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ARTICLE

Climate investments, stock markets, and the open economy

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Abstract

We analyze the effect of green patents on G7 stock market returns. First, we build a small IS-LM model to identify the relevant channels, augmented with open-economy channels and the *Green Tobin's q* (Faria et al., 2022). The model highlights that the intertemporal impacts of greening on stock returns are ambiguous. We then turn to an estimated global vector autoregressive model to more rigorously analyze the effect of monetary and green patenting shocks across the G7. Both shocks influence green patents through real and financial markets. As regards green patent shocks, results suggest that a tension exists over time between promoting pollution reduction and energy efficiency and the profitability of (green and brown) companies in the aggregate. We perform a variety of robustness exercises around our main results. Our results provide something of a challenge to the literature and call for more research effort to understand the various channels that might explain this dynamic—and in turn whether any particular policy recommendations follow.

Keywords: Green Tobin's *q*; sustainability; risk; interest rates; international spillovers; aggregate economy

JEL classifications: E37; F15; F47; O30; Q20

1. Introduction

Addressing climate change is now recognized as an urgent economic and social issue—see, inter alia, Stern (2007) and Nordhaus (2021). Accordingly, environmental concerns now permeate many levels of decision-making. In the public sphere, these concerns have manifested themselves through discrete regulatory and fiscal policies (e.g., reduced reliance on fossil fuels, emissions reduction targets, carbon taxes, green subsidies, etc). The intention is to reorient the economy toward sustainable energy sources and the development of new green technologies.

In the private sphere, this transformation is facilitated more continuously through climate investments, green financing through the stock market, and the real-time interaction of monetary and financial flows. In that respect, an important development has been the Environmental, Social, and Corporate Governance (ESG) agenda; see Global Compact (2004). ESG is a framework used to assess an organization's business practices and performance on various sustainability and ethical criteria (a form of stakeholder capitalism in which firms help society, employees, and the environment while still posting good returns). Many ESG investment funds have arisen to meet this demand and promote this agenda. Given the centrality of the link between the incentives for climate investments and firms' subsequent performance, this paper discusses the implications of an increasing influence of ESG on the stock market (specifically Tobin's q) and does so additionally in an open-economy setting.

The literature presents mixed evidence concerning environmental policies and their effect on financial markets. Faria et al. (2022) found a negative relationship between oil industries in the USA and UK and Tobin's q. Rassier and Earnhart (2010) analyzed if clean water regulation affected Tobin's q in a sample of chemical manufacturing firms and showed similarly negative effects on firms. Besides these studies, Hulshof and Mulder (2020) found that renewable energy has no significant impact on the profit of 920 firms in a panel from 2014 to 2018. By contrast, King and Lenox (2002), in a sample of US firms, found that reductions in pollution are related to better financial results. How greening—and the development of green technologies and green patents—affects aggregate stock market performance therefore remains an important open question, with the performance of and sentiment toward ESG funds being similarly variable at times (Master and Temple-West, 2023; Shifflett, 2023).[1]

Although these cited works help provide empirical evidence about green patents and technology, their econometric approach does not properly capture spillover effects. Faria et al. (2022) argued that green technologies present two market failures: externalities and public goods. In the case of the first, the green innovation of a firm or country is not limited to its boundaries: it can flow to other economies, provoking economic consequences not captured by the local market. Concerning the nature of public goods, other individuals/firms can benefit from the efforts of *other* involved parties. The relevant message is that we witness spillover effects when dealing with green technology adoption. However, despite this understanding, most works do not address this point. Our study contributes to the discussion on Porter's hypothesis, which suggests that environmental regulations can stimulate innovation within firms (Porter, 1989). Initially, the implementation of new environmental regulations may impose additional costs on firms. However, firms have the potential to adapt to these new regulations and innovate, surpassing the initial costs. Consequently, a country may mitigate climate change by implementing regulations that reduce gas emissions and pollution while encouraging green innovation, driven by firms' efforts to profit and sustain themselves (Mohr, 2002; Ambec and Barla, 2002; Zhang et al., 2023). Our econometric framework models this hypothesis through the interactions between green innovation and stock market returns. Unlike previous studies, our analysis adopts an open economies approach, considering spillover effects, transmission channels, and trade integration.

