The Macroeconomics of Energy-Transition Metal Bottlenecks *

Romain Houssa† Jolan Mohimont‡

November 14, 2026

Abstract

This paper develops a dynamic general equilibrium model in which energy-transition metals are essential inputs into both production and capital accumulation, while their supply capacity adjusts endogenously and gradually. The green transition shifts investment toward metal-intensive green technologies, generating bottlenecks that depress investment and potential output. Nominal rigidities amplify short-run losses while monetary-policy stabilization faces a trade-off: supporting economic activity raises demand for scarce transition inputs, increasing their relative prices and the cost of investment. Climate-policy continuation risk further increases transition costs by weakening investment in green capital and ETM production capacity, making bottlenecks more persistent and raising long-run output losses. We compare taxes and subsidies targeting sectoral output with those targeting metal use. Targeting metal use can reduce transition costs relative to output-based policies when metals enter production and demand is sufficiently elastic. When metals enter capital accumulation and demand is inelastic, however, taxing brown-sector metal use slows the transition and increases its macroeconomic costs because the policy raises investment costs while releasing few metals for green investment. Our findings show how endogenous metal-supply adjustment, policy credibility, and the choice of tax and subsidy bases jointly shape the macroeconomic consequences of the green transition.

JEL classifications: E22, E31, E52, Q31, Q58

Keywords: Energy transition metals; bottlenecks; fiscal policy; monetary policy trade-offs; climate-policy uncertainty; DSGE models.

*Earlier versions of this paper circulated under the title "Large Fiscal–Monetary Policy Mix under Commodity Supply Constraints and Climate Policy Uncertainty." We thank participants in various workshops (June 2025, December 2025, June 2026) of the NBB International biennial research conference on "Fiscal-monetary policy interactions in the 21st century". Disclaimer: The views expressed in this paper do not necessarily reflect those of the National Bank of Belgium.

†DeFiPP (CRED & CeReFiM) - University of Namur; CES (University of Leuven), and CESifo, romain.houssa@unamur.be

‡National Bank of Belgium; DeFiPP (CRED & CeReFiM) - University of Namur, jolan.mohimont@nbb.be

1 Introduction

Mitigating climate change requires a profound transformation in the composition of production, investment, and commodity demand. The green transition involves a shift away from fossil-fuel-intensive technologies and toward renewable energy production, energy storage, and electric mobility. For example, the European Union's Green Deal aims to achieve climate neutrality by 2050 (European Commission, 2019), while EU regulations require all new cars and vans registered in Europe to be zero-emission from 2035 onward (European Parliament and Council of the European Union, 2023). More broadly, governments are implementing a combination of taxes, subsidies and regulatory targets to accelerate the greening of the transportation, industrial, and energy systems.

Metals and minerals such as copper, cobalt, lithium, nickel, and graphite are critical inputs for building a greener economy. We refer to these inputs collectively as energy-transition metals (ETMs). For example, a typical electric vehicle (EV) requires about six times as much mineral input as a conventional car, while an onshore wind plant requires about nine times as much mineral input as a gas-fired power plant of the same capacity (International Energy Agency, 2021). As the green transition raises demand for ETMs, however, supply-side bottlenecks may put upward pressure on metal prices, with potentially adverse consequences for green investment, the pace of decarbonization, and aggregate economic activity.

In this paper, we build a general equilibrium model with green and brown final goods, in which ETMs are used as production inputs and investment-specific inputs.[1] Our model incorporates the three most salient characteristics of the ETM markets and their interactions with the macroeconomy. First, green investment is more ETM-intensive than brown investment. Second, ETM demand is price-inelastic because the technical scope for substituting metals with other inputs is limited. Third, ETM supply is price-inelastic, especially at short horizons, because expanding production capacity depends on the availability of natural resources and requires long investment horizons.

We assume that the green transition (GT) is triggered by the simultaneous, permanent, and fiscally balanced introduction of taxes on brown goods and subsidies to green goods. In a

[1] The brown sector can be interpreted as a reduced-form representation of fossil-fuel-intensive production. Adding an explicit fossil-fuel sector would provide a microfoundation for the brown sector, but it would also introduce additional commodity-price and substitution channels that are not central to our main mechanism. We therefore keep the model parsimonious and focus on ETM bottlenecks and on the reallocation of activity and metal inputs between the two final-good sectors.

perfectly symmetric economy in which ETM intensity is identical in the green and brown sectors, this policy only reallocates activity across sectors and has no aggregate effects on output or inflation. In our preferred calibration, however, green investment is more ETM-intensive than brown investment. Greening the economy therefore raises the ETM intensity of aggregate investment and increases aggregate demand for ETMs.

We use the model to assess how a transition-driven increase in ETM demand affects the green transition and the macroeconomy. When ETM supply cannot expand fast enough to meet this demand, bottlenecks arise and raise the relative price of ETMs. We characterize how these bottlenecks shape the pace, cost, and macroeconomic consequences of the green transition. The analysis delivers five results.

First, we show that ETM bottlenecks reduce potential output by lowering aggregate investment. They also slow the expansion of the green sector induced by climate policy. The decline in potential output is larger when the long-run elasticity of ETM supply is lower. Quantitatively, a permanent 10% tax on brown-good production, combined with a 10% subsidy to green-good production, reduces potential output by about 0.5% within two years and by about 0.3% in the long run under our baseline calibration. Green production increases bu about 6% while brown output declines by 7%.

Second, price and wage rigidities magnify the short-run macroeconomic cost of the GT. Nominal rigidities amplify the decline in employment, investment, and output because real wages and relative prices adjust gradually. In the New Keynesian economy, employment and output must therefore absorb more of the short-run adjustment than in the economy with fully flexible prices and wages.

Third, ETM bottlenecks create monetary-policy trade-offs between stabilizing inflation and stabilizing economic activity during the GT. The trade-off arises because supporting aggregate demand to close the output gap raises the demand for scarce ETMs. The resulting increase in ETM prices and raises the marginal costs of both green and brown producers, and raise the cost of investment goods. In the short run, the inflationary pressure originates from the production-input price channel but remains limited when ETMs are mostly used as investment-specific inputs. Over time, however, the investment-demand channel becomes a supply-side channel and imposes a trade-off that extends to the medium run. To close the output gap completely, the monetary authority must tolerate an inflation rate of about 0.15 percentage points above target for about 4 years, with inflation gradually returning to

target over the medium to long run. Strong inflationary pressures could arise, however, if the central bank tries to stabilize employment at its pre-GT level. Because ETM bottlenecks reduce potential output and the natural level of employment, this policy requires a persistently positive output gap and therefore generates substantially larger inflationary pressures.

Fourth, we uncover a strong interaction between climate-policy uncertainty and investment in ETM production capacity. Long investment horizons make the ETM sector particularly exposed to policy-continuation risk. This exposure operates through two channels. First, expected demand from the green sector is weaker when agents perceive a risk that climate policies may be discontinued. Second, investment in ETM capacity generates returns far in the future, making its expected discounted value especially sensitive to policy-continuation risk. Climate-policy uncertainty can therefore make ETM bottlenecks more persistent. The additional cost of uncertainty is larger when there is greater scope for long-run ETM supply adjustment, as measured by the gap between long-run and short-run ETM supply elasticities. In such economies, policy certainty would otherwise induce a strong expansion of ETM capacity and lower long-run metal prices. Policy-continuation risk weakens this investment response. In adverse scenarios, subdued ETM-capacity expansion can keep ETM prices persistently elevated, even though the green transition itself is slower.

Fifth, we show that the design of climate policy matters. While the literature has mostly focused on standard brown taxes and green subsidies, such as carbon taxes and subsidies to clean technologies, we also evaluate a policy that taxes the use of ETMs in the brown sector and subsidizes their use in the green sector. The relative performance of this ETM-input scheme, compared with the standard output-based scheme, depends on two structural features: the price elasticity of ETM demand and whether ETMs are used primarily as production or investment inputs. When ETMs are used as production inputs, the ETM-input scheme can reduce the long-run cost of the GT, provided ETM demand is sufficiently elastic. This scheme generates within-sector substitution effects between ETMs and other production inputs. In the brown sector, the ETM tax induces firms to economize on scarce metals. This reduces brown-sector ETM demand, lowers pressure on ETM prices, and redirects scarce metal inputs toward the green sector.

The GT can, however, become very slow and costly under the ETM-input scheme when ETMs are used as investment-specific inputs and ETM demand is inelastic. In that case, the policy affects the relative price of green and brown investment goods directly, while its effect on the relative price of final goods materializes only gradually as investment decisions

change sectoral capital stocks. Moreover, ETM bottlenecks can worsen. The subsidy to ETM use in green investment raises demand for scarce metals, while the tax on ETM use in brown investment does not induce a large reduction in metal use when ETM demand is inelastic. The policy therefore raises ETM prices without releasing enough scarce metals from the brown sector. As a result, it can slow the GT and amplify its macroeconomic cost. The policy implication is that brown-sector ETM taxes should be used with caution when ETMs are investment-specific inputs. If firms cannot easily substitute away from ETMs in the production of capital goods, such taxes raise the cost of investment without sufficiently relaxing the ETM bottleneck.

Our paper contributes to four related strands of literature. First, a large literature studies the macroeconomic consequences of carbon taxes and other climate policies (see, for example, Golosov et al., 2014; Blanchard et al., 2023; Sahuc et al., 2025; Metcalf and Stock, 2023; Coenen et al., 2024). This literature shows how transition costs depend on substitution possibilities, technology adoption, and the design of policies. The contribution of ETM bottlenecks to transition costs could be substantial. Back-of-the-envelope computation based on our model suggests that reducing emissions by 25% could lower potential output by about 1.8% within five years. With a similar emission reduction target, the IMF (2022) model predicts a decline in activity of about 1-2%.

A closely related study is Bartocci et al. (2026), who show that a reduction in critical-mineral supply from China can partly offset the expansionary effects of green subsidies in the euro area by raising critical-mineral prices. Their framework treats mineral supply as an exogenous endowment. We model investment in metal-production capacity, allowing climate policy to affect both metal demand and supply expansion. This feedback determines how bottlenecks evolve during the transition and how they affect potential output. We also compare tax-and-subsidy schemes targeting sectoral output with schemes targeting metal use. This comparison shows how the choice of policy base affects the allocation of scarce metals, the cost of green investment, and incentives to expand metal supply.

Second, our paper relates to the literature on metal markets and their role in capital accumulation. Boer et al. (2024) use a structural VAR to study metal-supply responses to metal-specific demand shocks and a structural scenario analysis to assess the implications of transition-related demand for metal prices. Concordel et al. (2026) develop a neoclassical growth model that distinguishes mineral-price shocks, which affect the cost of creating new capital, from oil-price shocks, which affect the cost of operating existing capital. Thus, min-

eral shocks propagate through investment and capital accumulation as in our framework. Other studies examine the functioning of mineral markets. For instance, Domínguez-Iino et al. (2026) model mineral extraction and battery demand to study how geographic concentration and cross-mineral linkages shape strategic mineral policies and green-technology adoption. Kirk et al. (2026) analyse how endogenous trade-network centrality creates pricing power and shifts strategic dependence during the transition.

Our characterisation of metal supply builds on our related work that derives horizon-dependent supply and demand elasticities in a general equilibrium model of the global oil market (Houssa and Mohimont, 2026). That analysis distinguishes impact elasticities, which govern immediate responses, from dynamic elasticities, which shape subsequent shock propagation. We adapt this approach to derive short- and long-run metal-supply elasticities and examine how gradual capacity adjustment shapes the persistence of transition bottlenecks.

Third, we contribute to the literature on inflationary effects of the GT and its implications for monetary policy (Bartocci et al., 2024; Airaudo et al., 2023; Ferrari and Nispi Landi, 2025; Feng and Cui, 2026; Nakov and Thomas, 2026; Olovsson and Vestin, 2026). A transition requires relative price adjustments, but these need not necessarily generate a trade-off between inflation and output stabilization. ETM bottlenecks provide a mechanism through which such a trade-off can arise. Compared to the trade-off induced by sectoral heterogeneity in price rigidities of Del Negro et al. (2023), the trade-off that originates from ETM bottlenecks is less severe in the short run, but persists for longer over the medium run.

In a related study, Miranda-Pinto et al. (2024) combine a production-network model with local-projection evidence (using supply shocks from the SVAR model of Baumeister et al., 2024) showing that metal supply shocks have persistent effects on headline and core inflation, particularly in economies with greater exposure to metals. Kirk et al. (2026) document a similar effect of ETM supply shocks on consumer prices with local projections, constructing their supply shocks from text. We examine how these inflationary pressures interact with endogenous capacity adjustment in a framework where metals enter both production and investment. We show that ETM bottlenecks affect current production costs and the accumulation of capital needed for the transition. The investment demand channel – that is absent in Miranda-Pinto et al. (2024) – plays a key role in explaining the gradual increase in consumer prices.

