not reliant on high growth, distributive policies to mitigate severe income and wealth disparities, and stringent institutional requirements for financial stability (Jackson et al., 2016). Indeed, the main point in this field is that the market cannot automatically orient all agents toward achieving environmental goals or targets. Thus, a debate on how to govern, promote and coordinate this type of change is needed and is starting to emerge, given the crucial role of public investments. A strand of ecological macroeconomics, instead, focuses on the ecological structural change necessary for the low-carbon transition, which requires the augmentation of the share of green activities in output to reduce CO₂ and other GHG emissions by each unit of output produced by means of increasing the green productivity (defined as the inverse of the environmental pressure intensity) of the economic system (Guarini and Oreiro, 2023). Given the complexity¹ of the ecological transition, an ecological structural change requiring smart and coordinated macroeconomic policies becomes fundamental to support the ecological transition in the short and medium terms.

Ecological macroeconomics tries to incorporate the role of money and the financial system in the ecological transition debate. Proposing one of the primary analytical ecological macroeconomic models, Fontana and Sawyer (2013, 2016) recognise that government policies can effectively promote sustainable growth by influencing the behaviour of banks, financial institutions, and borrowers to promote sustainable long-term investments and consumption. Instead, Dafermos et al. (2018) explored “green” monetary policy’s role in reducing financial instability and mitigating global warming. Svartzman et al. (2019) significantly suggest how an endogenous approach to money can provide innovative methods to expedite and enhance the volume of green investments required for the transition. This is achieved through a combination of government spending, financial regulation, and monetary policy. Central banks must actively engage in policy development to combat climate change, as they cannot remain passive or replace government actions. They should actively collaborate with governments and other sectors to develop climate policies, focusing on coordinating fiscal, monetary, and prudential (Svartzman et al., 2021). In particular, implementing the 3-equation model of Carlin & Soskice (2015) for empirical analysis, Roy (2024) proposes a green monetary policy framework by including an emission reduction target among the traditional monetary objectives, highlighting the need to align monetary policy and environmental sustainability and a central role of central banks in promoting low-carbon transition because an increased flow of green credits can contribute to reducing GHG emissions and, at the same time, favours the price stability. However, all these contributions, particularly the last one, which is mainly an empirical study, do not explicitly propose the coordination of fiscal and monetary policies to reach social and environmental goals, which indeed is the aim of this article.

The significance of exogenous shocks in shaping transition processes is of substantial interest across various sustainability science research domains. These shocks warrant focused attention due to the anticipated increase in their frequency in forthcoming decades, driven by the climate and biodiversity crisis, escalating inequalities, and the consequent heightened potential for conflict and war (Johnstone and Schot, 2023). Among them, energy price shocks possess the potential to influence the economy adversely, and countries characterised by a high dependency on energy imports demonstrate a pronounced susceptibility to the volatility of energy prices. Energy serves as an input across all

production sectors, and its pricing influences the overall economic price level. Consequently, price increases in intermediate goods typically manifest as inflationary effects (Ahlroth and Höjer, 2007). As posed by the Executive Board of the ECB, we are facing a new age of energy inflation with three distinct but interrelated shocks. Schnabel (2022) suggests that central banking institutions may need to adjust to a prolonged increase in inflation rates due to the expenses associated with environmental disasters related to climate change, a phenomenon referred to as “climateflation”. At the same time, the green transition could also expose the economy to “green inflation” because the required decrease in the investments in the exploitation of oil, coal and gas will produce a long-term increase in energy prices that is expected to pressure the prices of an extensive range of goods and commodities, especially for those with low elasticity and demand not declining. Finally, the author maintains that the “fossilflation” shock represents the enduring costs of reliance on fossil fuels and could significantly contribute to the recent surge in inflation. These aspects are now particularly relevant because the hike of energy prices due to the war in Ukraine is one of the drivers of current inflation acceleration; more precisely, energy prices started to rise in the summer of 2021, and the Ukraine War accelerated the significant increase in energy and food prices with a consequent surge in inflation rates (Jones, 2022).

Alterations in energy pricing exert multifaceted impacts on real and financial variables, subsequently initiating intricate feedback mechanisms that encompass responses from monetary and fiscal policies. As mentioned before, policymakers are discussing the advent of a novel era characterised by inflationary pressures associated with energy prices, and how monetary policy should respond to it has become the subject of intense debate (Schnabel, 2022). Introducing energy and capital accumulation in Blanchard & Gali (2007) model, Florent (2016) observes that an increase in energy efficiency significantly mitigates the impact of an oil shock, which may explain why the third oil shock (1999–2008) did not have the same macroeconomic effects. Within the ecological macroeconomics framework, Richters (2015) and Berg et al. (2015) observe that energy price shocks can suppress real wages, reduce demand, and consequently initiate severe recessions. However, none of these works directly evaluate any possible policy response.

Thus, this article aims to contribute to the existing literature by carrying out an analytical exercise by using a standard 3-equation model to analyse the relevance of policy coordination to face the challenges of ecological transition with a relevant case study concerning energy inflation. This exercise represents a variation of the traditional mainstream new Keynesian model, as other contributions that amend this base model to discuss some specific policy points, such as Michl and Oliver (2019). Indeed, our paper proposes an Eco 3-equation model that aims to highlight the need for policy coordination for supporting ecological conversion by responding to energy price shocks, bearing in mind the current policy dilemma between achieving a level of output compatible with some medium target for GHG emissions and a social level compatible with full employment. It explains how integrating macroeconomic, fiscal, and monetary policies is even more essential in the current geopolitical context with exogenously rising energy prices to achieve inclusive and sustainable development.

The remainder of the paper is structured in four sections to bring together policy coordination and ecological transition. Section 2 introduces the macroeconomic policies and the crucial role of policy coordination in ecological transition. Section 3 presents the eco 3-equation model. Section 4 illustrates the case study of the anti-energy inflation policy, highlighting the necessity of policy coordination for ecological structural change to reduce unit energy costs by increasing energy productivity. Finally, Section 5 is devoted to concluding remarks.

2. Policy coordination: the ecological policies

Recognising the potential of environmental sustainability as a catalyst for growth has prompted numerous national governments to

¹ On the one hand, revolutionary and fully effective green technologies will only be definitively developed and implemented in the long term (Ball, 2021), and on the other one, the technological progress could generate an energy rebound effect (Ahmad & Wu, 2022),

prioritise the promotion of new clean energy technologies, ultra-low carbon technologies, and enhanced energy efficiency (Di Tommaso, Tassinari, et al., 2020). Environmental fiscal policies have often been adopted to promote energy-saving technologies in industries that exhibit poor ecological performance or to foster innovation and international competitiveness due to their ability to internalise negative externalities in the price of polluting goods, enhancing employment and income distribution and reducing energy consumption simultaneously (Galindo et al., 2020). However, their effectiveness in stimulating companies to start the ecological transformation is debated today: they could produce a reverse effect, pushing companies first towards green technologies and moving them back towards polluting ones the more the regulation becomes stringent (Krass et al., 2013).