Alessi et al. (2021; 2023) posited that investors are willing to accept lower returns from greener firms. Despite receiving diminished returns, investors tend to retain stocks of firms demonstrating stronger commitments to environmental performance and transparency. This suggests the presence of a risk premium associated with the environmental stance of firms. While Porter's hypothesis suggests that firms can enhance productivity and innovation in response to environmental regulations, potentially leading to increased market value, Alessi et al. (2021) discovered evidence contrary to this notion, showing that firms deeply committed to environmental regulations yield lower returns.

Our econometric model adds to this discussion by examining the impact of green innovation on various countries' stock markets. Specifically, by constructing individual models for each country and interlinking them through economic variables, we incorporate the influence of spillover effects in the relationship between green innovation and stock markets. This approach complements the analysis conducted by Alessi et al. (2021; 2023).

Organization and overview. Section 2 builds a small reduced-form model to illustrate our themes of interest. Specifically, we use the Blanchard (1981) dynamic IS-LM model. However, we amend that model to include both *open-economy* linkages and the influence of *green investments* (and their associated R&D activities) on real output and financial variables (i.e, firms' stock valuations and interest rates). Since R&D is a risky activity, a firm's profits over time are impacted by the uncertainty of innovative activity. Intertemporal profit maximization on the model yields the Green's Tobin's q (Faria et al., 2022). This is the analogue to the standard Tobin's q of firm valuation and investment incentives. The Green Tobin' q is intended to reflect variables associated with the development of green technologies and pollution abatement efforts, in addition to standard investment channels.

This small model highlights several themes germane to our subsequent analysis:

(a) that greening has first-order impacts on output and stock market valuations;
(b) that its effects on firm profitability are potentially ambiguous: containing both positive and negative intertemporal elements;
(c) that patents shocks are an important source of international fluctuations and transmissions; and
(d) that monetary policies have a material bearing on green patenting activity.

Informed by that stylized framework, we then move in Section 3 to a larger, empirical framework, namely, the global vector autoregressive (or GVAR) model of Pesaran et al. (2004). Like standard VARs, note, the GVAR model is a reduced-form framework emphasizing data comovements and data coherence with a relatively loose theoretical underpinning. Essentially, it is a counterweight to the previous section and allows the data to speak and the results to then be interpreted in the light of theory. We describe the main variables that we use in our study including patent counts and describe the methodology behind the GVAR framework and the resulting impulse response function (IRF) analysis.

Section 4 is our results section. Motivated by our earlier analysis on the small model, our GVAR exercises focus on shocks related to changes in monetary policy and then changes to green patenting activity, focusing on the results for G7 stock markets. Increases in policy interest rates are found to have contractionary effects on output and stock markets and persistent negative effects on green patenting activity. This is largely an expected outcome since the policy change induces tighter financing standards and it is well known that R&D (perhaps especially green R&D) is heavily pro-cyclical. Nonetheless, the results do establish that—even if they have no explicit environmental motivation—changes in monetary policy do have implications for firms' incentives to adopt green technologies. This presents a challenge to monetary policymakers to understand better what contribution (if any) they might make to aid the green transition.[2]

Our second scenario is to look at the effect of changes in green patenting on home and foreign economies, with a focus on stock markets. Those results suggest a more curious outcome. While the literature tends to come down one way or the other on the effects of the green transition on stock markets, we find the impact to be initially positive and then negative.[3] Essentially, our results suggest (at least in the medium run) a fine and nuanced balance between promoting pollution reduction and energy efficiency and the profitability of companies in the aggregate. This provides something of a challenge to the literature, and we discuss the various channels that might explain this dynamic.

Finally, in this section, we provide a decomposition exercise over three different horizons to show how domestic variables and US patenting activity affect home and foreign stock markets. This demonstrates the increasing influence green patenting has over time on home and foreign stock markets. Section 5 concludes. Additional material appears in the online appendix.