Finally, our work relates to the literature on climate-policy uncertainty (see, for example,

Engle et al., 2020; Gavriilidis et al., 2026; Fried et al., 2021; Nguyen-Tien, 2026). For instance, Fried et al. (2021) show how expectations of future climate policy affect the level and composition of capital. Gavriilidis et al. (2026) find that higher uncertainty lowers output in the USA while raising commodity and consumer prices. Nguyen-Tien (2026) documents an association between perceived critical-mineral risks and weaker performance among downstream firms. We identify a complementary transmission channel through investment in upstream metal-production capacity. The risk that climate policy will be discontinued reduces expected returns to capacity investment and weakens the supply expansion needed to accommodate transition-related demand. Policy-continuation risk can therefore generate persistent ETM bottlenecks even when the underlying long-run price elasticity of metal supply is large.

The remainder of the paper is organized as follows. Section 2 presents motivating facts. Section 3 develops the general equilibrium model of the green transition. Section 4 presents the quantitative results, mechanisms, and policy counterfactuals. Section 5 concludes.

2 Motivating facts

This section presents two facts that motivate and guide the specification and interpretation of our DSGE model of the green transition (GT). Throughout the paper, we use the term *energy-transition metals* (ETMs) to refer to the broader set of critical mineral inputs required by clean-energy technologies, including copper, lithium, cobalt, nickel, graphite and rare earths. First, we present facts on energy-transition metal (ETM) bottlenecks (Section 2.1). Second, we present data on climate-policy uncertainty, which affects investment incentives in ETM production capacity (Section 2.2).

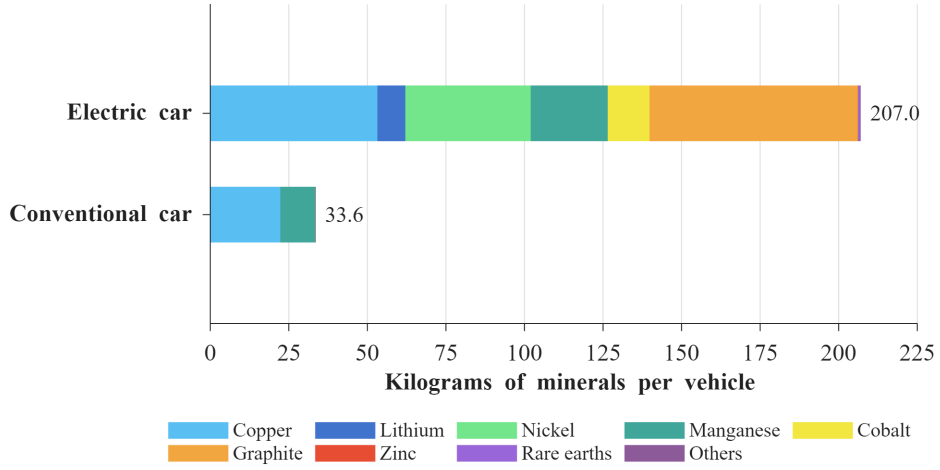
2.1 Energy-transition metal bottlenecks

Energy-transition metal bottlenecks arise when demand for critical minerals required to build the infrastructure for the green transition outpaces the supply of those inputs.

Demand for ETMs

On the demand side, the transition towards a greener economy generates a significant increase in demand for energy-transition metals and minerals such as copper, cobalt, lithium, nickel, and graphite, which are essential for producing electric vehicles, batteries, renewable-energy infrastructure, electricity grids and storage capacity (International Energy Agency, 2021, 2024, 2026). Figure 1 shows that producing an electric car requires about six times as much mineral input as producing a conventional car. Similarly, Figure 2 shows that renewable power technologies (with wind or solar energy) require substantially more mineral inputs than conventional technologies such as nuclear, coal, and natural gas plants.

Figure 1: ETM requirements for electric and conventional cars

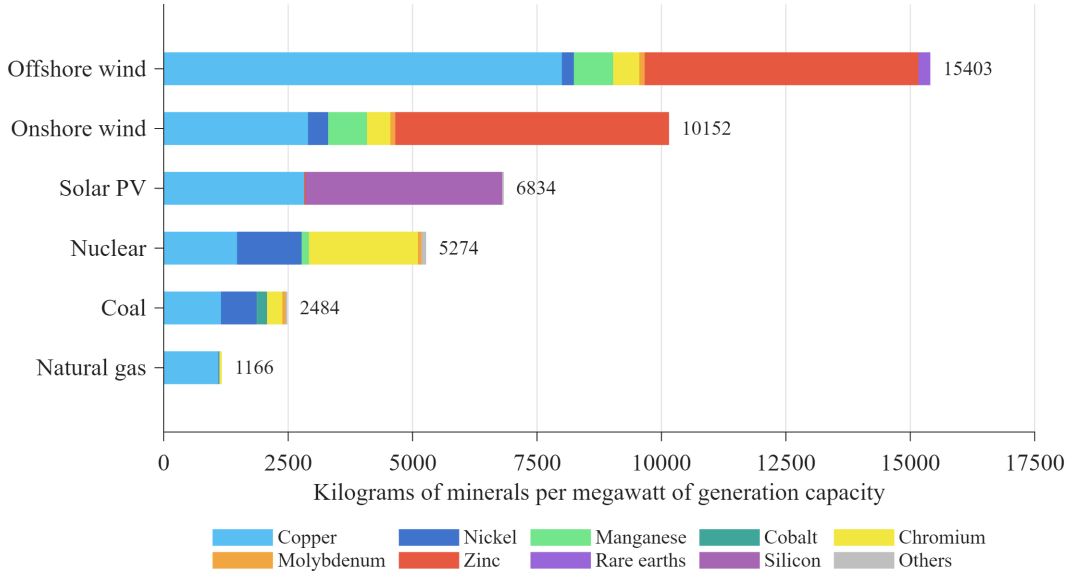


Unit: Kilograms of minerals per vehicle. Sources: Authors' calculations based on International Energy Agency (2021)

Consistent with this high mineral intensity, International Energy Agency (IEA) projections reported in Figure 3 show that clean-energy technologies are becoming a major source of demand for critical minerals (International Energy Agency, 2021, 2024, 2026). For instance, the share of clean-energy technologies in global lithium demand increases from almost 0% in 2010 to 74% in 2025, and is projected to reach 92% by 2040 under the IEA's Announced Pledges Scenario (APS).[2] For copper, the corresponding shares are 22%, 29%, and 44% in 2010, 2025, and 2040, respectively. Similar patterns are observed for other minerals.

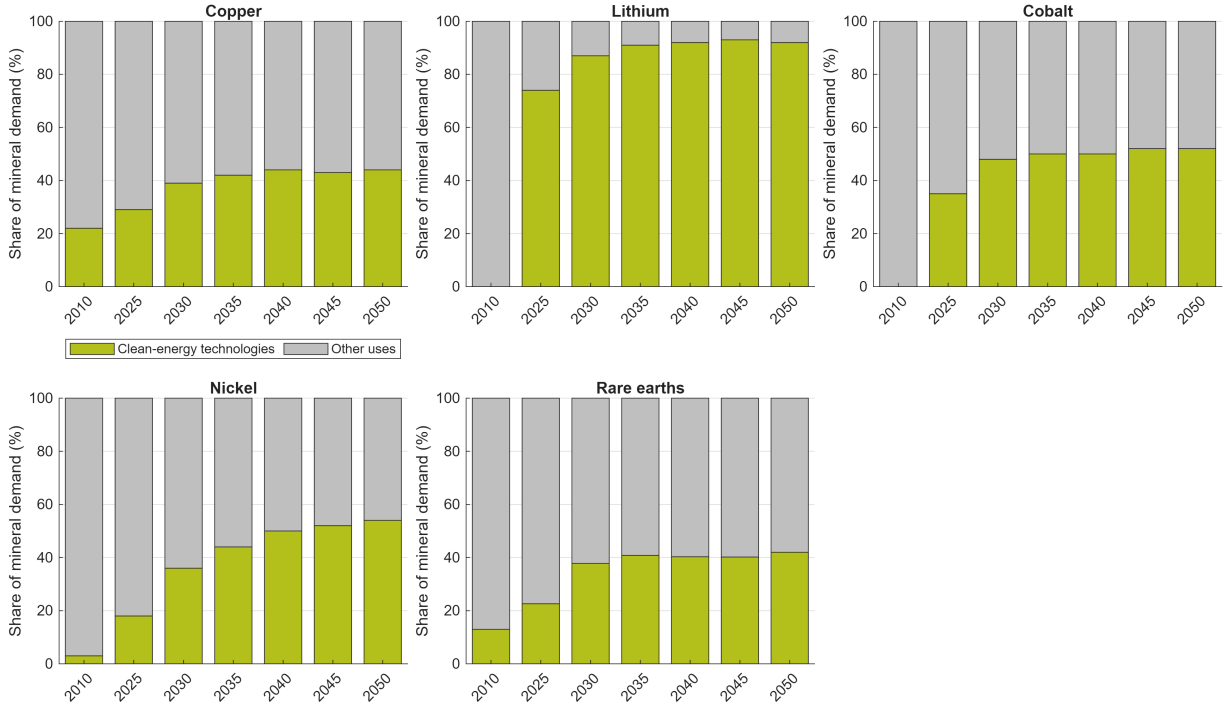
[2] The APS assumes that governments will meet, in full and on time, all of the climate-related commitments that they have announced, including longer-term net-zero emissions targets and pledges in nationally determined contributions (NDCs). The APS is associated with a temperature rise of 1.7 °C in 2100 (with a 50% probability) (International Energy Agency, 2024).

Figure 2: High ETM requirements in clean energy generation



Unit: Kilograms of minerals per megawatt of generation capacity. Sources: Authors' calculations based on International Energy Agency (2021)

Figure 3: Rising share of mineral demand from clean-energy technologies



Unit: Percentage. Sources: Authors' calculations based on IEA (International Energy Agency, 2021, 2024, 2026)

At the same time, these facts point to an investment-specific demand channel for the green transition. Many clean-energy technologies, such as electric vehicles, batteries, and renewable-energy infrastructure, are durable goods, infrastructure, and capital equipment that require upfront investment. The green transition therefore raises not only the level of critical mineral demand but also the mineral intensity of aggregate investment.

Table 1 reinforces this investment channel using OECD input-output tables for the year 2018, aggregated at the world level. We group products into four broad categories (metals, energy, durable goods, and non-durable goods and services), together with final consumption and investment as final-demand categories. The data show that metal products are used substantially as intermediate inputs in the production of durable goods. Durable goods, in turn, are largely absorbed by investment demand. This evidence supports the modelling choice in Section 3 that ETMs are primarily used as investment-specific inputs.

Table 1: Metal Products in the Global Supply Chain

	Energy	Metals	Durable	Non-durable	Consumption	Investment
Energy	3.87	0.53	0.50	3.60	2.09	0.08
Metals	0.11	2.65	3.11	0.72	0.23	0.41
Durable	0.30	0.24	6.07	3.35	3.84	15.36
Non-durable	1.85	1.55	9.15	45.42	55.71	5.81

Notes: OECD input-output tables (2018, USD trillion), aggregated at the world level. Rows denote supplying sectors and columns denote purchasing sectors or final demand categories. Energy comprises coal, crude oil, natural gas, coke and refined petroleum products, and electricity. Metals comprise mining and the manufacture of metal products. Durable and non-durable refer to durable goods and non-durable goods and services, respectively.

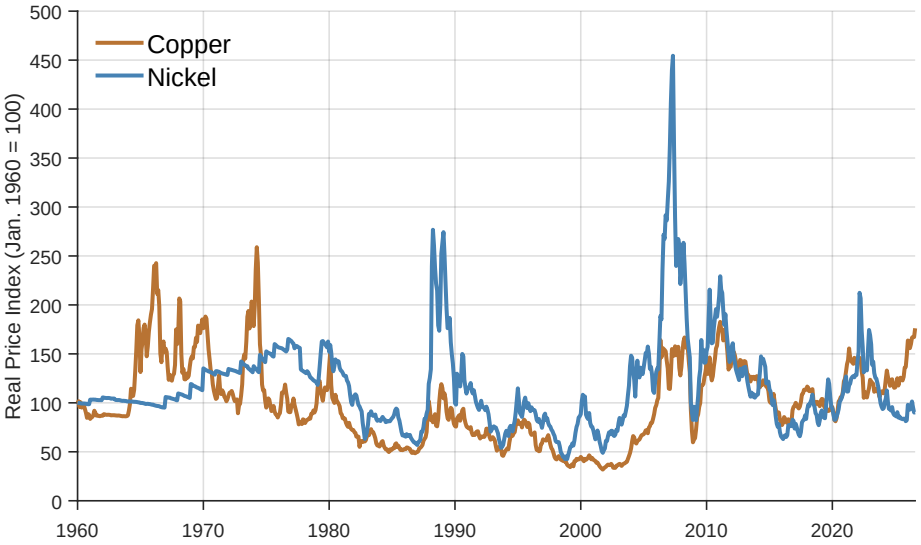
Supply-side constraints for ETM markets

While Figures 1–3 document the demand pressure created by the GT, the ETM supply capacity adjusts only slowly. In the mining and quarrying industry, it typically takes more than a decade to develop a new mine. Data from S&P Global Market Intelligence show that the discovery, exploration and studies stages take almost 12 years, while the mining construction stage takes almost four years (see, for example, Manalo, 2023). Once production begins, it is not always feasible or economically rational to adjust supply to meet fluctuating demand. The review by Dahl (2020) shows that the short-run price elasticity of metal supply tends to be low, with a median value of 0.15. Challenges associated with the permitting and

financing stages also limit long-run response, with a median long-run price elasticity of supply of 0.6.