Green investments² are more sensitive to financial constraints compared to traditional ones due to higher initial capital costs, longer payback horizons, riskier business projects, higher uncertainty and higher technological complexity (Ghisetti et al., 2015; Mazzucato and Semieniuk, 2018). An important constraint on green investments is their unfavourable risk-return profile. To attract investors, the returns on these investments must be substantially high due to inherent risks (Campiglio, 2016). From a macroeconomic perspective, they are considered a form of expenditure requiring public support so that institutional investors could have a crucial role in the ecological transition (Della Croce et al., 2011). A possible green monetary policy could act on green differentiated reserve requirements: the reserve ratio requirement for loans targeting low-carbon projects, especially in the energy sector, would be set below the average (Rozenberg et al., 2013). Since banks generate profits through lending and a lower reserve ratio allows for a greater credit capacity, this policy could encourage banks to increase their borrowing towards green investments. A similar proposal suggests implementing differentiated capital requirements and a regulatory framework with looser requirements for banks' lending to low-carbon sectors could direct more credit towards them. For example, the Reserve Bank of India (2014) mandates that commercial banks allocate a specified proportion of their lending to designated "priority sectors", which now encompass renewable energy.

Alternatively, the Bank of Japan's Loan Support Program provides loans to financial institutions at below-market rates to support various lending priority sectors, including environment businesses (Campiglio et al., 2018). However, this approach is more likely to succeed in emerging economies, where central banks typically have greater control over credit dynamics due to their use of diverse "quantitative" monetary policy tools. Conversely, in high-income economies, the reliance solely on interest rates limits central banks' ability to influence private banks' lending behaviour (Campiglio, 2016; Oreiro, 2024, chapter. 6). Finally, central banks could integrate climate-related criteria when determining asset eligibility for asset purchases and collateral and haircut frameworks. These frameworks specify assets financial institutions can pledge to borrow from central banks and the borrowing limits. The criteria for collateral eligibility and imposed 'haircuts' significantly affect asset desirability and pricing. Including climate considerations could incentivise the issuing of such financial instruments, impacting the economy (Campiglio et al., 2018).

Historically, industrial policy has emphasised enhancing productivity as the fundamental mechanism to guarantee increasing returns to capital and labour and fostering prosperity (Altenburg and Rodrik, 2017). Indeed, the world has witnessed an upsurge of industrial policy interventions, mainly as a tool to deal with sudden emergencies and shocks, such as the 2008 financial crisis, the COVID-19 pandemic, and

the geopolitical tensions following the war in Ukraine. Parallel to this, academia has paid renewed attention to industrial policy. Industrial policy can be considered a holistic approach to support growth, competitiveness, productivity, innovation, and employment generation, promoting a more dynamic and competitive industrial system. Focusing on environmental sustainability, it could include specific goals, such as reducing greenhouse gas emissions or energy intensity (Di Tommaso, Spigarelli, et al., 2020; Ferrannini et al., 2021). Industrial policy is frequently linked to governmental interventions aimed at influencing production dynamics to foster economic performance and achieve broader developmental goals through structural change. Despite the persistent need for such interventions to address various economic and social challenges, industrial policy, particularly selective sort-risk, may be highly ineffective and inefficient due to numerous unresolved issues related to government failures. In particular, the literature highlights potential failures, such as governments being swayed by special interests and rent-seekers, prioritising the loudest voices over societal interests. Additionally, governments may struggle with information asymmetries and the accurate identification of targets and tools necessary for achieving collective objectives (Di Tommaso et al., 2020).

Due to the several required transformations in various sectors, the ecological transition is nearly impossible without policy coordination (Altenburg and Rodrik, 2017). Indeed, a collaborative strategy encompassing environmental and industrial policies exhibits intricate linkages with fiscal, monetary, competition, trade, technology, labour, and wage policies, necessitating careful consideration (Pianta and Lucchese, 2020). Focusing on the Chinese context, Zeraibi et al. (2022) highlight the impossibility of achieving economic and environmental sustainability through unrelated fiscal and monetary policies in the short and long term. Governments and Institutions, like Central Banks and Development Banks, must strategically coordinate diverse sets of policy instruments operating in different domains and address various levels of the economy, aligning several policies and incentives in time and over time (Andreoni and Chang, 2019). Campiglio (2016) has suggested introducing a carbon price through a tax as a possible way to coordinate the fiscal system and the monetary incentives to stimulate green investments. However, this measure is often hampered by capitalists who deem it risky for business by driving up energy costs and have little faith in long-term political engagement.

On the contrary, ecological industrial policy encompasses any institutional measure designed to speed the structural shift towards a low-carbon economy while fostering green productivity enhancements (Altenburg and Rodrik, 2017). Therefore, they can coordinate industrial productivity with other policy fields, such as competitiveness, education and training, R&D, and environmental sustainability (Ferrannini et al., 2021). An example is the green quantitative easing proposed by Dafermos et al. (2018): to define the baseline interest rate and achieve the inflation target, central banks should buy green corporate bonds, favouring the stability of the financial system and reducing the borrowing cost of green projects.

Obstfeld and Rogoff (2002) highlight the significant role of policy coordination in managing the adverse effects of exogenous shocks and ensuring economic stability. In particular, Hein (2023a) and Hein & Stockhammer (2010) suggest that the macroeconomic policy mix offers an alternative strategy for addressing imported energy inflation shocks. To address energy inflation shocks, central banks should avoid macroeconomic fine-tuning, maintain stable, low long-term real interest rates, and manage asset price inflation and financial stability through means other than interest rate policies. Fiscal policies should be designed to stabilise aggregate demand and employment at optimal levels without triggering inflation while also aiming to diminish income inequality (Hein, 2023; Hein and Stockhammer, 2010).

² Green investment refers to investment across all productive sectors that enhance the environmental sustainability of the economic system, including the generation of energy from renewable sources, and improvements in energy efficiency within buildings and transportation (Campiglio, 2016).

We can define “ecological policies” as all macroeconomic policies³ that aim to promote, sustain and favour an ecological structural change aimed at increasing green productivity by growing both green sectors’ share and green productivity in all sectors as well as by changing the components of aggregate demand according to green and social instances (Guarini and Oreiro, 2022). Monetary and financial policies can promote green finance⁴ to sustain green investments by reducing financial costs in terms of lower interest rates and more financial facilities and by providing specific financial products such as green bonds for energy efficiency projects (Durrani et al., 2020). Favouring the emergence of new green sectors and activities, environmental regulations, in particular, fiscal policies, stimulate technological progress, increasing the country’s innovative capacity, production efficiency, and employment level (Domguia et al., 2022). According to the Porter Hypothesis, environmental regulations can reduce the uncertainty of green investments, stimulate the firms’ animal spirit of innovation and progress, and sustain firms engaged in green investments by prohibiting other firms with no green investments from gaining market power (Guarini, 2020; Porter and Van der Linde, 1995).