2. The model

There are several theoretical and empirical models of output, investment, and the stock market, for example, Blanchard (1981), Fama (1981, 1990), Barro (1990), etc. In the model that follows, we adapt the well-known Blanchard (1981) dynamic **IS-LM** model amended such that environmental channels can influence the stock market in an open-economy setting.[4]

Looking first at the **IS** relationship, output y is assumed to adjust to spending over time as follows:

$$\dot{y} = \sigma \left(aq + g + NX \left(\underset{+}{y^*}, \underset{-}{E} \right) - by \right) \tag{1}$$

where a dot above a variable denotes the time derivative. The variable q is the value of the stock market; NX is the trade balance (exports minus imports), which is an increasing function of world income (y^*) and a decreasing function of the real exchange rate (E); variable g is an index of fiscal policy; and a, b and σ are parameters. All variables are real.

Since q is part of wealth, it affects consumption and hence income. Taking q as Tobin's q, it determines the value of capital relative to its replacement cost, positively affecting new investment (Tobin, 1969). In this model, however, we consider the *green* Tobin's q as derived by Faria et al. (2022).[5] In this formulation, q is a function of a firm's green efforts (e.g., new abatement technology adaption), as well as traditional capital accumulation and investments.

The **LM** relation in inverse form is given by

$$i = cy - h(m - p) \tag{2}$$

where i denotes the short-term nominal rate, m and p are the logarithms of nominal money and the domestic price level, respectively, and where c and h are parameters. Thus, the demand for money is, as standard, a positive function of income and a negative function of the interest rate.

The short-term expected real rate of interest is defined as

$$r^{ex} = i - \dot{p}^{ex} \tag{3}$$

where $\dot{p}^{ex}$ is the expected rate of inflation. Let e be the nominal exchange rate (the number of foreign currency per domestic currency), P is the domestic price level, and P^* is the foreign price level (measured in its own currency), and then the real exchange rate is

$$E = e\frac{P}{P^*} \tag{4}$$

Assuming the uncovered nominal interest parity condition, we have

$$\dot{e} = (i - i^*) + \theta \tag{5}$$

where $\theta > 0$ captures a risk premia that would lead to divergences between real returns in the two countries, and i^* is the foreign interest rate. Linearizing equation (4), differentiating it with respect to time, and introducing equation (5), yields a dynamic equation for the real exchange rate:

$$\dot{E} = (i - i^*) + \left(\dot{P} - \frac{dP^*}{dt} \right) + \theta \tag{4'}$$

The long-term bonds are consols with yield I and price $1/I$. The expected short-term nominal rate of return from holding consols is the sum of the yield and the expected nominal capital gain. Arbitrage between short and long bonds can be shown to imply

$$i = I - \frac{\dot{I}^{ex}}{I} \tag{6}$$

Likewise, we define the long-term rate R:

$$r^{ex} = R - \frac{\dot{R}^{ex}}{R} \tag{7}$$

The expected real rate of return on holding shares is

$$\frac{\dot{q}^{ex}}{q}+\frac{\varphi}{q},$$

where φ is the real profit (defined below). The real stock market value, q, is given by the Green Tobin's q as derived by Faria et al. (2022). Arbitrage between short-term bonds and shares implies

$$\frac{\dot{q}^{ex}}{q}+\frac{\varphi}{q}=r^{ex} \tag{8}$$

and where real profits (the firm's discounted maximand) are given by

$$\varphi=\aleph\left(V\right)\left[\pi\ (K)-A\tau_{k}\right]+w\left(V\right)h\left(\mathcal{R}\right)\beth_{k}(k,A) \tag{9}$$

Specifically, $\pi(K)$ is the part of the real profits *before* green innovation occurs, that is decreasing in the industry-wide capital stock, K, Dasgupta (1982). The variable A is pollution abatement effort. The adjustment costs function τ is a convex function of the firm's capital stock k, with τ_k as its partial derivative. Thus, if the capital adjustments required to engage in low pollution efforts are particularly steep (as they can be under convexity), this will deplete current profits.

The term $w(V)$ is the subjective probability density function that the green innovation will occur at the state of knowledge, V, so the probability density that the innovation will occur at time t is the product $w(V)\times h(\mathcal{R})$, where $\mathcal{R}$ represents R&D expenditures directed toward the development of green patents. The state of knowledge variable is accumulated as an increasing function of R&D expenditures: $\dot{V}=h(\mathcal{R}), h'>0$. Term $\aleph(V)$ is the probability that the innovation will never occur. Finally, $\beth(k,A)\lesseqgtr 0$ denotes the maximized value of the integral of the profits *after* the innovation happens, and $\beth_k$ is its partial derivative with respect to k.