The limited short-run ETM supply responsiveness implies that changes in demand can translate into substantial movements in prices. Figure 4 illustrates this feature using copper and nickel prices. Both metals have experienced large and persistent price fluctuations. Metal price fluctuations tend to be primarily driven by demand factors (see, for example, Stuermer, 2018). The GT could thus lead to a large and persistent increase in ETM prices, in scenarios where supply is unable to expand. In fact, copper prices have already increased recently, amid a rise in demand from renewable energy, EVs, and AI data centers, combined with a decline in productivity in existing mines facing declining ore grades.

Figure 4: ETM prices: copper and nickel



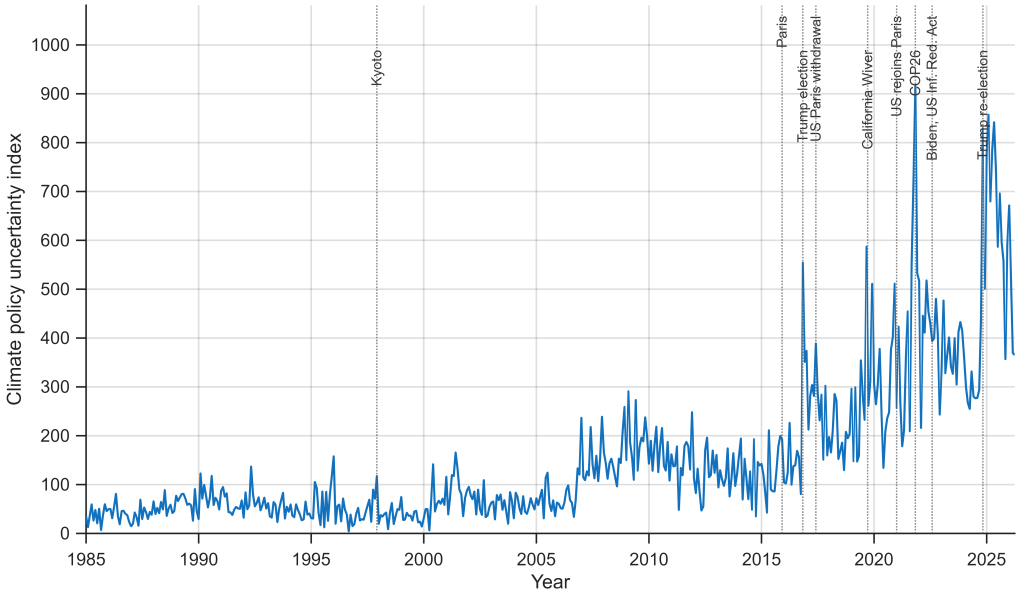
Unit: Index. Real prices deflated by the US CPI. Sources: Authors' calculations based on the World Bank Pink Sheet and Bureau of Labor Statistics.

2.2 Climate policy uncertainty

In addition, while the world needs a GT to address climate risks, there is growing regulatory uncertainty around the implementation and continuity of climate policies. For instance, the Trump administration recently withdrew the US from the Paris climate agreement and reversed commitments made during the Biden presidency, a stark reminder that green policies can end unexpectedly. Outside the US, global trade disruptions, energy crises, and increased

defense spending could also affect the ability of governments to finance the GT. Green policies can also take different forms, including outright bans, a carbon tax, or subsidies targeted at the production or use of green goods and services. This situation creates uncertainty around adjustment decisions by households and businesses around the world. More formally, rising climate-policy uncertainty in the United States is reflected in the index developed by Gavriilidis et al. (2026).

Figure 5: Climate policy uncertainty index



Unit: Index. Sources: Authors' calculations based on Gavriilidis et al. (2026)

Uncertainty over GT policy is particularly challenging for natural resource producers, and may thus amplify the issue of metal bottlenecks. While expectations about the continuity of green policies are important for all sectors of the economy, the commodity sector stands out because of the length of its exploration and development phases, which introduce a significant lag between large upfront investment costs and distant returns. The implication is that some policies, such as subsidies for the purchase of EVs or a carbon tax, may encourage households to adjust their consumption patterns, while at the same time they may fail to encourage investment in ETM production capacity – if producers expect that the resulting increase in demand may not be sustained. In this case, supply shortages of key inputs could jeopardize the GT and amplify price pressures originating from the metal sector.

3 Model

We extend a standard two-sector New Keynesian framework to study how energy-transition metals (ETMs) shape the macroeconomic consequences of the green transition (GT). The economy produces two final goods: a green good, denoted by g, and a brown good, denoted by b. Time is discrete and one period corresponds to one quarter. Capital is sector specific, while labor is imperfectly mobile across sectors (metal, green, and brown).

ETMs are produced by firms that combine labour and capital with land, whose aggregate supply is fixed. They shape production and capital accumulation through two distinct channels. First, ETMs are used as production inputs in the final-goods sectors, together with labour and sector-specific capital. Second, they enter the production of new capital goods as investment-specific inputs. This second channel is central to our mechanism. As discussed in Section 2, the GT involves a reallocation of investment towards sectors and technologies that are relatively more ETM-intensive. Because ETM supply adjusts slowly, this reallocation can generate ETM bottlenecks that affect metal prices, marginal production costs, the relative price of investment goods, and the aggregate cost of the transition.

The GT is triggered by fiscal policy, with the simultaneous and permanent introduction of brown taxes and green subsidies. In the baseline economy, the monetary authority sets the interest rate according to a Taylor-type rule.

The rest of the section presents our framework in detail. Section 3.1 describes ETM producers and derives the short- and long-run elasticities of ETM supply. Section 3.2 introduces green and brown final-good sectors. Section 3.3 presents households, while Section 3.4 describes capital-goods producers. Sections 3.5 and 3.6 introduce the fiscal and monetary authorities, respectively. Section 3.7 discusses the calibration.

3.1 ETM producers

Metal producers operate in perfectly competitive markets. A representative metal producer i takes prices of its inputs and outputs as given. It combines capital (K_t^m), labor (H_t^m), and land (L_t^m) to produce metals Y_t^m, which are sold to final-good producers and capital-good producers at price P_t^m. We assume that relative prices, real wages, and real rental rates of capital are expressed with lower-case variables. For example, $p_t^m = \frac{P_t^m}{P_t^c}$ is the real price of

metals, where the consumer price index, P_t^c, is used as numeraire (see Section 3.3).

The ETM producer owns a fixed stock of land and chooses capital and labor to maximize profits, $\Pi_t^m(i)$, expressed in real terms as

$$\Pi_t^m(i) = p_t^m Y_t^m(i) - w_t^m H_t^m(i) - r_t^m K_t^m(i),$$

where w_t^m and r_t^m denote, respectively, the real wage rate and the real rental rate of capital in metal production.

Metal output is produced using a CES technology that combines the three factors:

$$Y_t^m(i) = \left[(1-\alpha_m-\gamma_m)^{\frac{1}{\theta_m}} \left(H_t^m(i)\right)^{\frac{\theta_m-1}{\theta_m}} + (\alpha_m)^{\frac{1}{\theta_m}} \left(K_t^m(i)\right)^{\frac{\theta_m-1}{\theta_m}} + (\gamma_m)^{\frac{1}{\theta_m}} \left(L_t^m(i)\right)^{\frac{\theta_m-1}{\theta_m}}\right]^{\frac{\theta_m}{\theta_m-1}}, \quad (1)$$

where θ_m denotes the elasticity of substitution among production factors. The parameters α_m and γ_m govern the weights of capital and land, respectively, while $1-\alpha_m-\gamma_m$ is the weight on labor. The supply of land is assumed to be fixed, so that $L_t^m(i) = L^m$.

Following Houssa and Mohimont (2026), we derive closed-form expressions for the short-run and long-run price elasticities of ETM supply, denoted by σ_{SR} and σ_{LR}, respectively. With capital and land fixed in the short run, only labour can adjust, and the supply elasticity is given by $\sigma_{\text{SR}} = \frac{\theta_m(1-\alpha_m-\gamma_m)}{\alpha_m+\gamma_m}$. In the long run, capital and labor can adjust while land remains fixed and the elasticity becomes $\sigma_{\text{LR}} = \frac{\theta_m(1-\gamma_m)}{\gamma_m}$. In the quantitative analysis, we choose the structural parameters to match plausible values of these elasticities.

The metal market clears when production equals the demand for metals as *production inputs* (from green, M_t^{yg}, and brown, M_t^{yb} firms) and as *investment inputs* (from green, M_t^{Ig}, and brown, M_t^{Ib} firms): $Y_t^m = M_t^{yg} + M_t^{yb} + M_t^{Ig} + M_t^{Ib}$ (see Sections 3.2 and 3.4). We assume that metals are not used in the production of capital for the metal sector, K_t^m, so that $M_t^{Im} = 0$.[3]

3.2 Green and brown final-good sectors

Green and brown final-good producers operate in imperfectly competitive markets. A firm i in sector $j \in \{b, g\}$ combines capital, $K_t^j(i)$, labor, $H_t^j(i)$, and metals, $M_t^{yj}(i)$, to produce

[3] This assumption avoids an additional feedback from metal prices to the cost of expanding metal-production capacity. Allowing for such a channel would tend to amplify ETM bottlenecks and is therefore unlikely to weaken our main mechanism.

final goods $Y_t^j(i)$. A representative final-good producer sets its own price, $P_t^j(i)$, and takes its input prices as given. The firm sells its differentiated product to a distributor that aggregates the differentiated products into baskets of final green and brown goods distributed to households.

Green and brown producers face sector-specific policy wedges designed to induce the GT: the green producer receives subsidies whereas the brown counterpart faces taxes. The fiscal authority can either introduce taxes and subsidies on production or on the use of metal inputs.[4] A producer i in sector j maximizes its profits, $\Pi_t^j(i)$, expressed in real terms as

$$\Pi_t^j(i) = (1+\tau_t^j)p_t^j(i)Y_t^j(i) - w_t^j H_t^j(i) - r_t^j K_t^j(i) - (1-\mu_t^j)p_t^m M_t^{yj}(i),$$

where $p_t^j(i) = \frac{P_t^j(i)}{P_t^c}$ is the real price of the good produced by firm i in sector j. The term τ_t^j denotes a production tax or subsidy: $\tau_t^g > 0$ represents a production subsidy to green producers, while $\tau_t^b < 0$ represents a production tax on brown producers. The term μ_t^j denotes a tax or subsidy on the use of metal inputs.

Production Production of the green and brown goods takes place in two stages. In the first stage, a firm i in sector $j \in \{b, g\}$ combines capital and labor using a standard Cobb-Douglas technology to produce an intermediate good $(X_t^j(i))$

$$X_t^j(i) = K_t^j(i)^{\alpha_j} H_t^j(i)^{1-\alpha_j}, \tag{2}$$

where α_j denotes the capital income share in sector j.

In the second stage, the firm combines the intermediate good with ETMs using a CES production function to produce the sector-specific final good

$$Y_t^j(i) = \left[(1-\omega_m^{yj})^{\frac{1}{\eta_m}} \left(X_t^j(i)\right)^{\frac{\eta_m-1}{\eta_m}} + (\omega_m^{yj})^{\frac{1}{\eta_m}} \left(M_t^{yj}(i)\right)^{\frac{\eta_m-1}{\eta_m}}\right]^{\frac{\eta_m}{\eta_m-1}}, \tag{3}$$

where ω_m^{yj} denotes the share of metals in the production of the final good j, and η_m denotes the elasticity of substitution between the intermediate input, $X_t^j(i)$, and ETMs. From the cost-minimization problem, this parameter also governs the price elasticity of demand for ETMs used as production inputs as in Houssa and Mohimont (2026).

[4] Note that taxes and subsidies on the use of metal inputs also affect investment-good producers, see Section 3.4.