Most of the interventions mentioned above intend to promote a structural change that modifies the composition of output (and labour) towards green sectors, or influences targeted companies’ behaviour towards greening⁵ their production processes. In this framework, the distinction between pure macroeconomic policies and industrial policies becomes blurred. Considering the complementarities between traditional macroeconomic policies and industrial and innovation policies, which combine technological processes and sectoral division of labour to achieve sustainability goals, becomes necessary (Pianta, 2010). Industrial policy can be seen as a set of connected actions – involving governments and private agents – aimed at governing the process and the speed of structural changes toward normatively defined development goals. In this framework, the ecological transition is a change that society considers desirable and public policies are how economic systems promote a collective effort toward that direction. Fiscal or monetary policies providing incentives to companies to green their production processes or to people to buy electric vehicles or public expenditures for the development of renewable energy sectors are also industrial policies, given that they aim at the industrial structure of countries. In this sense, the ecological transition entails a new comprehensive policy strategy based on designed industrial and macroeconomic policies.

³ The article sets out a critical, albeit simple, macroeconomic model that seeks to integrate some sectorial mechanisms typical of industrial policy. In fact, the critical exercise considers its impacts on labour productivity and energy productivity, which are variables that are exogenous to the theoretical model.

⁴ Green finance encompasses a wide range of financial investments directed towards projects and initiatives focused on sustainable development, as well as environmental products and policies that promote the advancement of a more sustainable economy. In essence, green finance represents a necessary model for project financing that harmonises the pursuit of economic gains with environmental protection and social equity (Sharma & Kautish, 2023). In particular, “Green finance embraces long-term investment principles that lead to environmental benefits, propels innovations in green industrial technologies, thereby causing improvements in energy consumption and its accompanying benefits [...]. Distinct from conventional financing, which excludes issues of social and environmental justice, green finance primarily promotes ethical investments that preserve the environment and climate, minimizing the negative impact of energy consumption” (Akomea-Frimpong et al., 2022, p. 356).

⁵ A green economy can be defined as an economic system that emphasises sustainability and environmental protection while advancing social and economic well-being. It is marked by a transition from polluting industries to cleaner ones, more efficient technologies and practices. This includes adopting renewable energy sources, implementing circular economy models, and developing green infrastructure and services (Karri et al., 2024).

3. The eco 3-Equation Model

Modern monetary macroeconomics is mainly based on the so-called 3-Equation Model: AD curve, Phillips curve, and interest rate-based monetary policy rule (Carlin and Soskice, 2009). This model replaced the old-fashioned IS/LM and AD/AS models as the primary analytical tool for teaching and macroeconomic policymaking. This model incorporates how Central Banks conduct monetary policy in the real world. Instead of considering the money stock as given as it occurs in IS/LM and AD/AS models, the 3-equation model takes money interest rate as a policy variable determined by a forward-looking Central Bank and money as an endogenous variable. Inflation can be modelled as the result of conflict claims on income made by workers or trade unions and firms, which are affected by the relative bargaining power of the two groups (Carlin and Soskice, 2015, chapter 2). In this framework, institutional features such as the level of centralisation and coordination of wage bargaining, the proportion of employees belonging to a union (union density), and the proportion of employees whose wages are covered by union wage agreements (coverage) can affect the relative bargaining power of workers and hence real wages, inflation, and employment level (Ibid, chapter 15). Institutional change, such as an increase in the level of centralisation and coordination of wage bargaining, can improve the macroeconomic performance of market economies, reducing the equilibrium level of inflation and unemployment (Oreiro and Basilio, 2022). Hope and Soskice (2016) proposed the 3-equation model as the textbook representation of the macroeconomic foundations of Comparative Political Economy (Stockhammer, 2022). The authors suggest that a significant advantage of the 3-equation model is its reflection of macroeconomic institutions typical of advanced economies. It demonstrates how an inflation-targeting central bank stabilises the economy and how fiscal policy can influence effective demand. They sustain that the 3-equation model offers a coherent framework further to explore the interaction between macroeconomic policy and growth models, highlighting the importance of monetary, fiscal, and other government policies. Due to its simplicity and widespreadness for teaching macroeconomics, it could be adapted and used to illustrate merely and effectively the differences between conventional and ecological policies. Especially, it helps evaluate commodity price shocks and the consequent policy response (Fontana and Setterfield, 2016).

Thus, let us carry out an eco 3-equation model to analyse a general policy issue concerning ecological transition and policy coordination with a specific case study on energy inflation. The Phillips curve is modified to incorporate the effect of “ecological structural change” through energy productivity improvement. Macroeconomic policy-making must also consider the constraint imposed by *environmental sustainability* in terms of using an intermediate input (energy) that produces a negative externality (CO₂ and other GHG emissions).

3.1. The baseline model

We consider a closed economy that produces a homogenous output using labour and energy as variable inputs. A Leontief production function represents technology⁶ as in Eq. (1):

$$Y = \min\{\varepsilon E; \pi L\} \quad (1)$$

Where: Y is the level of real output, E is the quantity of energy used in the production process, L is the number of workers employed in the production process, $\varepsilon = \frac{Y}{E}$ is energy productivity, namely the quantity of output produced by each unit of energy used (a higher ε means that the production process is more efficient in terms of energy use), and $\pi = \frac{Y}{L}$ is

⁶ Since we are using a Leontief function, technology, and then, scale returns are constant at firms level.

the labour productivity.

According to [Kalecki \(1971\)](#), firms use mark-up pricing over unit costs, fixing a mark-up $\sigma = (1 + \mu)$ over total unit costs. Since technology does not allow for substitution between labour and energy, we assume that unit labour and unit energy costs have a constant share in total unit costs. So, the pricing equation is given by:

$$p = \sigma \left(\frac{p_e}{\varepsilon} \right)^\theta \left(\frac{w}{\pi} \right)^{1-\theta} \quad (2)$$

Where p is the unit price of output, p_e is the unit price of energy,⁷ w is the unit price of labour, i.e., the nominal wage rate.

Taking logs and time derivative in [Eq. \(2\)](#), we get:

$$\hat{p} = \theta \hat{p}_e + (1 - \theta) \hat{w} \quad (3)$$

Where: $\hat{p}$ is the rate of inflation, $\hat{p}_e$ is the rate of change in energy prices, $\hat{w}$ is the wage inflation.

[Eq. \(2\)](#) gives the real product wage. After some mathematical manipulations, we get the following:

$$\omega = \frac{w}{p} = \left[\frac{\varepsilon \pi}{\sigma q^\theta} \right]^{\frac{1}{1-\theta}} \quad (4)$$

Where: ω is the real product wage and $q = \frac{p_e}{p}$ is the relative price of energy.

The dynamics of the relative price of energy is given by:

$$\hat{q} = \hat{p}_e - \hat{p} \quad (5)$$

Let us consider that the rate of change of the relative price of energy is zero so that the relative price of energy is constant, i.e. $\hat{q} = 0$, thus obtaining:

$$\hat{p} = \hat{p}_e \quad (6)$$

Substituting (6) in (3), we get:

$$\hat{p} = \hat{w} \quad (7)$$

Nominal wage inflation depends on inflation expectations by labour unions and the difference between the target real wage and the actual wage rate or the “aspiration gap”, in the words of [Rowthorn \(1980, p. 149–151\)](#).

Wage inflation⁸ is given by [Eq. \(8\)](#):

$$\hat{w} = \hat{p}^* + \gamma(\bar{\omega} - \omega) \quad (8)$$

Where: $\bar{\omega}$ is the target real wage and $\hat{p}^*$ is expected inflation by labour unions.