The function (9) reveals both positive and negative influences at the firm level from greening policies. One clear negative factor is associated to cleanup costs for polluting firms. To illustrate, if the firm assigns no resources to pollution abatement, that is, $A=0$, current profits can be higher than otherwise. On the other hand, intertemporal profits will be higher if green innovations occur and can be then implemented into the production process. However, the return and viability of those investments are inevitably uncertain, and gestation times could be long (e.g., Brynjolfsson et al., 2021). Of course, if the firm makes no efforts to develop new green technologies, that is, $\mathcal{R}=0$, this source of profit/loss plays no role. Condition (9) therefore reveals some of the trade-offs and tensions for firms involved in the ESG framework. The overall stock market index, and its performance, will though be a combination of the outcomes of green firms (engaging in these activities) and brown firms (who do not devote such resources). The overall impact is of selective green patenting on aggregate stock returns is therefore an open, empirical question.[6]

From equations (8) and (9), we have

$$\frac{\dot{q}^{ex}}{q}=r-\frac{\aleph\left(V\right)\left[\pi\ (K)-A\tau_{k}\right]+w\left(V\right)h\left(\mathcal{R}\right)\beth_{k}(k,A)}{q}=r-\frac{\varphi}{q} \tag{10}$$

These systems of equations, (1)–(10), characterize output, the stock market, interest and exchange rates as functions of policy variables m and g; expectations $\dot{q}^{ex}$ and $\dot{p}^{ex}$; and the price levels P and P^*. The system is block recursive: short and long rates are determined by equations (6) and (7) yielding $r=i$. To close the model, we assume expectations are model consistent and consider the IS relationship, given by equations (1) and (4), the LM relationship, and the dynamics of E, given by equations (2) and (4'), with r replacing i, and equations (8) and (10) that determine

q, which yields the following system of equations:

$$\dot{y} = \sigma\left(aq + g + NX\left(y^*, e\frac{P}{P^*}\right) - by\right) \tag{11}$$

$$r = cy - h\left(m - p\right) \tag{12}$$

$$\dot{E} = (r - i^*) + \left(\dot{P} - \frac{dP^*}{dt}\right) + \theta \tag{13}$$

$$r = \frac{\dot{q}^{ex}}{q} + \frac{\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k, A)}{q} \tag{14}$$

2.1 Steady state with fixed prices

We follow Blanchard's (1980) treatment (see p. 9) and consider the simple case of fixed prices for illustrative and motivational purposes. Hence, there is no actual and no expected inflation; nominal and real rates are identical, and the system simplifies. In that steady state, we have from equation (12), $\dot{E} = 0$:

$$r = i = i^* - \theta \tag{15}$$

The domestic real interest rate, which is equal to the domestic nominal interest rate, depends on the world's nominal interest rate and risk premia. Substituting (15) into (12) yields

$$i^* - \theta = cy - h\left(m - p\right) \tag{16}$$

From the IS curve, equation (11), with $\dot{y} = 0$, we have

$$y = b^{-1}\left[aq + g + NX\left(y^*, e\frac{P}{P^*}\right)\right] \tag{17}$$

Output depends on the stock market q, the balance of trade NX, and fiscal policy g. Note that since NX depends on the real exchange rate $E = eP/P^*$, so too does output.

In the steady state, the stock market is given by introducing equations (15) into equation (14) and imposing $\dot{q} = 0$:

$$q = \frac{\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k, A)}{i^* - \theta} \tag{18}$$

In the steady state, accordingly, the stock market equals the ratio of profit to the steady-state real interest rate. The Green Tobin's q depends on variables associated with the development of green technologies and cleaning efforts such as the stock of knowledge V, pollution abatement efforts A, and R&D expenditures $\mathcal{R}$. This is what makes the Green Tobin's q, green.