Distributors and price stickiness In each sector $j \in \{g, b\}$, individual producers sell differentiated goods to a competitive distributor, which aggregates these varieties into a sectoral final good using a Dixit-Stiglitz technology

$$Y_t^j = \left(\int_0^1 \left[Y_t^j(i) \right]^{\frac{\epsilon_j - 1}{\epsilon_j}} d(i) \right)^{\frac{\epsilon_j}{\epsilon_j - 1}}, \tag{4}$$

where $\epsilon_j > 1$ denotes the elasticity of substitution across varieties in sector j.

Individual producers set their own prices and face Calvo-type price rigidities. In each period, a producer in sector j can reset its price with probability $1 - \xi_j$; with probability ξ_j, it keeps its price unchanged.

When allowed to reset its price at time t, a producer in sector j chooses $P_t^{j,*}$ to maximize the expected present value of profits

$$\mathrm{E}_t \sum_{s=0}^{\infty} Q_{t+s|t} \xi_j^s \left((1 + \tau_{t+s}^j) P_t^{j*} - MC_{t+s}^j \right) Y_{t+s}^j(i), \tag{5}$$

where $Q_{t+s|t}$ is the discount factor, P_t^{j*} is the optimal price chosen at time t, MC_{t+s}^j is the marginal cost, and $Y_{t+s}^j(i) = Y_{t+s}^j \left(\frac{P_t^{j*}}{P_{t+s}^j} \right)^{-\epsilon_j}$ is the demand for good i in sector j from the competitive distributor. This demand depends negatively on the ratio of the price of good i to the sectoral price index P_{t+s}^j.

Market clearing Brown and green goods are used for consumption and investment purposes. The market for each final good clears when production equals the demand for consumption plus the demand from the production of investment goods

$$Y_t^g = G_t^C + G_t^{Ig} + G_t^{Ib} + G_t^{Im}, \tag{6}$$

$$Y_t^b = B_t^C + B_t^{Ig} + B_t^{Ib} + B_t^{Im}, \tag{7}$$

where G_t^C (B_t^C) denotes household consumption of green (brown) goods. The terms G_t^{Ig}, G_t^{Ib}, and G_t^{Im} (B_t^{Ig}, B_t^{Ib}, and B_t^{Im}) denote the amount of green (brown) good used to produce new capital for green, brown, and metal good producers, respectively.

3.3 Households

Utility and budget constraint A household i derives utility from a consumption basket, $C_t(i)$, and disutility from labor, $H_t(i)$. Households maximize their utility given by

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t(i) - \mathbf{b}C_{t-1}\right)^{1-\sigma_c}}{1-\sigma_c} - A_h \frac{\left(H_t(i)\right)^{1+\sigma_h}}{1+\sigma_h} \right], \tag{8}$$

where $\mathbf{b}$ is an external habit parameter, σ_c is the inverse of the intertemporal elasticity of substitution in consumption, and σ_h is the inverse Frisch elasticity of labor supply. The consumption basket is a bundle of green and brown consumption goods

$$C_t(i) = \left(G_t^C(i)\right)^{\omega_g} \left(B_t^C(i)\right)^{1-\omega_g}, \tag{9}$$

where ω_g denotes the expenditure share of green consumption goods.

The household's budget constraint, expressed in real terms, is

$$C_t(i) + S_t(i) + \sum_{j \in g,b,m} p_t^{Ij} I_t^j(i) = R_{t-1} \frac{S_{t-1}(i)}{\pi_t} + w_t(i) H_t(i) + \sum_{j \in g,b,m} r_t^j K_t^j(i) + \Pi_t + \Gamma_t, \tag{10}$$

where the price of the consumption basket, P_t^c, is the relative-price numeraire. S_t denotes real bond holdings and R_t is the nominal interest rate. The term $R_{t-1}\frac{S_{t-1}}{\pi_t}$ is the real income from bonds purchased in the previous period. $w_t(i)$ is the wage rate. p_t^{Ij} is the real price of investment goods in sector $j \in \{g, b, m\}$ and r_t^j is its real rental rate. The term $\Pi_t = \int_0^1 \Pi_t^m(i)\mathrm{d}(i) + \int_0^1 \Pi_t^g(i)\mathrm{d}(i) + \int_0^1 \Pi_t^b(i)\mathrm{d}(i)$ represents profits transferred from the firms producing metal, green, and brown goods (the distributors, investment-good producers, and labor union make no profit in equilibrium). Government transfers Γ_t ensure that the public sector has no debt.

Capital is sector specific. In sector $j \in \{g, b, m\}$, the capital stock, K_t^j, evolves according to

$$K_{t+1}^j = \left[1 - \frac{\psi}{2} \left(\frac{I_t^j}{I_{t-1}^j} - 1 \right)^2 \right] I_t^j + (1 - \delta_j) K_t^j, \tag{11}$$

where I_t^j denotes investment, ψ governs investment adjustment costs and δ_j is the depreciation rate of capital.

Wage rigidities Each household sets its own wage ($W_t(i)$) and faces Calvo-type wage rigidities. A household i has a probability $1-\xi_w$ of adjusting its wage in every period; with probability ξ_w, this household keeps its nominal wage unchanged.

Households sell their labor services to a competitive labor union that combines differentiated labor varieties $H(i)$ into labor services:

$$H_t = \left(\int_0^1 H_t(i)^{\frac{\epsilon_h - 1}{\epsilon_h}} \mathrm{d}i \right)^{\frac{\epsilon_h}{\epsilon_h - 1}}, \tag{12}$$

where $\epsilon_h > 1$ denotes the elasticity of substitution across labour varieties.

This specification gives rise to a standard wage Phillips curve, according to which wage inflation depends on expected future wage inflation and on the gap between the real wage and households' marginal rate of substitution between consumption and labor.

Sectoral labor mobility Labor unions allocate labor services across sectors under this sectoral labor mobility friction:

$$H_t = \left[\sum_{j \in g,b,m} (\omega_{hj})^{\frac{-1}{\eta_h}} (H_t^j)^{\frac{\eta_h + 1}{\eta_h}} \right]^{\frac{\eta_h}{\eta_h + 1}} \tag{13}$$

where H_t^j denotes labour used in sector $j \in \{g, b, m\}$, ω_h^j governs the sectoral weight of labour demand, and η_h captures the degree of labour mobility across sectors.

An implication of this imperfect sectoral labor mobility is that sectoral unit labor costs depend not only on the aggregate wage paid to households, but also on the sector's share of total hours worked. As labor is imperfectly mobile across sectors, reallocating workers toward a given sector causes an increase in unit labor costs in that particular sector. For example, unit labor cost in sector j is given by $W_t^j = W_t \left(\frac{H_t^j}{\omega_{hj} H_t} \right)^{1/\eta_h}$. Labor is perfectly mobile across sectors when $\eta_h = \infty$. In that case, unit labor costs do not increase with sectoral labor demand and are identical in all sectors.

3.4 Investment-good producers

Investment-good producers combine green and brown final goods with metals to produce investment goods. They operate under perfect competition. A representative producer i of investment goods destined to raise the stock of capital in sector $j \in \{g, b, m\}$ maximizes its real profit, $\Pi_t^{Ij}(i)$, given by

$$\Pi_t^{Ij}(i) = p_t^{Ij} I_t^j(i) - p_t^g G_t^{Ij}(i) - p_t^b B_t^{Ij}(i) - (1 - \mu_t^j) p_t^m M_t^{Ij}(i),$$

where μ_t^j denotes a tax or subsidy on the use of metal inputs: $\mu_t^g > 0$ represents an ETM-input subsidy to green investment goods, while $\mu_t^b < 0$ represents an ETM-input tax to brown investment goods.

The investment basket is a bundle of green, brown and metal inputs:

$$I_t^j = \left((\omega_m^{Ij})^{\frac{1}{\eta_m}} \left[M_t^{Ij} \right]^{\frac{\eta_m - 1}{\eta_m}} + (1 - \omega_m^{Ij})^{\frac{1}{\eta_m}} \left[(G_t^{Ij})^{\omega_g} (B_t^{Ij})^{1-\omega_g} \right]^{\frac{\eta_m - 1}{\eta_m}} \right)^{\frac{\eta_m}{\eta_m - 1}} \tag{14}$$

where M_t^{Ij} denotes ETM inputs used in the production of new capital in sector j, while G_t^{Ij} and B_t^{Ij} denote green and brown goods used. ω_m^{Ij} denotes the investment expenditure share of metal inputs, and η_m is the elasticity of substitution between ETM inputs and the green-brown goods composite. We impose the same elasticity of substitution for ETMs used in production and investment.

3.5 Fiscal authority

The fiscal authority implements the benchmark GT through output-based sector-specific policy wedges. Green final-good production is subsidized, represented by $\tau_t^g > 0$, while brown final-good production is taxed, represented by $\tau_t^b < 0$. The results of this benchmark output-based scheme are presented in Sections 4.1-4.4. In Section 4.5, we also consider the role of ETM-input taxes and subsidies (with $\mu_t^g > 0$ and $\mu_t^b < 0$).

We assume that the GT is triggered by the simultaneous and permanent introduction of these two policy wedges. The policy is introduced as an unexpected permanent shock, which we interpret as an unexpected acceleration of the transition. The wedges are calibrated to be fiscally balanced a priori, with $\tau_t^g Y^G = -\tau_t^b Y^B$, where Y^G and Y^B are the initial levels of

green and brown production, respectively. Any net fiscal balance generated by these wedges is offset through lump-sum transfers to households.

This joint use of green subsidies and brown taxes provides a useful benchmark. In a perfectly symmetric economy, this policy mix reallocates production from the brown sector to the green sector without affecting aggregate outcomes (up to a first-order approximation of the model). We use this symmetric case as a reference point to isolate the role of ETM bottlenecks, defined as the limited ability of ETM supply to accommodate the increase in ETM demand induced by the GT. This interpretation is consistent with the view that more aggressive transition paths (such as the IEA Net Zero Emissions (NZE) scenario) are more likely to generate ETM bottlenecks than slower transition paths, such as the IEA Stated Policies Scenario.

3.6 Monetary authority

In our baseline simulations, the monetary authority sets the nominal interest rate according to a Taylor-type rule

$$R_t = (R_{t-1})^{\rho_r} R^{(1-\rho_r)} \left((\pi_t)^{\phi_p} \left(\frac{\bar{Y}_t}{\bar{Y}_t^n} \right)^{\phi_g} \right)^{1-\rho_r}, \tag{15}$$

where R is the steady-state level of the interest rate, π_t is the (gross) CPI inflation rate defined by $\pi_t = P_t/P_{t-1}$ where the CPI is $P_t = (P_t^g)^{\omega_g}(P_t^b)^{1-\omega_g}$, with P_t^b and P_t^g denoting the brown- and green-good prices, respectively. $\bar{Y}_t = \int_0^1 C_t(i)\mathrm{d}(i) + \sum_{j\in g,b,m} \int_0^1 I_t^j(i)\mathrm{d}(i)$ is aggregate GDP and $\bar{Y}_t^n$ is the natural level of output, defined as output in the flexible-price and flexible-wage economy.

3.7 Calibration

Table 2 reports the calibrated parameter values used in the model. We organize the calibration discussion in three steps. First, we describe the baseline calibration. Second, we discuss the calibration of the New Keynesian economy and the corresponding fully flexible price-and-wage economy. Finally, we present the counterfactual calibrations used to isolate specific mechanisms, including the perfectly inelastic ETM supply case, the symmetric economy, and the climate-policy uncertainty case.

Baseline calibration The production and use of ETMs are characterized by price elasticities of demand and supply, especially in the short run, and by long horizons for expanding ETM production capacity. We set the short- and long-run price elasticities of ETM supply, σ_{SR} and σ_{LR}, to 0.15 and 0.63, respectively, based on the median elasticities for all metals reported in the literature review by Dahl (2020). The resulting horizon-dependent elasticities are also consistent with the estimates in other studies (see, for example, Boer et al., 2024; Bogmans et al., 2024). This calibration implies that our structural parameters in the production function of metals are given by $\theta_m = 0.30$ and $\gamma_m = 0.33$, under the assumption that the labor share is set to $1/3$.

We set the demand elasticity, η_m, to 0.11, corresponding to the median long-run price elasticity of metal demand reported by Dahl (2020). This choice is conservative in our framework because the elasticity of ETM demand is assumed to be constant across horizons, whereas the median short-run elasticity reported by Dahl (2020) is only 0.03. The depreciation rate of ETM capital, δ_m, is set to 0.0025, implying that the horizon for expanding ETM production capacity is ten times larger than in the other sectors.