The target real wage will depend on the bargaining power of unions relative to firms in wage negotiations. Among several factors that can influence the relative bargaining power of unions, one of the most important is the employment rate ([Rowthorn, 1980, p. 154](#)). So, the target real wage can be expressed by:

$$\bar{\omega} = \omega_0 + \omega_1 e \quad (9)$$

Where: ω_0 is a positive parameter representing the several institutional factors that affect the target real wage by unions, $e = \frac{L}{N}$ is the employment rate, ω_1 is a positive parameter capturing the sensitivity of the

target real wage to changes in the employment rate, N is the amount of labour force.

Substituting (9) into (8), we get:

$$\hat{w} = \hat{p}^* + \gamma(\omega_0 + \omega_1 e - \omega) \quad (8a)$$

After substituting (8a) into (7), we arrive at the equation of the Phillips curve:

$$\hat{p} = \hat{p}^* + \gamma(\omega_0 + \omega_1 e - \omega) \quad (10)$$

3.2. Social sustainable level of output

[Hope and Soskice \(2016\)](#) sustain that, in the 3-equation model, increased economic activity is associated with higher employment levels, which subsequently results in elevated inflation rates. The model represents a variant of the natural rate of unemployment, also known as the NAIRU (non-accelerating inflation rate of unemployment) model. The natural rate refers to the level of unemployment at which inflation remains stable, determined solely by labour market institutions such as the extent of collective bargaining, the configuration of the welfare state, and the organizational capabilities of unions rather than by demand factors or the actual unemployment rate. Therefore, labour market institutions, such as collective bargaining, contribute to wage rigidities, which in turn result in unemployment. Typically, there exists a singular (liberal) socially optimal institutional equilibrium ([Stockhammer, 2022](#)).

In [Eq. \(10\)](#), the actual inflation depends on expected inflation and the employment rate. From [Eq. \(10\)](#), we can define the *equilibrium rate of employment* as the employment rate for which actual and expected inflation is equal, namely $\hat{p} = \hat{p}^*$. [Eq. \(11\)](#) gives the equilibrium rate:

$$e^{**} = \frac{\omega - \omega_0}{\omega_1} = \frac{\left[\frac{\varepsilon \pi}{\sigma q^\theta} \right]^{\frac{1}{1-\theta}} - \omega_0}{\omega_1} \quad (11)$$

In [Eq. \(11\)](#), we can see that the equilibrium level of employment depends on the relative price of energy. Indeed, a once and for all increase in the relative price of energy – which is compatible with energy inflation being equal to general inflation after the shock – will result in a decrease in real product wage, thus increasing the “aspiration gap” and hence producing an acceleration of inflation due to conflict claims over real income. In order to make claims of workers and firms over real income compatible with one another, the employment rate must be reduced in order to reduce the bargaining power of trade unions and the desired real wage.

Aimed to identify a sustainable and inclusive development path, we can define the level of output⁹ which is *Socially Sustainable* (Y^{SS}) from [Eqs. \(1\)](#) and (11) since it is the level of output for which both firms and unions are satisfied with the level of the real wage. Hence, there are no distributive claims.

$$Y^{SS} = \pi N e^{**} = \pi N \left(\frac{\omega - \omega_0}{\omega_1} \right) \quad (12)$$

3.3. AD-with central bank equation

Following [Carlin & Soskice \(2009, p.16\)](#), the AD equation is given by:

$$Y = A - \alpha r \quad (13)$$

⁷ In many countries, as for example, Brazil, energy prices can be considered a policy variable since the government set rules for changes in the prices of oil and electricity making these prices to be managed prices instead of free prices that can be changed according to firms' discretion.

⁸ Wage increases are supposed to be based on last period inflation. This is due to the inflation indexation of wage contracts in many countries that had a history of high inflation such as in Latin American Countries (see [Oreiro & Santos, 2023](#)).

⁹ For reasons of clarity of exposition, we had to stress that we are defining two different concepts of sustainable level of output. One is the socially sustainable level of output, which is the level of output for which there are no conflicting claims over real income. The other one is the ecologically sustainable level of output, which is defined as the level of output that is compatible with some target for GHG net emissions. There is no a priori reason to suppose that both levels of sustainable output are equal.

Where: A is the level of autonomous expenditure, including government expenditure and taxation, $r = i - \hat{p}$ is the level of real interest rate, i is the level of nominal interest rate, and α is the sensitivity of aggregate demand to changes in real interest rate.

The Central Bank sets the nominal interest rate to achieve target inflation, $\hat{p}^T$. For simplicity, we assume that the Central Bank adopts *strict inflation targeting*, so its monetary policy rule is given by:

$$i = \bar{i} + \beta(\hat{p} - \hat{p}^T) \quad (14)$$

Where $\beta > 1$ is the degree of inflation aversion¹⁰ of the Central Bank and $\bar{i}$ is the Central Bank's estimation of the long-run equilibrium value of the nominal interest rate.

From Fisher's identity, we know that:

$$r = i - \hat{p} \quad (15)$$

Replacing (14) and (15) into (13), we get:

$$Y = A - \alpha(\bar{i} + (\beta - 1)\hat{p} - \beta\hat{p}^T) \quad (16)$$

$$\text{Where: } \frac{\partial Y}{\partial \hat{p}} = -\alpha(\beta - 1) < 0$$

Eq. (16) describes the aggregate demand (AD) curve, the *locus* of combinations between the output level and the current inflation for which aggregate demand is equal to the output level.

3.4. The environmentally sustainable level of output

Then, we introduce a vertical curve representing the Environmentally Sustainable level of output (Y^{ES}):

$$Y^{ES} = \frac{Y}{E} \frac{E}{H^S} H^S = \frac{\varepsilon}{\eta} H^S \quad (17)$$

Where: Y^{ES} is the level of output compatible with some target level for the net of GHG emissions (H^S) defined by some institutional ecological targets coherently to the Sustainable Development Goals of the UN Agenda 2030 (UN, 2015), ε is energy productivity, while $\eta = \frac{H^E}{E}$ is the net flow of GHG emissions per-unit of energy produced.

The idea behind Eq. (17) is that production requires the use of energy which cannot be produced without a negative externality over the environment, which is the emission of GHG responsible for the so-called *greenhouse effect* (See Grazini et al., 2024). Since GHG emissions must be reduced to some target level in the medium term, Eq. (17) gives the level of output that is compatible with such target. As we can see in Eq. (17), the Environmentally Sustainable Level of Output can be increased by policies that aim to (i) increase the energy productivity (ε) or (ii) reduce the net flow of GHG per unit of energy produced (η).

Given the target level of GHG net emissions (H^E), a decrease in η thanks to the employment of renewable energies and/or an increase of ε allows for a rise in the real output and employment in an environmentally sustainable way through a direct impact on the sectors providing goods and services needed for implementing green innovations; an indirect one in industries producing intermediate goods and induced one due to energy costs reduction and an increase of income and wages (Yushchenko and Patel, 2016).