By substituting (16) into (18), we write the Green Tobin's q as

$$q = \frac{\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k, A)}{cy - h\left(m - p\right)} \tag{19}$$

Overall, thus, through equation (11), r increases with transactions demand for money, while through equation (8), profits grow in line with output. Since we are dealing with an open economy model, and output depends on the real exchange rate, E, then E also impacts the stock market.

As we have two unknowns y and q for two equations (17) and (19), solving them yields the steady-state equilibrium values of y and q:[7]

$$y_{ss} = \frac{bh\left(m-p\right) + \sqrt{\left[bh\left(m-p\right)\right]^2 + 4abc(\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k,A))}}{2bc} \tag{20}$$

$$q_{ss} = \frac{\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k,A)}{\begin{array}{l}\left(2b\right)^{-1}\left[bh\left(m-p\right)\right. \\ \left. + \sqrt{\left[bh\left(m-p\right)\right]^2 + 4abc\left(\aleph\left(V\right)\left[\pi\left(K\right) - A\tau_k\right] + w\left(V\right)h\left(\mathcal{R}\right)\beth_k(k,A)\right)}\right] - h\left(m-p\right)\end{array}} \tag{21}$$

Thus, the equilibrium values of real output and the Green Tobin's q are a function of monetary balances (and thus directly changes in monetary policy) and profits $\varphi(\cdot)$ and the determinants of profits.

The system (10)–(14), linearized around the steady-state equilibrium of conditions (20) and (21), yields the following Jacobian:

$$J = \begin{bmatrix} \frac{\partial \dot{y}}{\partial y} & \frac{\partial \dot{y}}{\partial q} \\ \frac{\partial \dot{q}}{\partial y} & \frac{\partial \dot{q}}{\partial q} \end{bmatrix}_{y_{ss},q_{ss}} = \begin{bmatrix} -b\sigma & a\sigma \\ cq_{ss} & cy_{ss} - h(m-p) \end{bmatrix}$$

As long as the domestic real interest rate is positive in the steady state,[8] then $cy_{ss} > h(m-p)$, and the determinant of the Jacobian is negative, and the steady-state equilibrium is a saddle point.

2.2 Discussion

The model presented above, though simple in motivation, becomes quite involved in exposition and would also clearly require a careful parametrization. However, the key mechanisms are readily apparent. When seen through equations (20) and (21), the steady-state equilibrium output and stock market valuation depend critically on changes in monetary policy and changes in green technology development (i.e., new patents) as well as open-economy variables such as the world interest rate ($i^\star$), risk premia (θ), the trade balance (NX), on the real exchange rate (e),[9] and finally also on monetary and (implicitly) fiscal policies.

Accordingly, in our later Section 4, we assess how changes in US monetary policy and US patent counts affect international stock market valuations. We do so using an estimated global econometric model. Before coming to those results, we describe the underlying methodology that we use.

3. Data and global var methodology

In this section, we discuss first the data definitions and sources that we use for our exercises and then the associated methodology. The data follow directly from those related to the stylized model in the previous section. The methodology follows simulation analysis on a large global econometric model with fully specified technology and trade linkages.

3.1 Data

Table 1 presents the variables, definitions, and sources. We collected most variables from the GVAR database of Mohaddes and Raissi (2020). Consistent within the small model of the previous section, we use quarterly real GDP (y), changes in the consumer price index (cpi), the real

Table 1. Variables and sources

Variables	Definition	Source
y	Log of real GDP (2010 = 100)	Mohaddes and Raissi (2020)
cpi	Log difference of consumer price index (2010 = 100)	Mohaddes and Raissi (2020)
e	Real exchange rate (domestic currency per US dollar)	Mohaddes and Raissi (2020)
r	Short-term nominal interest rate per quarter	Mohaddes and Raissi (2020)
l	Long-term nominal interest rate per quarter	Mohaddes and Raissi (2020)
q	Log of equity price index deflated by price index	Mohaddes and Raissi (2020)
$green$	Patents on environment technologies-to-total patents	OECD Green Growth Indicators

Notes: Data are in natural logs. The short and long rates are computed as $ln(1+R^x_{it})/4$, where R^x, $x=\{r,l\}$ is the nominal rate of interest per annum, in percent.

exchange rate (e), the short-term and long-term interest rates (r and l, respectively), and the real stock market value (q).