The green and brown sectors differ in their reliance on ETM inputs, especially in investment. Clean-energy technologies are substantially more metal-intensive than their fossil-fuel counterparts. For example, the IEA estimates that an electric car requires about six times as many minerals as a conventional car. Similarly, solar and wind technologies require between three and six times as many minerals per megawatt of generation capacity as coal plants (see Section 2). We therefore set ω_m^{Ib} and ω_m^{Ig} to 0.10 and 0.30, respectively, so that the ETM share in green investment is three times that in brown investment. This choice lies at the lower end of the evidence reported in Section 2 and is therefore conservative.

To reflect the fact that metals are used primarily for investment, we set the ETM share in green and brown final-good production, $\omega_m^{Yg} = \omega_m^{Yb}$, to 0.02. This implies that ETMs account for about 6% of GDP, with two-thirds of metals use taking the form of investment-specific inputs. These values are consistent with the OECD input-output evidence presented in Table 1 of Section 2. Overall, when considering both the production and investment-specific uses of ETMs, the green sector requires about 1.7 times as much ETM input as the brown sector.

A set of parameters (β, σ_c, b, σ_h, α_g, α_b, ψ, δ_g, δ_b, ϵ_h, η_h) is calibrated to standard values in the literature and reported in Table 2. In particular, the degree of sectoral labor mobility, η_h, is set to one as in Horvath (2000).

Table 2: Calibration

Parameter	Description	Value
β	Discount factor	0.99
σ_c	Inverse intertemporal elasticity of substitution	1.00
b	Habits in consumption	0.70
σ_h	Inverse Frisch elasticity of labor supply	2.00
$\alpha_g = \alpha_b$	Green and brown capital income shares	0.33
ψ	Investment adjustment cost	4.00
$\delta_g = \delta_b$	Depreciation rate of green and brown capital	0.025
δ_m	Depreciation rate of ETM capital	0.0025
η_m	ETM demand elasticity	0.11
ω_m^{Ig}	ETM share in green investment	0.30
ω_m^{Ib}	ETM share in brown investment	0.10
$\omega_m^{Yg} = \omega_m^{Yb}$	ETM share in green and brown production	0.02
η_h	Degree of sectoral labor mobility	1
σ_{SR}	Short-run elasticity of ETM supply	0.15
σ_{LR}	Long-run elasticity of ETM supply	0.63
$\xi_g = \xi_b$	Calvo price stickiness (green and brown)	0.75
ξ_w	Wage stickiness	0.875
ϵ_h	Labor demand elasticity	5
ϕ_p	Taylor rule coefficient: inflation	1.5
ϕ_g	Taylor rule coefficient: output gap	0

The New Keynesian economy We assume that ETM prices are fully flexible, while final-good prices are sticky in the New Keynesian economy. The Calvo parameters in the green and brown sectors, ξ_g and ξ_b, are both set to 0.75. This value is close to the estimate reported by Gagliardone et al. (2025). In a robustness exercise, we follow Del Negro et al. (2023) and allow price stickiness to differ across sectors, with a lower degree of price rigidity in the brown sector.

We set the wage Calvo parameter, ξ_w, to 0.875, implying that wages are stickier than prices. This calibration is consistent with the evidence from micro data showing that wages adjust less frequently than prices. For example, Thomas (2008) and Smets et al. (2018) rely on micro evidence from Klenow and Kryvtsov (2008); Gottschalk (2005); Peneva (2011); Bils et al. (2022). Estimating a DSGE model with commodities using US data, Houssa et al. (2023) also find that wages are stickier than prices.

In the baseline calibration, the central bank responds to inflation ($\phi_p = 1.5$) but assigns no weight to the output gap ($\phi_g = 0$). Under strict inflation targeting, the nominal interest rate

adjusts so that inflation always remains at target: the equation $\pi_t = 1$ replaces the Taylor rule (and is equivalent to $\phi_p = \infty$). Under output gap targeting, policy stabilizes GDP at the path of the FFPW economy: $\bar{Y}_t = \bar{Y}_t^n$ (and is equivalent to $\phi_g = \infty$). Under employment targeting, policy stabilizes employment at its pre-GT steady-state level: $H_t = H$ where H is the initial steady state of employment.

The fully flexible economy In the fully flexible price-and-wage (FFPW) economy, we set $\xi_g = \xi_b = \xi_w = 0$. The FFPW economy is used to construct the natural level of output and to measure the output gap effect of the GT (see Section 4.1). It also provides a benchmark for assessing the role of nominal rigidities and the monetary-policy trade-offs between inflation and output-gap stabilization during the GT (see Sections 4.2 and 4.3).

Perfectly inelastic ETM supply In the inelastic ETM supply case, we set the price elasticity of ETM supply to zero at all horizons. This counterfactual is used to assess the consequences of severe ETM shortages during the GT. In this economy, ETM output does not respond to prices and remains fixed at its steady-state level throughout the transition.

The symmetric economy In the symmetric economy, we impose symmetry between the green and the brown sectors, including ETM intensities in investment, $\omega_m^{Ig} = \omega_m^{Ib}$. Under this benchmark, the contraction in the brown sector induced by the brown tax is exactly offset by expansion in the green sector induced by the green subsidy under a first-order approximation of our model. As a result, the GT has no aggregate effects. We use this benchmark as a reference point against which to measure the macroeconomic cost of the GT under the more realistic calibration.

Climate-policy uncertainty: policy-continuation risks Finally, we consider a case in which agents form expectations under a perceived risk that climate policies may be discontinued. We set the expected probability of policy discontinuation to 10% per year. We then simulate a path in which climate policies continue ex post, but agents behave as if the discontinuation risk could materialize. This exercise allows us to study how policy-continuation risk affects the macroeconomic costs of the GT.

4 ETM bottlenecks and the macroeconomic costs of the green transition

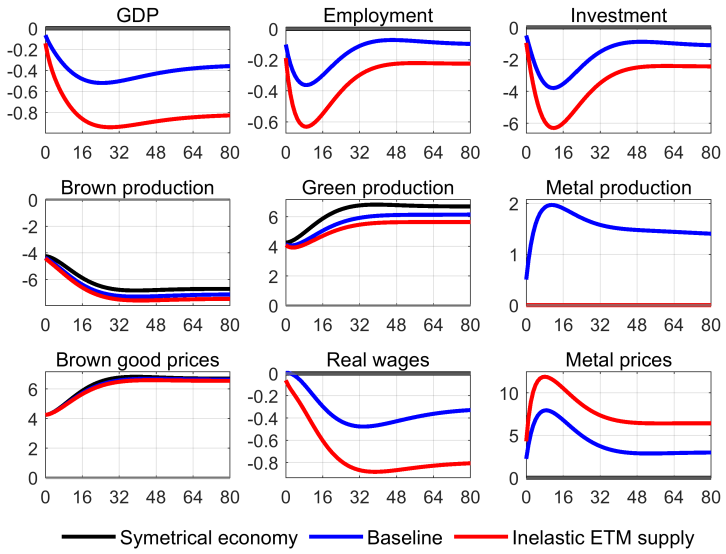
This section studies the quantitative implications of ETM bottlenecks during the green transition (GT).

4.1 ETM bottlenecks and potential output

This section quantifies how ETM bottlenecks affect potential output during the GT. We simulate the transition under three calibrations: (i) a symmetric benchmark economy in which the green and brown sectors use ETMs in the same proportions; (ii) our baseline calibration, in which green investment is more ETM-intensive and the short- and long-run price elasticities of ETM supply are set to 0.15 and 0.63, respectively; and (iii) an acute-bottleneck case in which ETM supply is perfectly inelastic at all horizons.

In all three cases, prices and wages are fully flexible, so that the allocation corresponds to the natural economy and determines potential output. The GT is triggered by an unexpected, credible and permanent fiscal-policy shock consisting of a brown production tax and a green production subsidy. Figure 6 reports the results of the three scenarios.

Figure 6: Bottlenecks in the fully flexible price-and-wage economy



In the symmetric benchmark economy, the fiscal authority can engineer a green transition

that has no effect on potential output, aggregate employment, real wages, or investment, using a balanced combination of taxes and subsidies. When $\tau_t^b = -\tau_t^g$ and $Y^b = Y^g$ before the shock, the policy changes the relative price of brown and green goods and reallocates production from the brown sector to the green sector. Because the two sectors are symmetric, the contraction in brown-sector activity is exactly offset by an expansion in green-sector activity. As long as the real frictions, such as investment adjustment costs, are also identical across the sectors, aggregate variables remain at their steady-state levels during and after the GT. In particular, metal inputs are simply redirected from the brown sector to the green sector, with no effect on total metal demand or on metal prices.

The baseline calibration delivers a sharply different outcome. Because green investment is more ETM-intensive than brown investment, the GT raises aggregate demand for metals. A permanent 10% tax on brown-good production, combined with a 10% subsidy to green-good production, reduces potential output by about 0.5% within two years. Real metal prices increase by 8% over the same horizon and remain about 3% above the initial steady state in the long run.

The decline in potential output operates through two channels. The first is a production-input price channel. Higher metal prices raise marginal costs and reduce demand for labor and capital in the green and brown sectors, because ETMs and the capital-labor composite are gross complements in production when $\eta_m < 1$. The second is an investment-demand channel that originates from the use of metals as investment-specific inputs. Higher metal prices increase the price of investment goods relative to consumption goods, reducing investment demand. Together, these two channels generate a permanent decline in potential output, unless ETM supply becomes sufficiently elastic in the long run.

Overall, the GT reduces potential output, employment, investment and real wages in the baseline calibration. The joint decline in employment and real wages indicates a fall in labor demand. This decline operates directly through higher ETM prices, which reduce labor demand because ETMs and other production inputs are complements, and indirectly through a gradual decline in the capital stock following the fall in investment.

The increase in metal prices and the decline in potential output are larger when the price elasticity of ETM supply is low. In the perfectly inelastic ETM supply case, metal prices peak at about 12% above their steady-state level, compared with 8% in the baseline, and remain 6% higher in the long run, compared with 3% in the baseline. Potential output falls

by 0.8% in the long run, compared with 0.4% in the baseline. Employment is also persistently reduced by 0.2 percentage points, compared with 0.1 in the baseline. The ability of ETM supply to accommodate the increase in metal demand induced by the GT is therefore a crucial determinant of the macroeconomic cost of the transition.

Together, these results show that ETM bottlenecks create a trade-off between decarbonization and economic activity, without making the GT infeasible. Bottlenecks do not prevent the relative-price adjustment between brown and green goods that reallocates activity toward the green sector. For a given combination of brown taxes and green subsidies, emissions may even decline more when bottlenecks are present, because lower aggregate activity further depresses activity in the brown sector. The cost is that the expansion of the green sector is also weaker. Since green investment is more ETM-intensive, the green sector is disproportionately exposed to higher metal prices. ETM bottlenecks therefore lower potential output while still allowing the economy to reduce emissions.

4.2 Nominal rigidities and the short-run cost of the GT

This section shows how price and wage rigidities magnify the short-run cost of the GT. We compare the effects of the same fiscal-policy shock studied in Section 4.1 under two environments: the fully flexible price-and-wage economy (FFPW) and the New Keynesian economy (NK). In the NK economy, prices and wages are sticky, and the monetary authority sets the interest rate according to the baseline Taylor rule. Alternative monetary-policy rules are considered in Section 4.3.

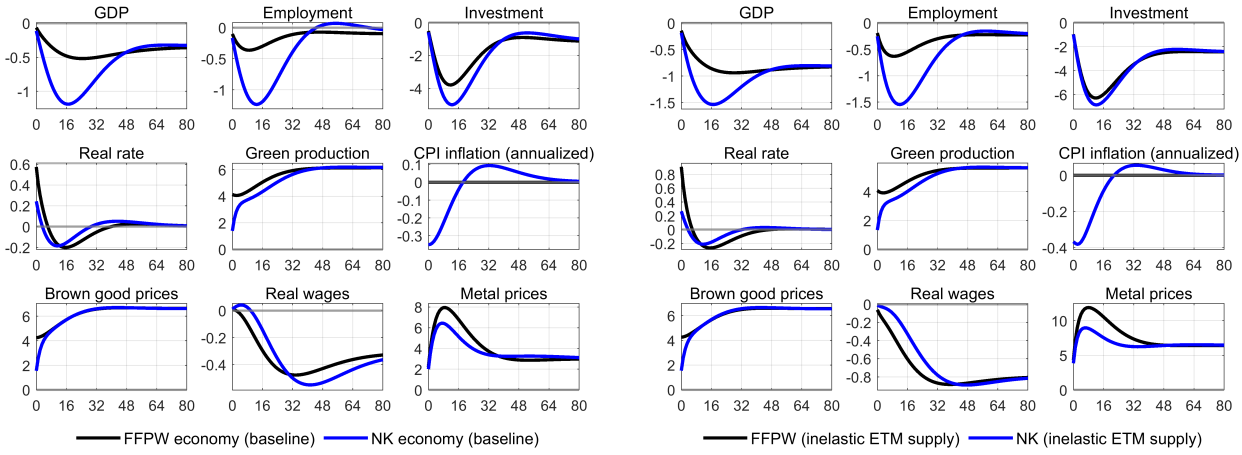
Figure 7 contrasts the dynamics of the GT in the FFPW and NK economies. The left panel reports the baseline calibration, while the right panel reports the acute bottleneck case in which ETM supply is perfectly inelastic.