3.5. The phillips curve

The Phillips curve can be expressed in terms of real output instead of the rate of employment, as we can see in Eq. (18):

$$\hat{p} = \hat{p}^* + \gamma(\omega_0 + \omega_2 Y - \omega) \quad (18)$$

Where: $\omega_2 = \frac{\omega_1}{\pi N}$

Replacing Eq. (4) into Eq. (18), we obtain¹¹:

$$\hat{p} = \hat{p}^* + \gamma \left(\omega_0 + \omega_2 Y - \left[\frac{\varepsilon \pi}{\sigma \varphi^\theta} \right]^{\frac{1}{1-\theta}} \right) \quad (19)$$

Considering that the Monetary Regime is Inflation Targeting and that target inflation ($\hat{p}^T$) is fully credible than:

$$\hat{p}^* = \hat{p}^T \quad (20)$$

Inserting (20) into (19), we get:

$$\hat{p} = \hat{p}^T + \gamma \left(\omega_0 + \omega_2 Y - \left[\frac{\varepsilon \pi}{\sigma \varphi^\theta} \right]^{\frac{1}{1-\theta}} \right) \quad (21)$$

Eq. (21) is the full version of the Phillips curve (PC curve). An increase in energy productivity (ε) or the productivity of labour (π) will reduce the current level of inflation for a given expected inflation. An increase in the relative price of energy ($\varphi = \frac{p_e}{p}$) – as caused by the War in Ukraine – will increase the current inflation rate for a given expected inflation.

So, our Eco 3-equation model¹² is composed of the following equations:

$$\text{AD curve : } Y = A - \alpha(\bar{i} + (\beta - 1)\hat{p} - \beta\hat{p}^T) \quad (16a)$$

$$\text{PC curve : } \hat{p} = \hat{p}^T + \gamma \left(\omega_0 + \omega_2 Y - \left[\frac{\varepsilon \pi}{\sigma \varphi^\theta} \right]^{\frac{1}{1-\theta}} \right) \quad (21a)$$

$$\text{Social sustainability curve : } Y^{ss} = \pi N e^{**} = \pi N \left(\frac{\omega - \omega_0}{\omega_1} \right) \quad (12a)$$

$$\text{Environmental sustainability curve : } Y^{ES} = \frac{Y}{E} \frac{E}{H} H = \frac{\varepsilon}{\eta} H^S \quad (17a)$$

3.6. The short-medium run equilibrium

In the short-medium run, inflation can accelerate or decelerate over time due to the incompatibility of claims over the income of unions and firms. We assume that the output level compatible with the target level of utilisation of energy is lower than the output level that satisfies both firms and unions with the real wage. In other words, the environmentally sustainable output level is lower than the socially sustainable output level.

Fig. 1 shows the short-medium run equilibrium of the economy,

¹¹ We have to discuss the nature of the relative price of energy. Equation (18) assumes that $\varphi = \frac{p_e}{p}$ is constant due to the fact that energy inflation and general inflation are equal. This does not mean that the relative price of energy can not be changed at all, but we have to differentiate between changes in the level of the relative prices from changes in the rate of change in relative prices. Our model supposes that the rate of change of the relative price of energy is zero – see equations (5) and (6) – but this does not mean that the level of relative price of energy can never change due to exogenous factors in the international market of energy. Indeed, energy is a tradeable good whose price is determined at international markets, so that it can be taken as an exogenous variable in our model.

¹² Even if the final system is composed of 4 equations, the term 3-equation has been maintained by adding the only term “Eco” to make the explicit reference to the literature to which the paper wants to contribute. In particular, the choice is made to make it clear to the reader, already by the title, that the purpose of the article is to present a critical exercise aimed at extending the traditional 3-equation model, which serves as the baseline reference model, to address ecological issues through the case study of energy price inflation.

¹⁰ The parameter β represents the weight attributed to inflation in the central bank loss function. According to Carlin & Soskice (2009), if $\beta > 1$, central bank is more adverse to a inflation deviation than to a deviation of output or employment from the target.

where Y^{SMRE} and $\hat{p}^{SMRE}$ are the equilibrium level of output and inflation, respectively, which are formally determined in Appendix A. The position of the aggregate demand curve depends on the level of autonomous expenditure (A) and target inflation ($\hat{p}^T$). The position of the Phillips curve depends on the expected inflation ($\hat{p}^*$) and the relative price of energy (φ). In the equilibrium, we have $Y^{ES} < Y^{SMRE} < Y^{SS}$, so policymakers face a *trade-off between environmental and social sustainability*. This initial condition imposes an ecological trade-off: income should shrink from being environmentally sustainable and expanding to be socially sustainable.

4. Prudential monetary policy vs coordinated ecological policies: the energy inflation case

In this section, we develop a possible policy scenario to achieve social and sustainable development within the above-mentioned macroeconomic framework to examine the positive effects of an expansionary ecological policy. Therefore, we introduce an inflationary shock produced by an exogenous rise in energy prices and compare mainstream monetary and ecological macroeconomic policies.

4.1. A prudential monetary policy

Following the 2008 crisis, the effectiveness and relevance of the central bank's monetary policy frameworks centred around inflation targeting are often the subjects of debate due to the already minimal interest rate levels (Duarte, 2019). To examine an inflation shock caused by increased energy prices, we start from the short-medium run equilibrium condition in Fig. 1. An increase in the relative price of energy ($\uparrow\varphi$) shifts the PC curve to the left from point 1 to point 2 in Fig. 2a, which shows a mainstream policy strategy based on a conservative central bank decision to increase interest rates (Qanas and Sawyer, 2023).

According to the Taylor rule (Poutineau et al., 2015, p. 15), the increase in the actual level of inflation will require a more than proportionate increase in the level of nominal interest rates (since $\beta > 1$) to reduce the level of output and employment and force a decrease in the expected inflation and hence a shift of the PC curve to the right returning to the original position in point 1 in Fig. 2b. This policy response to the energy shock does not change the situation of social and environmental unsustainability before the shock. According to the standard mainstream view, the initial rise in the nominal interest rate translates into a corresponding increase in the real interest rate during the initial period. Consequently, as the Euler condition indicates, this reduction in demand prompts households to postpone consumption through intertemporal consumption smoothing. As demand drives economic activity, firms experience a decline in production. Simultaneously, the reduction in demand results in disinflation. Over time, the economy begins to recover, as the Taylor rule states, which suggests that a decrease in both

economic activity and inflation rate leads to a reduction in the nominal interest rate after the initial period (Poutineau et al., 2015).

However, when inflation is caused by an increase in the relative price of energy, institutional measures can move the PC curve toward the right by managing the dynamics of energy prices. Financial institutions must be able to regulate energy markets, such as by implementing price caps or reducing speculation activities that create instability. Indeed, the economy may not be able to return to the initial equilibrium point if financial speculation amplifies energy inflation. Recently, “energy financialization” has become a relevant topic because the swift growth of energy futures markets has drawn significant financial capital towards speculative activities, overshadowing investment in industrial production, with speculation now dominating energy futures markets (Xiao and Wang, 2022). The speculation on energy financial markets negatively affects the volatility of international oil and natural gas prices and their indeterminacy (Guo et al., 2022). Especially in the presence of an exogenous increase in energy prices, financial speculation can produce price deviations from their basic level, leading to speculative bubbles (Yao and Alexiou, 2022). In this case, this monetary policy could fail because finance speculation does not reduce price expectations but increases them, thus preventing the reduction of output and employment, which would allow the PC curve to be brought back to the initial equilibrium point. Indeed, institutions should consider the large increasing impact of financial operations on the dynamics of intermediate input prices (Guo et al., 2022).