We use the proportion of patents on environmental technologies to total patents to represent green patents (labeled *green*). We collected this data from the Organization for Economic Cooperation and Development (OECD) *Green Growth Indicators.*[10] Because the green patent series is annual, we used the Denton procedure to change to a quarterly frequency. Green patents represent our proxy for green innovation. A green patent denotes the efforts of firms to create new green innovations to make their production and organization more efficient and compatible with clean energy. There is also the consideration that green patents can represent a cost for nonholders of these patents, particularly firms with poor financial resources. However, in the long term, when the monopoly granted by the patent expires, green innovation becomes available to all firms. In the appendix, Table A.1 presents the full descriptive statistics of the variables. Specifically, we collected quarterly data for the G7 (Canada, France, Germany, Italy, Japan, the UK, and the USA) from 1980q1 to 2019q4.

Moreover, Keller (2001) examined the diffusion of technology among these seven most industrialized economies (see also Growiec, 2012). That study explored three potential channels of technology diffusion: international trade, foreign direct investment, and communication. The estimates indicated that international trade is one of the main drivers to explain technology spillover effects. Our econometric model exploits this finding by employing bilateral trade to connect the economies and transmit the US green patent shock.[11] Note, we use the economy-wide q measure since (a) there is no aggregate and internationally comparable green-specific measures and (b) our interest is precisely in looking at total stock market performance within and across countries reflecting green and brown industries.

Moreover, Figure 1 shows the share of green patents to total patents over 2000–2019 for the G7. We see that France, Italy, and the UK almost doubled the share of green patents since 2000, reflecting a concerted effort to increase the production of green technologies. Germany shows the highest propensity to develop green patents, while Italy and the USA are among the weakest. Notably, the upward trajectory of green patenting activities stalled after 2008. This likely reflected the effect of the Great Recession and perhaps some reduction of appetite for green investment given some assessment of the performance of such funds (e.g., Master and Temple-West, 2023; Shifflett, 2023).

3.2 Methodology

We follow Pesaran et al. (2004) to describe the GVAR framework. Equation (22) presents a $VARX(1,1)$ with one lag for the vector of domestic variables and one lag for the vector of

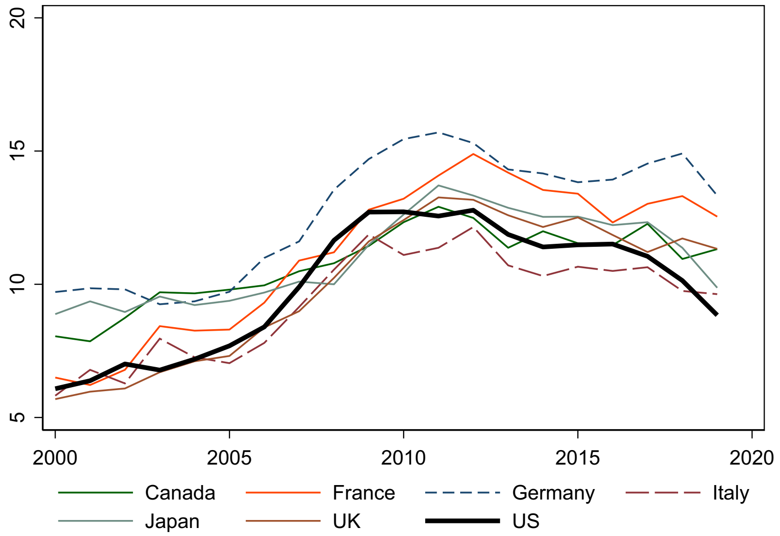

Figure 1. Environmental technology patents (% of total patents, G7).
Notes: This figure shows for the G7 countries the percentage of total patents registered that are labeled environmental technology patents by the OECD methodology, over 2000 to 2019. **Source:** "Green Growth Indicators," the OECD.