Nominal rigidities magnify the short-run trade-off between decarbonization and economic activity that emerges with ETM bottlenecks. Under the baseline calibration, GDP and employment fall by about 1.2% in the short run in the NK economy, compared with about 0.5% in the FFPW economy. Relative price adjustments between green and brown goods are also slower in the NK economy. As a result, the expansion of the green sector is delayed when relative prices and real wages adjust only gradually.

Figure 7: Nominal rigidities and the short-run cost of the GT

(a) Baseline calibration

(b) Inelastic ETM supply



This amplification operates mainly through sluggish real-wage and relative-price adjustment. During the GT, higher metal prices reduce labor demand because ETMs and other production inputs are complements. In addition, the increase in the relative price of investment goods lowers investment, which gradually reduces the capital stock and further weakens labor productivity. Firms are therefore willing to pay lower real wages. At the same time, households' marginal rate of substitution between labor and consumption declines with the fall in hours worked and the medium- to long-run decline in consumption. Households are therefore encouraged to accept lower wages.

Real-wage adjustment is slower in the NK economy for two reasons. First, only a small fraction of households can re-optimize their wages in every period, while the wages of non-re-optimizing households remain fixed in nominal terms. Second, CPI inflation initially falls in the NK economy, which raises the real wage of households whose nominal wages cannot adjust.

In the NK economy, CPI inflation declines in the initial stage of the GT when the central bank follows the Taylor rule. Inflation reflects two opposing forces. On the one hand, higher ETM prices raise marginal costs through the input-cost channel and put upward pressure on inflation. On the other hand, the real-wage adjustment channel and the decline in investment demand reduce inflationary pressure. Under our baseline calibration, the disinflationary effects of weaker labor and investment demand dominate in the early stages of the transition. This initial fall in inflation slows the required real-wage adjustment and

amplifies the decline in employment and output.[5]

These results have important implications for monetary policy. The combination of disinflation and a negative output gap suggests that a Taylor rule that responds strongly to inflation but assigns no weight to the output gap may not be well suited to a GT with ETM bottlenecks. A more accommodative policy could reduce the gaps between the NK and FFPW economies by supporting investment and facilitating real-wage adjustment when nominal wages are sticky. However, the cost-push pressure generated by higher metal prices implies that the monetary authority may face a trade-off between stabilizing inflation and stabilizing economic activity during the GT. We examine this trade-off in detail in the next section.

4.3 Monetary-policy trade-offs during the GT

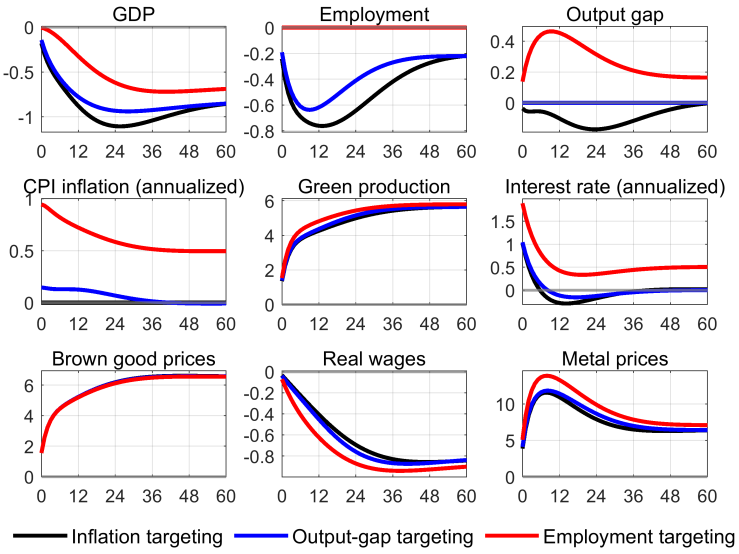
This section studies the monetary-policy trade-offs between inflation stabilization and economic-activity stabilization during the GT. We compare three different monetary policy rules: (i) under strict inflation targeting, the nominal interest rate adjusts so that inflation always remains at target; (ii) under output-gap targeting, policy stabilizes GDP at the path of the FFPW economy; and (iii) under employment targeting, policy stabilizes employment at its pre-GT steady-state level.

We evaluate these rules in the acute ETM-bottleneck case, in which ETM supply is perfectly inelastic at all horizons. This extreme case provides a stark benchmark for identifying trade-offs created by ETM bottlenecks. Figure 8 reports the transition paths under different monetary-policy rules.

The trade-off between CPI inflation and output gap stabilization is relatively mild and confined to the short and medium runs. To close the output gap completely, the monetary authority must tolerate CPI inflation about 0.15 percentage point above target for roughly 4 years, with inflation gradually returning to target in the long run. Conversely, keeping inflation on target throughout the GT requires the central bank to tolerate a negative output gap in the short and medium runs, with output falling about 0.2% below potential at its trough. The trade-off disappears in the long run once relative prices and wages fully adjust.

[5] Note that we can isolate the effects of the cost-push channel by assuming that metals are not used as intermediate production inputs. In these simulations, the fall in inflation is more pronounced, which indicates that the input-cost channel contributes positively to inflation.

Figure 8: Monetary policy trade-offs in the GT



This trade-off arises because supporting aggregate demand raises ETM prices, which eventually increase marginal production cost for green and brown producers and raise the cost of investment goods. In the short run, the inflationary pressure originates from the production-input price channel but remains limited for two reasons: (i) metals are used primarily for investment rather than consumption and (ii) the fall in investment demand initially dampens inflation. Over time, however, the investment-demand channel becomes a supply-side channel: the persistently lower investment demand reduces the capital stock, which lowers potential output and raises production costs. This mechanism creates a medium-run trade-off between stabilizing inflation and stabilizing the output gap.

These results suggest that ETM bottlenecks can generate monetary-policy trade-offs, but they are unlikely, by themselves, to generate a burst of inflation when the central bank aims to close the output gap. This should be interpreted with caution. These experiments isolate the contribution of ETM bottlenecks to stabilization trade-offs in the model. In a richer model, other shocks or frictions could interact with ETM scarcity and generate a larger trade-off. Moreover, the transition considered here already implies a decline in the brown-sector output of about 7% within eight years. A faster GT would likely magnify the trade-off.

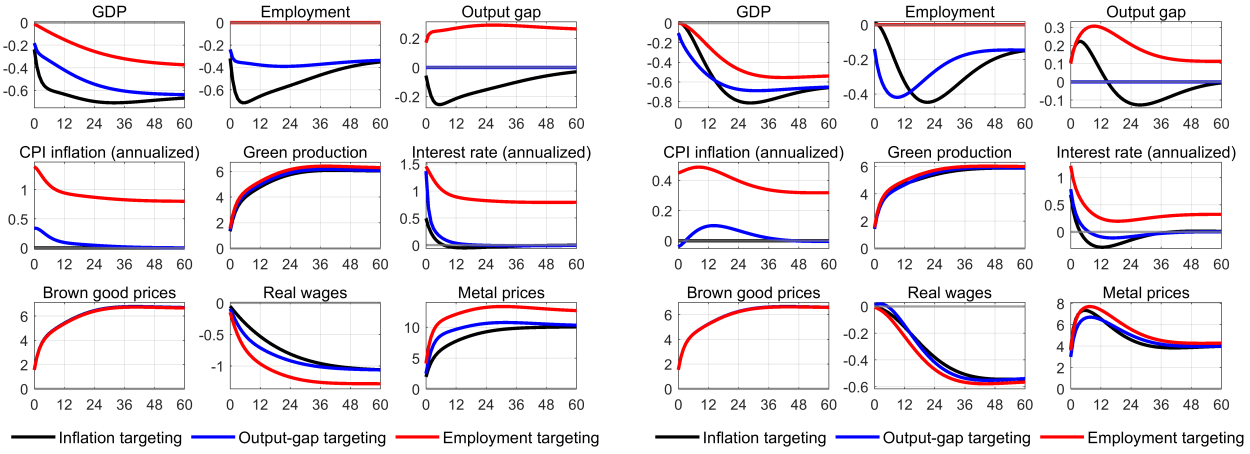
Strong inflationary pressures could arise, however, if the monetary authority tries to stabilize employment at its pre-GT level. A GT with ETM bottlenecks reduces potential output and, therefore, the natural level of employment (see Sections 4.1 and 4.2). Stabilizing employment

at its pre-GT level therefore requires the central bank to engineer a positive output gap in the short, medium, and long runs. This comes at the cost of higher inflation: CPI inflation rises to about 1 percentage point above target on impact and settles around 0.5 percentage point above target in the long run.

Figure 9: Monetary policy trade-offs with different ETM uses

(a) ETMs used as production inputs

(b) ETMs used as investment-specific inputs



The magnitude of the monetary-policy trade-offs is sensitive to the extent to which ETMs are used as production or investment-specific inputs. Figure 9 shows the transition paths under different monetary-policy rules, when ETMs are exclusively used as production inputs (panel a) or as investment-specific inputs (panel b). In the first case, we set $\omega_m^{Ig} = \omega_m^{Ib} = 0$, $\omega_m^{Yg} = 0.08$, and $\omega_m^{Yb} = 0.05$. In the second case, we set $\omega_m^{Yg} = \omega_m^{Yb} = 0$, $\omega_m^{Ig} = 0.33$, and $\omega_m^{Ib} = 0.20$. With these calibrations, the total share of ETM use in GDP remains at 6% and the green sector continues to require about 1.7 times as much ETM input as the brown sector.

When ETMs are exclusively used as production inputs, the monetary authority must now tolerate CPI inflation about 0.33 percentage points above target on impact to close the output gap completely (compared to 0.15 in the baseline). Keeping inflation on target throughout the GT requires the central bank to tolerate output falling about 0.26% below potential at its trough (compared to 0.17% in the baseline). The short-run trade-off thus increases with the share of ETMs used as production inputs, but this trade-off also softens in the medium run.

In contrast, when ETMs are exclusively used as investment-specific inputs, the short-run trade-off almost disappears. To close the output gap completely, the monetary authority

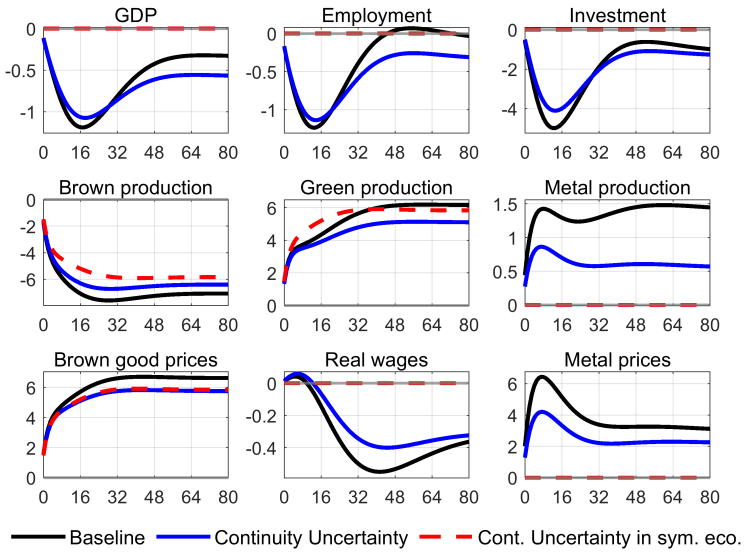
must now tolerate CPI inflation about 0.10 percentage points above target in the medium run, but this does not yield inflationary pressures in the short run.

4.4 The cost of climate-policy uncertainty

This section evaluates how climate-policy uncertainty affects the transition and the macroeconomy. We focus on policy-continuation risks in which agents perceive a probability that climate policies may be discontinued in the future. Such risks can discourage investment in the green sector and, through this channel, reduce demand for ETMs. The ETM sector may be affected particularly strongly because expanding ETM production capacity requires longer investment horizons.

We quantify these effects using three versions of our model: (i) the baseline calibration described in Section 3.7 without uncertainty; (ii) the baseline calibration with a perceived policy-discontinuation risk of 10% per year; and (iii) the symmetric economy with the same discontinuation risk. In the second and third cases, we simulate a path in which climate policies continue ex post, using a sequence of policy-continuation shocks. Agents, however, make decisions as if the discontinuation risk could materialize. Figure 10 reports the results.