This first case can regard the debate about the current strategy of the European Central Bank (ECB) in facing energy inflation. In November 2022, European energy prices exceeded the average of the last two years by four times, bringing with them the rate of inflation that has increased by 10 %. As referred to by Luis De Guindos,¹³ the ECB vice president, the three key interest rates have risen by 75 basis points to stabilise inflation around the 2 % medium-run target. However, the rise of interest rates is expected to weaken the European real economy through a permanent increase in unemployment (Andersson, 2023). Adopting inflation targeting could harm the average output growth and the level of employment (Khan, 2022). To avoid this effect, monetary policies should be integrated with fiscal policies and structural changes supporting the real economy (Andersson and Jonung, 2023).

4.2. A potential ecological policy strategy

The only way to make socially and politically acceptable the ecological transition is through ecological structural change. So, this section examines a *potential ecological policy strategy* based on policy coordination: institutions accelerate an ecological structural change by implementing expansionary ecological macroeconomic policies to reduce unit energy costs by increasing energy productivity ($\uparrow\epsilon$); the potential inflationary effects of an increase in autonomous expenditure (mainly *state-led investment in green technologies*) are compensated by the reduction in unit production costs allowing an expansion of the level of employment and output with a non-inflationary growth in the real wage (see Eq. (3)).

As in the previous case, the economy is in point 1 in Fig. 3a, the short-medium run equilibrium condition. The inflation shock shifts the PC curve to the left, switching from PC_0 to PC_1 and the economy moves from point 1 to point 2 in Fig. 3a. Since traditional monetary policy can only restore the economy towards the initial equilibrium or even towards a deterioration in the presence of financial speculation, we assume that the central bank decides to adopt a less austere monetary strategy, reducing the parameter β , namely *the central bank becomes less averse to the inflation*. In other words, the central bank will increase the interest rate less than in the previous case because it is willing to accept a

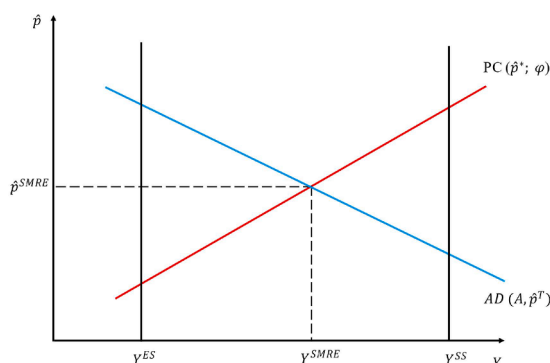


Fig. 1. Short-medium run equilibrium in the Eco-3- Equation model.

¹³ <https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp221104~b1fcbe7e6.en.html>

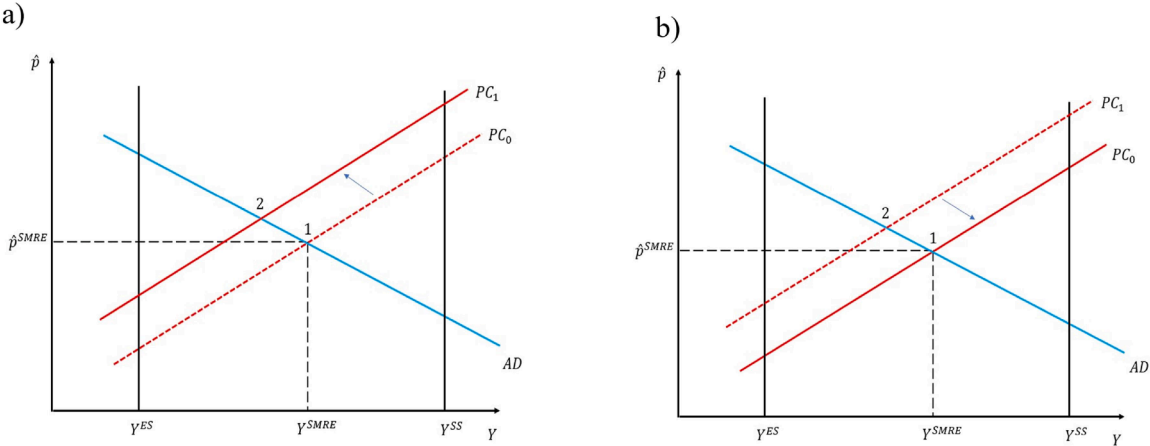


Fig. 2. A prudential monetary policy.

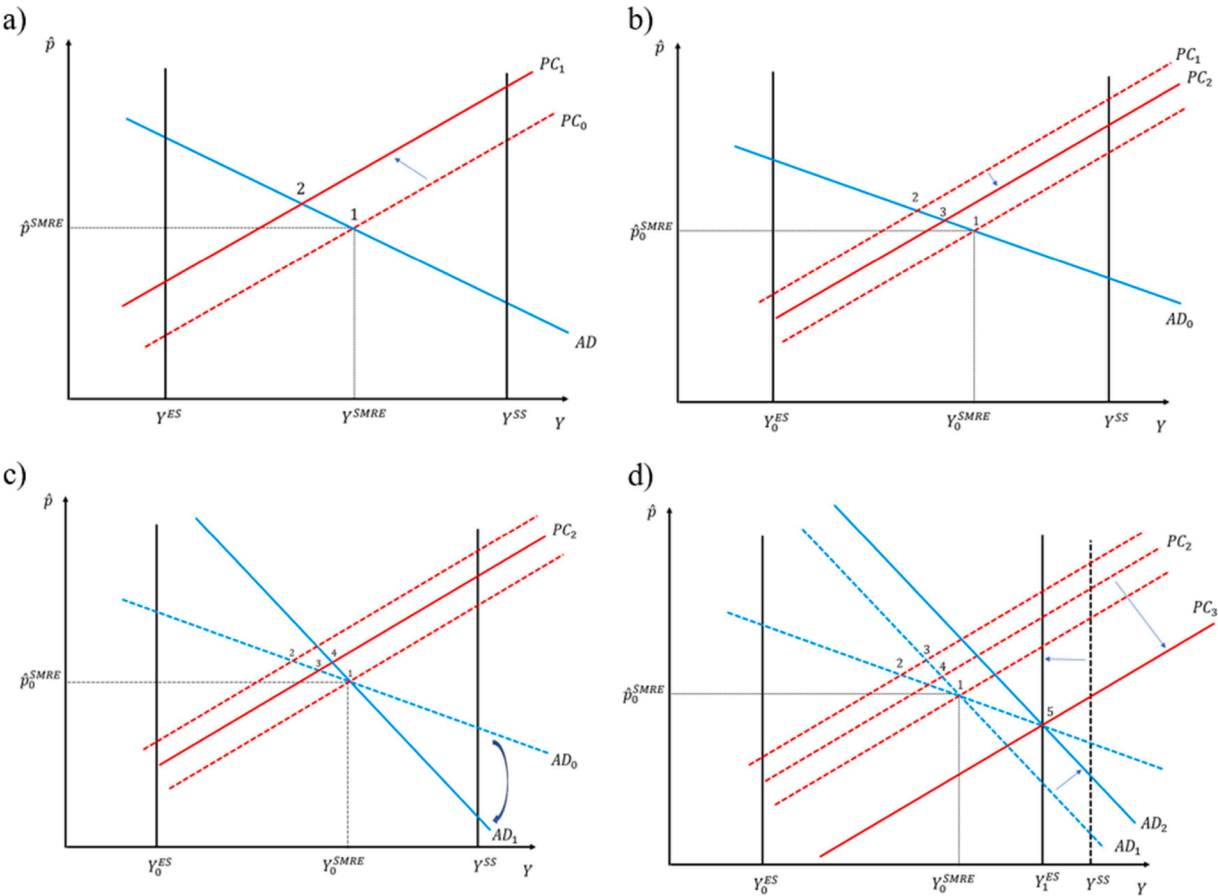


Fig. 3. Policy coordination.