(exogenous) foreign variables. The left side of equation (22) shows the vector of domestic variables of the region i at time t, x_{it}. On the right side, a_{i0} is the constant of the region i; a_{i1} is the parameter of the trend term; $x_{i,t-1}$ is the vector of domestic variables lagged one period; x^*_{it} and $x^*_{i,t-1}$ are, respectively, the vector of current and lagged foreign variables; and ε_{it} is the vector of idiosyncratic errors:

$$x_{it} = a_{i0} + a_{i1}t + \Phi_i x_{i,t-1} + \Lambda_{i0} x^*_{it} + \Lambda_{i1} x^*_{i,t-1} + \varepsilon_{it} \tag{22}$$

We connect each region using foreign variables:

$$x^*_{it} = \sum_{j=0}^{N} w_{ij} x_{jt} \tag{23}$$

The vector of foreign variables of region i, x^*_{it}, uses bilateral trade between regions i and j, w_{ij}, and the variables of the region j, x_{jt}. Foreign variables essentially capture the vulnerability of different regions to external shocks, spillovers, and international fluctuations. Most GVAR studies use bilateral trade to connect regions (Dees et al., 2007; Attílio et al., 2023). We use bilateral trade and bilateral financial flows in the empirical section to test the robustness of the results (see below).

We create the vectors $z_{it} = (x_{it}, x^*_{it})'$ and $x_t = (x'_{0t}, x'_{1t}, x'_{2t}, x'_{3t}, \ldots, x'_{Nt})'$ and the identity $z_{it} \equiv W_i x_t$ and use them to rewrite equation (22). In equation (24), z_{it} is a vector with domestic and foreign variables, x_t is a vector with all domestic variables of the model, and W_i is the link matrix, with some zero elements and shares of bilateral trade.

$$A_i W_i x_t = a_{i0} + a_{i1}t + B_i W_i x_{t-1} + \varepsilon_{it} \tag{24}$$

where $A_i = [I_{k_i}, -\Lambda_{i0}]$, I is the identity matrix, and $B_i = [\Phi_i, \Lambda_{i1}]$. We can stack equation (24) as follows:

$$G x_t = a_0 + a_1 t + H x_{t-1} + \varepsilon_t \tag{25}$$

where

$$a_0 = \begin{pmatrix} a_{00} \\ a_{10} \\ \cdots \\ a_{N0} \end{pmatrix}, a_1 = \begin{pmatrix} a_{01} \\ a_{11} \\ \cdots \\ a_{N1} \end{pmatrix}, \varepsilon_t = \begin{pmatrix} \varepsilon_{0t} \\ \varepsilon_{1t} \\ \cdots \\ \varepsilon_{Nt} \end{pmatrix}, G = \begin{pmatrix} A_0 W_0 \\ A_1 W_1 \\ \cdots \\ A_N W_N \end{pmatrix}, H = \begin{pmatrix} B_0 W_0 \\ B_1 W_1 \\ \cdots \\ B_N W_N \end{pmatrix}$$

We obtain the GVAR by using the inverse matrix of G in equation (25):

$$x_t = G^{-1} a_0 + G^{-1} a_1 t + G^{-1} H x_{t-1} + G^{-1} \varepsilon_t \tag{26}$$

Equations (27) and (27.1) below present the vectors of domestic and foreign variables. Following Dees et al. (2007), we do not include the exchange rate in the US model. However, we only include the exchange rate as a foreign variable in the US model. These equations show that the international stock market (q^*) and international credit markets (r^*) affect the domestic dynamics of the economies.

$$\begin{aligned} x_{it} &= (y_{it}, q_{it}, cpi_{it}, e_{it}, r_{it}, l_{it}, green_{it}) \\ x^*_{it} &= (q^*_{it}, r^*_{it}) \quad \text{for all regions, except the US} \end{aligned} \tag{27}$$

$$\begin{aligned} x_{it} &= (y_{it}, q_{it}, cpi_{it}, e_{it}, r_{it}, l_{it}, green_{it}) \\ x^*_{it} &= (e^*_{it}) \quad \text{for the US} \end{aligned} \tag{27.1}$$

Equations (27) illustrate one relevant difference with our econometric approach compared to VAR/VEC/SVAR models (for an overview of the VAR methodology, see Kilian and Lütkepohl, 2018). In these models, there are no foreign variables built as in equation (23) (i.e., the vectors x^*_{it}). In the GVAR, on the other hand, we use these vectors to connect economies and model linkages of economic integration. In equation (27), the *foreign* variables, the stock market and the interest rate (q^*_{it}, r^*_{it}), are exogenous to domestic economies, implying restrictions on individual economies (we test this hypothesis using the weak-exogeneity test, see Tables A.4 and A.5 in Section A). In other words, when we analyze IRFs, these variables are treated as given for economies; economies adjust to shocks according to international financial markets (q^*_{it}, r^*_{it}).