Figure 10: Climate policy continuation risks during the GT

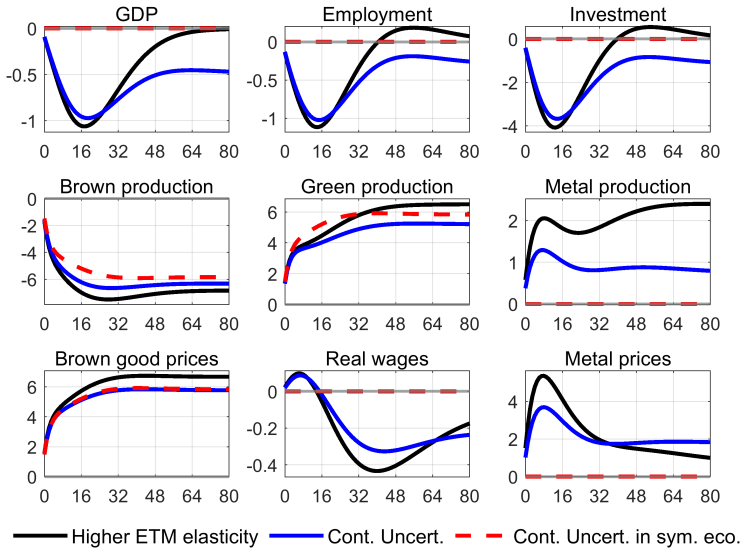


Climate-policy uncertainty weakens the green transition. When agents perceive a risk that climate policies may be discontinued, the expected future payoff from green investment declines, because the policy-induced relative-price advantage of the green sector may not

persist. As a result, the reallocation of activity from the brown sector to the green sector is less pronounced than in the baseline scenario. Figure 10 shows that green production expands less under policy-continuation risk, while the contraction in brown production is also smaller. In the symmetric economy, this weaker transition has no aggregate cost: GDP, aggregate investment and employment remain at their steady-state levels. This confirms that, in our framework, policy-continuation risk alone does not generate aggregate losses in the absence of ETM bottlenecks.

The key result is that policy-continuation risk interacts with ETM bottlenecks under the baseline calibration. Because expanding ETM production capacity requires long investment horizons, the ETM sector is especially exposed to uncertainty about the duration of climate policies. The sector is affected through two channels. First, expected demand from the green sector is weaker when agents perceive a risk that policies supporting this sector may be discontinued. Second, policy-continuation risks lower the expected discounted value of future returns from investment in ETM capacity. As a result, investment in ETM capacity is lower, making ETM bottlenecks more persistent. ETM production increases by only 0.5% under policy-continuation risk, compared with 1.5% in the baseline scenario without uncertainty. In particular, policy-continuation risk increases the long-run GDP loss by 0.2 percentage points, from about 0.3% without uncertainty to 0.5% with uncertainty.

Figure 11: Climate policy continuation risks with high long-run ETM supply elasticity



The additional cost of policy-continuation risk is larger when long-run ETM supply is more elastic (see Figure 11). Under policy certainty, a more elastic ETM supply allows production capacity to expand more strongly, thereby reducing long-run metal prices and mitigating the

macroeconomic cost of the GT. Policy-continuation risk weakens precisely this investment response. For example, when the long-run price elasticity of ETM supply is set to 5, the long-run GDP loss is close to zero under policy certainty. Under policy-continuation risk, however, the long-run GDP loss remains close to 0.5%. With this higher long-run elasticity of ETM supply, policy-continuation risk therefore raises the long-run GDP loss by 0.5 percentage points.

4.5 ETM-input taxes and subsidies

Can ETM-input policies mitigate the macroeconomic costs of the GT? A natural policy alternative is to tax the use of ETMs in the brown sector and use the proceeds to subsidize their use in the green sector. The argument for such a policy is that an ETM-input tax in the brown sector can release scarce metal inputs and redirect them toward the green sector, thereby supporting green investment. The policy can also generate favorable general-equilibrium price effects: by reducing ETM demand from the brown sector, it may lower the price of the scarce ETMs required for green investment.

This section asks whether such an ETM-input tax and subsidy can mitigate or even eliminate the GT costs and stabilization trade-offs documented above. We compare this ETM-input scheme (or ETM scheme, for short) with the output-based scheme used in Sections 4.1– 4.4, which we refer to as the baseline scheme.

The attractiveness of the ETM scheme depends on two structural features: the price elasticity of ETM demand and the extent to which ETMs are used as production or investment-specific inputs. To show this result, we compare the two policy schemes in two model variants. In the first variant, ETMs are used only as production inputs (Section 4.5.1). In this case, consumption and investment goods embody ETMs in the same proportions. In the second variant, ETMs are used only as investment inputs, so that ETMs are required to produce capital goods but not current consumption goods (Section 4.5.2). In both variants, the green sector is more ETM-intensive than the brown sector, either in production or in investment.

We also consider different calibrations of the price elasticity of ETM demand, ranging from 0.05 to 1. To make the two policy schemes comparable, we calibrate the taxes and subsidies so that they generate the same long-run reduction in brown-good production, namely a 10% decline. We obtain similar results if policies are instead calibrated to generate the same long-

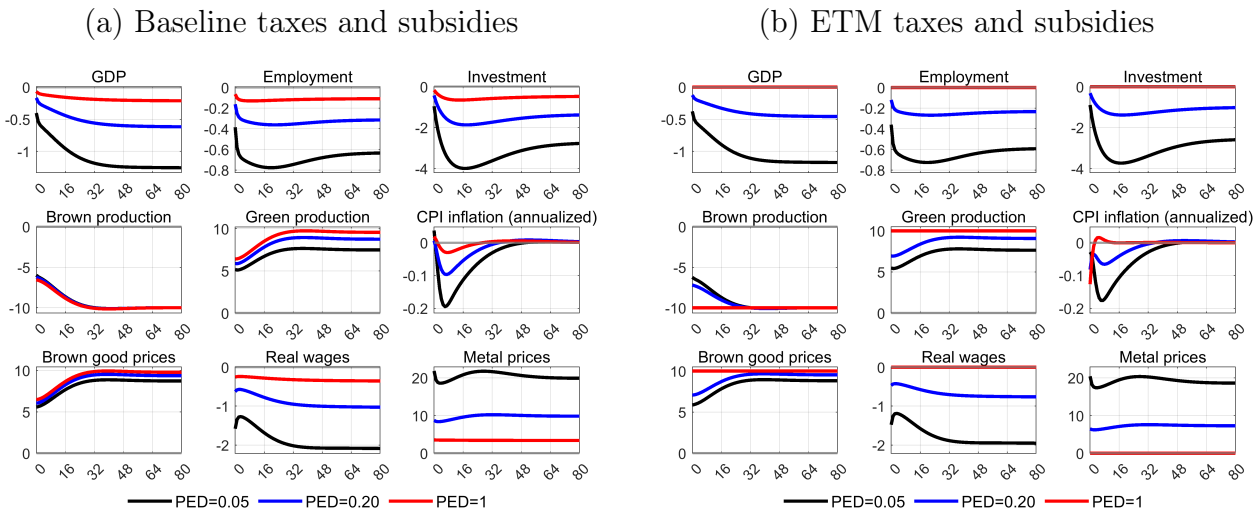
run adjustment in the relative price of brown and green goods, which can be interpreted as targeting a given carbon-price wedge.

4.5.1 ETM production inputs

Figure 12 compares the macroeconomic cost of two ways of inducing the GT in a model in which ETMs are used only as production inputs. The first is the baseline output-based scheme, which consists of broad-based brown taxes and green-output subsidies. The second is the ETM-input scheme, which taxes ETM use in the brown sector and subsidizes ETM use in the green sector. Specifically, we set $\omega_m^{Ig} = \omega_m^{Ib} = 0$, $\omega_m^{Yg} = 0.08$, and $\omega_m^{Yb} = 0.05$, so that the total share of ETM in GDP remains at 6% and the green sector continues to require about 1.7 times as much ETM input as the brown sector.

In this model variant, the ETM-input scheme generates lower macroeconomic costs than the baseline scheme. The reason is that it targets the scarce input directly rather than taxing and subsidizing all sectoral output. Two channels explain this result.

Figure 12: Baseline vs ETM-input schemes when ETMs are used as production inputs



Note: PED=price elasticity of ETM demand

The first channel is common to both schemes and operates through relative sectoral production costs. Under both schemes, the policy wedge makes brown production relatively more expensive and green production relatively more attractive. Final demand therefore shifts from brown goods towards green goods. Because the green sector uses ETMs more inten-

sively than the brown sector, this reallocation raises aggregate demand for ETMs. The ETM price rises, generating the output, employment, and investment losses described in Sections 4.1 and 4.2.

The second channel operates only under the ETM-input scheme. By taxing ETM use in the brown sector and subsidizing ETM use in the green sector, the policy changes the relative price of ETMs faced by firms in each sector. This generates within-sector substitution between ETMs and the other production inputs (labor and capital). The strength of this substitution channel depends on the price elasticity of ETM demand, η_m. When η_m is close to zero, firms have little scope to substitute away from ETMs in the brown sector or toward ETMs in the green sector. In this case, the ETM-input scheme produces effects that are close to those of the baseline scheme.

As η_m increases, the ETM scheme outperforms the baseline scheme. The reason is that substitution away from ETMs in the brown sector becomes quantitatively important. By reducing brown-sector demand for ETMs, the ETM tax mitigates the increase in metal prices and thereby benefits the green sector. At the same time, the ETM subsidy lowers the effective cost of ETMs for green producers. The ETM scheme therefore reallocates scarce ETMs towards the green sector while reducing the aggregate pressure on ETM markets.

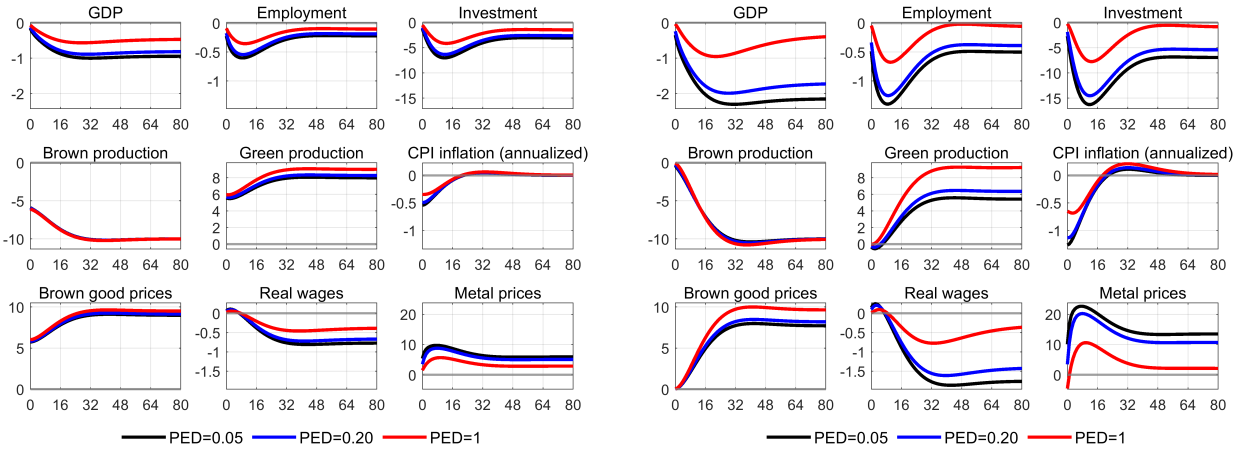
The output cost of the GT can even fall to zero when the price elasticity of ETM demand is equal to one. This is a special case in which the two channels approximately offset each other under the ETM scheme. Under this calibration, the elasticity of substitution between green and brown goods and the elasticity of substitution between ETM and other production inputs (capital and labor) are both equal to one.

4.5.2 ETM investment inputs

Figure 13 compares the macroeconomic cost of a GT under the baseline output-based scheme and the ETM-input scheme, in a model in which ETMs are used only as investment inputs. Specifically, we set $\omega_m^{Yg} = \omega_m^{Yb} = 0$, $\omega_m^{Ig} = 0.33$, and $\omega_m^{Ib} = 0.20$, so that the total share of ETM use in GDP remains at 6% and the green sector continues to require about 1.7 times as much ETM input as the brown sector. This case delivers a sharp contrast with Section 4.5.1. When ETMs are investment inputs, taxing and subsidizing ETM use can amplify rather than mitigate the macroeconomic cost of the GT.