decrease in inflation only in the face of a minor reduction in output (Carlin and Soskice, 2009). Capitalist economies need regulations to control financial speculation and excesses (Palley, 2013). For instance, the Federal Reserve redirected credit expansion towards speculative endeavours, focusing primarily on managing consumer price inflation while neglecting the inflation of asset prices. Consequently, the central bank's macroeconomic strategy evolved to leverage the wealth effect of asset price inflation to stimulate consumer spending. (Coombs and Thiemann, 2022). Therefore, the central bank adopts a strategy that allows it also to limit speculative finance, thus shifting the PC curve to the right from PC_1 to PC_2 and the economy could be in the point 3 in Fig. 3b.

At the same time, as the parameter β decreases, the AD curve becomes steeper¹⁴ going from AD_0 to AD_1 : the slight increase in the real interest rate will boost investments, especially since it has a relatively greater impact on green investments. High development costs, high business uncertainty, and the lack of a favourable political framework represent significant financial constraints on their diffusion (Lai et al., 2022). The high upfront costs and the riskiness tend to reduce the returns of green investments, which largely depend on macroeconomic conditions and, in particular, on the interest rate (Saeed et al., 2021). In particular, the interest rate influences the competitiveness of green investments over brown ones because green technologies are more capital-intensive than traditional ones (Eyraud et al., 2013). Therefore, green investments seem to show greater sensitivity to changes in the interest rate, which means more excellent responsiveness to a low increase/decrease in this variable (Monnin, 2015). To allow a less restrictive monetary policy, the central bank requires the economic system to invest in energy efficiency projects supporting the transition to a low-carbon economy. Just the coordination between monetary policy and an ecological industrial policy can represent the solution to the inflationary shock by bringing the economy back to point 1, supporting at the same time the ecological transition through the improvement of energy productivity ($\uparrow\epsilon$). Therefore, due to the shift of AD curves, and the economy from point 3 to point 4 in Fig. 3c.

Furthermore, if the central bank's green investment stimulus is strong enough to trigger public or autonomous ones, the AD curve ($AD_1 \rightarrow AD_2$), the PC curve ($PC_2 \rightarrow PC_3$), and the environmental constraint ($Y_0^{ES} \rightarrow Y_1^{ES}$) would shift further to the right, pushing the economy into point 5 in Fig. 3d even closer to the objective of environmental and social sustainability. The shift of the PC curve to the right could also express an increase in labour productivity ($\uparrow\pi$), reducing unit labour costs because the energy productivity improvements can generate spillovers for economic efficiency, producing complementarities between green and labour productivity in terms of knowledge spillovers, economies of scope and economies of scale (Guarini, 2015). This further aspect evidences the relevance and the complexity of complementarity between industrial and green policies (Pianta, 2010).

The right shifts of PC and AD can be obtained thanks to coordination between fiscal and monetary policies. Still, the Central Bank must consider the possible effects on real output due to the need to decrease the aggregate demand to reduce the inflation level (for example, pursuing a low inflation target leads to a reduction in the level of employment) (Setterfield, 2006). Thus, the mainstream policy dichotomy between the Central Bank and the government and between monetary and fiscal policies results in a weak response to energy inflation shock and, in general, to ecological challenges.

An independent central bank emphasizes monetary policy's dominance over fiscal policy, with its credibility linked to inflation control. However, the coordination between fiscal and monetary policies could create a cohesive political strategy to promote investment and economic growth effectively. Indeed, our model suggests that the responsibility for designing environmentally friendly policies primarily rests with the government. It is incumbent upon the government to establish regulations and frameworks that address climate change. Central banks and other financial institutions should define their policy to support the government's objectives. Therefore, the ecological challenge necessitates coordination between the central bank and the government, which may require reconsidering the traditional independence of central banks. This coordination should encompass the provision of financial support for government expenditures by the central bank, alongside the adoption of a unified taxonomy to categorize investments and activities that are environmentally sustainable.

Two good examples of this policy intervention are the 2021 climate action plan¹⁵ of the European Central Bank and the 2022 United States Inflation Reduction Act. The ECB recognised the need to include ecological implications in its monetary policy, presenting a climate action plan in 2021. To ensure price stability and efficient resource allocations, the ECB will develop new theoretical models, empirical analysis, and indicators; it intends to introduce climate change considerations into the collaterals' risk evaluation and control framework and eligibility criteria, linking them to environmental sustainability disclosure. Finally, it wants to intervene in greening its corporate bond purchases by buying bonds issued by green firms to increase the liquidity and resilience of the green bond market. However, given the mainstream reaction of the ECB to the energy inflation, they are actually far from being implemented. Instead, the 2022 US Inflation Reduction Act contains a specific package of measures concerning energy and climate. With a financial endowment of \$370 billion, domestic and primary energy costs will be reduced, while simultaneously fostering private investment in clean energy solutions across all economic sectors and geographical regions. This initiative will also enhance supply chains from crucial raw materials to energy-efficient electric appliances and generate new employment opportunities and well-paying jobs for workers. To do this, it provides subsidies for vehicle purchases, and production, investment subsidies for manufacturers of clean-tech products, and subsidies for producers of carbon-neutral electricity. Aimed to decrease two-thirds of the greenhouse gas emissions gap, this package is expected to accelerate the US economy's decarbonisation process and produce a positive global effect by reducing the international costs of clean energy technologies (Kleimann et al., 2023).

5. Concluding remarks

Ecological transition is based on ecological structural change that requires opportune "ecological policies" based on policy coordination promoting a structural change that increases green productivity by growing green sectors' share and green productivity in all sectors and greening the components of aggregate demand. The above-mentioned macroeconomic exercise provides a simplified representation of the impact of ecological macroeconomic policies on the economic system. The primary limits concern the use of static comparative analysis to study intrinsically dynamic processes, which could lead to an excessive simplification of the challenging mechanisms of the ecological transition. However, the article's contribution is to adopt standard macroeconomic modelling to highlight the complexity of the ecological transition and the required ecological structural change. Indeed, the

¹⁴ One possible future development of the model could be to incorporate the possible relationship between monetary policy and the composition of investment through endogenization of the parameter α as a function of the share of green investments on the total one. As green investments are more sensitive to the interest rate, the greater their share, the greater the sensitivity to change in the interest rate (α). Therefore, a reduction in the parameter β could make the curve AD even more steeper.

¹⁵ European Central Bank (2021), "ECB presents action plan to include climate change considerations in its monetary policy strategy", press release with annex "Detailed roadmap of climate change-related actions", Frankfurt am Main, 8 July.

advancement of ecological macroeconomics involves engagement with the prevailing standard models to highlight the constraints of the mainstream approach and explore the possibilities presented by the ecological macroeconomics perspective concerning coordination across fiscal, monetary and industrial political interventions.

The simplest strategy to achieve environmental sustainability is ecological de-growth. However, this strategy imposes a substantial economic cost by placing the economy in front of the trade-off between the social and environmental dimensions of sustainability. Promoting sustainable and inclusive ecological macroeconomic policies could overcome this potential trade-off, especially to avoid possible rebound effects. Moving from the short-medium run equilibrium, the eco-3 equation model highlights ecological macroeconomic policies' essential role in promoting win-win strategies concerning environmental and social sustainability by stimulating an ecological structural change.

The energy inflation case study seems to suggest the ineffectiveness of mainstream monetary policy in responding to ecological challenges. The only increase in interest rates can restore the economy to the initial equilibrium characterized by environmental and social unsustainability, if not lead even to a deterioration in the presence of financial speculation, making energy markets increasingly unstable. Already, the first case identifies expansionary ecological policies as a critical driver of ecological structural change, but the need for political coordination is even more evident in the current geopolitical context of rising energy prices. The ecological challenge questions the independence of monetary and fiscal policies. The ecological transition requires coordination between a less austere monetary framework and expansionary ecological industrial and fiscal policies. In the context of rising energy prices, this ecological policy strategy could enable inflationary pressures to be contained and the goal of sustainable and inclusive development to be achieved.

A limitation of the paper is not to consider, for simplicity, the labour market inequalities of ecological transition. Greening the economy requires the green transformation of the labour force, equipping the workforce with the necessary skills for green jobs and ensuring a sufficient supply of qualified workers in green sector growth (UNEP, 2008). Human capital investment has a scale effect because green activities tend to be more knowledge and skill-intensive (Consoli et al., 2016). Therefore, suppose it relies solely on technological progress and environmental policies, the ecological transition may precipitate a scenario characterized by “the emergence of winners and losers”, thereby

exacerbating income inequalities and unemployment, compromising social cohesion (Gatti, 2022; Sovacool et al., 2021). In particular, the working class is most affected by green growth, as green technological changes require more skilled workers, potentially exacerbating socio-economic inequalities between less and highly-skilled workers. Therefore, further research, according to Bouzarovski (2022), will contribute to the debate surrounding potential social inequalities resulting from decarbonization, emphasizing the importance of acknowledging the social justice dimension of the ecological transition. Moreover, further negative impact on employment may be caused by higher energy prices negatively affecting overall production, indicating a possible trade-off between environmental, economic and social objectives (Marin and Vona, 2021). Therefore, further research will evaluate the price effect of decarbonization, and in particular, the impact of changes in energy prices.

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CRediT authorship contribution statement

Chiara Grazini: Writing – review & editing, Writing – original draft, Validation, Investigation, Formal analysis. **Giulio Guarini:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **José Luis da Costa Oreiro:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Marco Rodolfo Di Tommaso:** Writing – review & editing, Investigation, Formal analysis, Conceptualization.

Declarations of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. They state that no financial assistance was received for this article. The authors declare that there are no patents or copyrights to be asserted that are relevant to the work in the manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.strueco.2025.05.013](https://doi.org/10.1016/j.strueco.2025.05.013).

Appendix A. Short-medium run equilibrium point

$$\begin{cases} Y = A - \alpha(\bar{i} + (\beta - 1)\hat{p} - \beta\hat{p}^T) \\ \hat{p} = \hat{p}^T + \gamma\left(\omega_0 + \omega_2 Y - \left[\frac{\varepsilon\pi}{\sigma q^\theta}\right]^{\frac{1}{1-\theta}}\right) \end{cases}$$

$$\begin{cases} Y = A - \alpha\bar{i} - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p} = \hat{p}^T + \gamma\left(\omega_0 + \omega_2 Y - \left[\frac{\varepsilon\pi}{\sigma q^\theta}\right]^{\frac{1}{1-\theta}}\right) \end{cases}$$

$$\begin{cases} Y = A - \alpha\bar{i} - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p} = \hat{p}^T + \gamma\omega_0 + \gamma\omega_2 Y - \gamma\left[\frac{\varepsilon\pi}{\sigma q^\theta}\right]^{\frac{1}{1-\theta}} \end{cases}$$

$$\begin{aligned}
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p} = \hat{p}^T + \gamma\omega_0 + \gamma\omega_2[A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T] - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} \end{cases} \\
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p} = \hat{p}^T + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\omega_2(\beta - 1)\alpha\hat{p} + \gamma\omega_2\alpha\beta\hat{p}^T - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} \end{cases} \\
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p} + \gamma\omega_2(\beta - 1)\alpha\hat{p} = \hat{p}^T + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 + \gamma\omega_2\alpha\beta\hat{p}^T - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} \end{cases} \\
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p}[1 + \gamma\omega_2(\beta - 1)\alpha] = \hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} \end{cases} \\
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\hat{p} + \alpha\beta\hat{p}^T \\ \hat{p}^E = \frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \end{cases} \\
& \begin{cases} Y = A - \bar{\alpha}i - (\beta - 1)\alpha\frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} + \alpha\beta\hat{p}^T \\ \hat{p}^E = \frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \end{cases} \\
& \begin{cases} Y[1 + \gamma\omega_2(\beta - 1)\alpha] = A[1 + \gamma\omega_2(\beta - 1)\alpha] - \bar{\alpha}i[1 + \gamma\omega_2(\beta - 1)\alpha] - (\beta - 1)\alpha\left[\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}\right] \\ + \alpha\beta\hat{p}^T[1 + \gamma\omega_2(\beta - 1)\alpha]\hat{p}^E = \frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \end{cases} \\
& \begin{cases} Y[1 + \gamma\omega_2(\beta - 1)\alpha] = A - \bar{\alpha}i - \gamma(\beta - 1)\alpha\omega_0 + \gamma(\beta - 1)\alpha\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} + \alpha\hat{p}^T \\ \hat{p}^E = \frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \end{cases} \\
& \begin{cases} Y^{SMRE} = \frac{A - \bar{\alpha}i - \gamma(\beta - 1)\alpha\omega_0 + \gamma(\beta - 1)\alpha\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}} + \alpha\hat{p}^T}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \\ \hat{p}^{SMRE} = \frac{\hat{p}^T[1 + \gamma\omega_2\alpha\beta] + \gamma\omega_0 + A\gamma\omega_2 - \bar{\alpha}i\gamma\omega_2 - \gamma\left[\frac{\varepsilon\pi}{\sigma\varphi^\theta}\right]^{\frac{1}{1-\theta}}}{[1 + \gamma\omega_2(\beta - 1)\alpha]} \end{cases}
\end{aligned}$$

Data availability

No data was used for the research described in the article.

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