Figure 13: Baseline vs ETM-input schemes when ETMs are used as investment inputs

(a) Baseline taxes and subsidies (b) ETM taxes and subsidies



Note: PED=price elasticity of ETM demand

The ETM scheme can generate very large costs in an economy that depends on ETMs for capital accumulation. The GT is nevertheless slower under the ETM scheme and becomes especially costly when the price elasticity of ETM demand is low. When η_m is low, capital-goods producers have little scope to substitute away from ETMs toward the green-brown final-good composite. The ETM tax therefore makes brown investment more expensive, without inducing a large reduction in ETM use. At the same time, the subsidy to ETM use in the green sector raises demand for scarce metals. Because ETM supply adjusts slowly, this additional demand pushes up metal prices, which weakens the investment response that the green subsidy is meant to stimulate. Aggregate investment falls sharply, causing large and persistent GDP losses.

In economies where ETMs are used only as investment inputs, the ETM scheme outperforms the baseline scheme only in the long run and only when the price elasticity of ETM demand is sufficiently high. In that case, the tax on ETM use in brown investment induces substitution away from scarce metals, which reduces pressure on ETM prices and eventually lowers the macroeconomic cost of the GT. The GT is nevertheless slower under the ETM scheme. Unlike the baseline scheme, which directly changes the relative price of green and brown final goods, the ETM scheme operates through the cost of investment goods. Its effects on green and brown production therefore materialize gradually, as investment decisions affect sectoral capital accumulation. The policy implication is that brown ETM taxes should be used with caution when ETMs are investment inputs. If firms cannot easily substitute away

from ETMs in the production of capital goods, such taxes raise the cost of investment without releasing enough scarce metals. In that case, the ETM scheme can slow the GT and amplify its macroeconomic costs.

5 Conclusion

This paper develops a dynamic general equilibrium model with green and brown final goods, in which energy-transition metals (ETMs) enter production directly and capital accumulation through investment-specific inputs. ETMs refer collectively to metals and minerals such as copper, cobalt, lithium, nickel, and graphite that are critical inputs for building a greener economy. The green transition (GT) reallocates production and investment from brown activities toward green, ETM-intensive technologies such as renewable energy, energy storage, and electric mobility. The interaction between transition-driven ETM demand and sluggish ETM supply generates ETM bottlenecks. The model includes fiscal and monetary authorities and is calibrated to a stylized global economy. We show that ETMs are a propagation mechanism through which climate policy affects investment, potential output, inflation, and the pace of decarbonization.

Three main lessons emerge. First, ETM bottlenecks make the GT costly even in the absence of nominal rigidities. When green investment is more ETM-intensive than brown investment, the GT raises aggregate demand for ETMs. Because ETM supply adjusts only gradually, this increase in demand generates bottlenecks that raise ETM prices. Higher ETM prices reduce investment and lower potential output. Nominal rigidities amplify these real-side costs in the short run by delaying the adjustment of real wages and relative prices.

Second, ETM bottlenecks affect both the conduct of monetary policy and the costs of climate-policy uncertainty. Because supporting economic activity raises demand for scarce ETMs and pushes up their prices, ETM bottlenecks generate a stabilization trade-off between inflation and real activity. This trade-off is relatively moderate when the central bank stabilizes the output gap, but becomes sharper when policy attempts to stabilize employment at its pre-transition level. Conversely, strict inflation targeting deepens activity losses. Climate-policy continuation risk further raises the cost of the transition by weakening green investment and investment in ETM production capacity, thereby making bottlenecks more persistent.

Third, policy design matters. ETM-input policies can mitigate transition costs when ETMs

are production inputs and ETM demand is sufficiently elastic. However, the same policies can amplify transition costs when ETMs are investment-specific inputs and demand is inelastic, because they raise the cost of capital accumulation without releasing enough scarce metals. The effectiveness of input-based climate policy therefore depends on where ETMs enter the economy and on how easily firms can substitute away from them.

Our framework abstracts from a number of features, including endogenous mineral exploration and geopolitical fragmentation of mineral supply chains. The framework also provides a natural basis for studying ETM supply disruptions and their macroeconomic transmission. Future work could extend the framework to study ETM supply disruptions, strategic mineral policies, and welfare-based optimal fiscal-monetary policy under scarce transition inputs.

References

Airaudo, F., Pappa, E., Seoane, H.D., 2023. The green metamorphosis of a small open economy. CEPR Discussion Papers 17863. Centre for Economic Policy Research.

Bartocci, A., Cantelmo, A., Cova, P., Pisani, M., 2026. Macroeconomic effects of the green transition in the euro area and critical mineral bottlenecks. Temi di discussione (Economic working papers) 1531. Bank of Italy, Economic Research and International Relations Area.

Bartocci, A., Notarpietro, A., Pisani, M., 2024. "Green" fiscal policy measures and nonstandard monetary policy in the euro area. Economic Modelling 136, 106743. doi:https://doi.org/10.1016/j.econmod.2024.106743.

Baumeister, C., Ohnsorge, F., Verduzco-Bustos, G., 2024. Evaluating the role of demand and supply shocks in copper and aluminum price fluctuations. Unpublished manuscript.

Bils, M., Chang, Y., Kim, S.B., 2022. How sticky wages in existing jobs can affect hiring. American Economic Journal: Macroeconomics 14, 1–37. doi:10.1257/mac.20190338.

Blanchard, O., Gollier, C., Tirole, J., 2023. The portfolio of economic policies needed to fight climate change. Annual Review of Economics 15, 689–722. doi:https://doi.org/10.1146/annurev-economics-051520-015113.

Boer, L., Pescatori, A., Stuermer, M., 2024. Energy Transition Metals: Bottleneck for Net-Zero Emissions? Journal of the European Economic Association 22, 200–229. doi:10.1093/jeea/jvad039.

Bogmans, M.C., Pescatori, M.A., Petrella, I., Prifti, E., Stuermer, M., 2024. The Power of Prices: How Fast Do Commodity Markets Adjust to Shocks? IMF Working Papers 2024/077. International Monetary Fund.

Coenen, G., Lozej, M., Priftis, R., 2024. Macroeconomic effects of carbon transition policies: An assessment based on the ECB's New Area-Wide Model with a disaggregated energy sector. European Economic Review 167, 104798. doi:https://doi.org/10.1016/j.euroecorev.2024.104798.

Concordel, A., Ho, P., Knittel, C.R., 2026. The Differential Impacts of Critical Mineral Prices and Oil Prices on the Economy. NBER Working Papers 34847. National Bureau of Economic Research, Inc. URL: https://ideas.repec.org/p/nbr/nberwo/34847.html.

Dahl, C.A., 2020. Dahl Mineral Elasticity of Demand and Supply Database (MEDS). Working Papers 2020-02. Colorado School of Mines, Division of Economics and Business.

Del Negro, M., di Giovanni, J., Dogra, K., 2023. Is the Green Transition Inflationary? Staff Reports 1053. Federal Reserve Bank of New York.

Domínguez-Iino, T., Elliott, J.T., Hsiao, A., 2026. Critical Minerals, Geopolitics, and the Green Transition. NBER Working Papers 35654. National Bureau of Economic Research, Inc. URL: https://ideas.repec.org/p/nbr/nberwo/35654.html, doi:None.

Engle, R.F., Giglio, S., Kelly, B., Lee, H., Stroebel, J., 2020. Hedging climate change news. The Review of Financial Studies 33, 1184–1216. doi:10.1093/rfs/hhz072, arXiv:https://academic.oup.com/rfs/article-pdf/33/3/1184/32449246/hhz072.pdf.

European Commission, 2019. The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Technical Report. European Commission.

European Parliament and Council of the European Union, 2023. Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition. Technical Report. European Commission.

Feng, Z., Cui, L., 2026. The mineral constraint: Energy transition under supply chain bottlenecks and greenflation. Journal of Cleaner Production 563, 148527. URL: https://www.sciencedirect.com/science/article/pii/S0959652626010681, doi:https://doi.org/10.1016/j.jclepro.2026.148527.

Ferrari, A., Nispi Landi, V., 2025. Will the Green Transition be Inflationary? Expectations Matter. IMF Economic Review 73, 1195–1258. doi:10.1057/s41308-024-00262-x.

Fried, S., Novan, K., Peterman, W.B., 2021. The Macro Effects of Climate Policy Uncertainty. Finance and Economics Discussion Series 2021-018. Board of Governors of the Federal Reserve System (U.S.). doi:10.17016/FEDS.2021.018.

Gagliardone, L., Gertler, M., Lenzu, S., Tielens, J., 2025. Anatomy of the Phillips Curve: Micro Evidence and Macro Implications. American Economic Review 115, 3941–74. doi:10.1257/aer.20231569.

Gavriilidis, K., Känzig, D.R., Raghavan, R., Stock, J.H., 2026. The Macroeconomic Effects of Climate Policy Uncertainty. NBER Working Papers 34762. National Bureau of Economic Research, Inc.

Golosov, M., Hassler, J., Krusell, P., Tsyvinski, A., 2014. Optimal Taxes on Fossil Fuel in General Equilibrium. Econometrica 82, 41–88. doi:https://doi.org/10.3982/ECTA10217.

Gottschalk, P., 2005. Downward nominal-wage flexibility: Real or measurement error? The Review of Economics and Statistics 87, 556–568.

Horvath, M., 2000. Sectoral shocks and aggregate fluctuations. Journal of Monetary Economics 45, 69–106. doi:10.1016/S0304-3932(99)00044-6.

Houssa, R., Mohimont, J., 2026. Oil Prices and Global Activity in a General Equilibrium Model with Dynamic Elasticities. Manuscript. University of Namur.

Houssa, R., Mohimont, J., Otrok, C., 2023. Commodity exports, financial frictions, and international spillovers. European Economic Review 158, 104465. doi:https://doi.org/10.1016/j.euroecorev.2023.104465.

IMF, 2022. Near-Term Macroeconomic Impact of Decarbonization Policies. International Monetary Fund, USA. chapter Chapter 3. pp. 71–95. doi:10.5089/9798400218439.081.CH003.

International Energy Agency, 2021. The Role of Critical Minerals in Clean Energy Transitions. Technical Report. International Energy Agency.

International Energy Agency, 2024. Global Critical Minerals Outlook 2024. Technical Report. International Energy Agency.

International Energy Agency, 2026. Global Critical Minerals Outlook 2026. Technical Report. International Energy Agency.

Kirk, J., Passari, E., Rey, H., 2026. Exorbitant privilege of the periodic table? geoeconomics, endogenous centrality and strategic minerals for the green transition. Journal of the European Economic Association URL: https://doi.org/10.1093/jeea/jvag051, doi:10.1093/jeea/jvag051.

Klenow, P.J., Kryvtsov, O., 2008. State-Dependent or Time-Dependent Pricing: Does it Matter for Recent U.S. Inflation? The Quarterly Journal of Economics 123, 863–904. doi:10.1162/qjec.2008.123.3.863.

Manalo, P., 2023. Discovery to Production Averages 15.7 Years for 127 Mines. Technical Report. S&P Global Market Intelligence.

Metcalf, G.E., Stock, J.H., 2023. The Macroeconomic Impact of Europe's Carbon Taxes. American Economic Journal: Macroeconomics 15, 265–86. doi:10.1257/mac.20210052.

Miranda-Pinto, J., Pescatori, A., Stuermer, M., Wang, X., 2024. Beyond Energy: Inflationary Effects of Metals Price Shocks in Production Networks. IMF Working Papers 2024, 1. URL: http://dx.doi.org/10.5089/9798400291630.001, doi:10.5089/9798400291630.001.

Nakov, A., Thomas, C., 2026. Climate-Conscious Monetary Policy. Journal of Political Economy Macroeconomics 4, 385–424. doi:10.1086/740430.

Nguyen-Tien, V., 2026. Input uncertainty and firm performance: evidence from critical minerals. CEP Discussion Papers. Centre for Economic Performance, LSE. URL: https://EconPapers.repec.org/RePEc:cep:cepdps:dp2197.

Olovsson, C., Vestin, D., 2026. Greenflation? European Economic Review 184, 105237. doi:https://doi.org/10.1016/j.euroecorev.2025.105237.

Peneva, E., 2011. Some evidence on factor intensity and price rigidity. Journal of Economic Dynamics and Control 35, 1652–1658. doi:https://doi.org/10.1016/j.jedc.2011.03.011.

Sahuc, J.G., Smets, F., Vermandel, G., 2025. The New Keynesian Climate Model. EconomiX Working Papers 2025-1. University of Paris Nanterre, EconomiX.

Smets, F., Tielens, J., Van Hove, J., 2018. Pipeline Pressures and Sectoral Inflation Dynamics. Working Paper Research 351. National Bank of Belgium.

Stuermer, M., 2018. 150 years of boom and bust: What drives mineral commodity prices? Macroeconomic Dynamics 22, 702–717. doi:10.1017/S136510051600050X.

Thomas, C., 2008. Search and matching frictions and optimal monetary policy. Journal of Monetary Economics 55, 936–956. doi:10.1016/j.jmoneco.2008.03.007.