3.3 Impulse response analysis

In standard VAR models, the IRF analysis adopts the orthogonalized impulse responses, which use orthogonal shocks instead of the original shock (or residual associated with a particular equation); see, for example, Kilian and Lütkepohl (2018).

In the GVAR, we use a generalized form of the IRF (GIRF). This uses the original shock. We assume that this original shock follows a multivariate normal distribution. GIRFs allow contemporaneous dependence between the error terms (the elements of the idiosyncratic vector) between regions i and j, where the covariance between the errors of region i and region j tends to be zero as the number of observations goes to infinity. Under conditions of stability, smallness, and weak dependence, the GIRFs consider that the covariance between the foreign variables and the error term tends to be zero. Finally, given that we use the GVAR in the error correction form, the shocks imposed are permanent in nature and thus lead to permanent level differences in the response variables.

A variant of the GIRF is the structural GIRF (SGIRF), which imposes a particular causal ordering on the shock processes. For a more detailed description of the underlying methodology for both types of IRFs, see Section B.

3.4 Specifying trade linkages

Given the importance of the international dimension to our theme, we use a number of different ways of linking the economies together to ensure robustness. We connect economies using three frameworks:

1. First, we use bilateral trade from Mohaddes and Raissi (2020). Their variable is the sum of exports and imports. We use the average of bilateral trade in the years 2014–2016.
2. The second addresses the possibility that the impact of green patents on the stock market is mainly through financial markets. Thus, we collected bilateral financial flow from the Coordinated Direct Investment Survey of the International Monetary Fund (IMF). We use the sum of the inflow and outflow of direct investment positions. We use the average of bilateral financial flow in the years 2019–2021.
3. The third framework addresses the concern that bilateral trade structurally changes over time. We incorporate this possibility by using varying bilateral trade in the years 1980–2022. We collected this data from the IMF's *Direction of Trade Statistics*.

We shall examine the impact of these alternatives when discussing robustness in the subsequent section.

3.5 Stationarity and exogeneity

In the appendix, Tables A.2 and A.3 present the unit root tests. Most variables are stationary only in the first differences. Table A.4 shows the existence of cointegrating relationships. Consequently, we use the GVAR in the error correction form (see Pesaran et al., 2004, for details). Table A.4 also shows the lags of each *VARX*. Table A.5 displays the weak exogeneity tests, which evaluate the inclusion of foreign variables in the individual models. Most estimates do not reject the null.

4. Econometric results: monetary and green patent shocks

We have seen from the small model of Section 2 that key determinants of the Green Tobin's q are changes in monetary policy and changes in patenting activity (and thus the development of green technologies). And that a key transmission channel is the stock market, which is precisely the arena in which the ESG framework operates. In this section, therefore, we take our GVAR model supplemented with the stated variables of interest and examine the effect of appropriate shocks.

Our exercises are performed using shocks originating in the US economy. This is natural given its global dominance in income, financial depth, and its leadership role in technology. But we trace the effect of these US shocks across the G7. This allows us to quantify the nature of international spillovers. This is important since we have already noted that the full benefits of climate adaptation efforts will not be fully captured by the home economy. In so far as this leads to a socially suboptimal innovation, this is one rationale for public subsidies to encourage R&D.

4.1 Monetary policy shocks

Figure 2 shows a 50 basis point initial increase in the federal funds rate and its effect on real output, stock market valuations, and green patents for the US economy. As remarked upon before, we see that even if they have no explicit environmental motivation, changes in monetary policy affect greening incentives and their resulting stock market valuations and so on.[12] The panel of figures show the median response and associated 68% confidence intervals as calculated by a bootstrap of 1000 replications, over a 40-quarter (10-year) horizon.

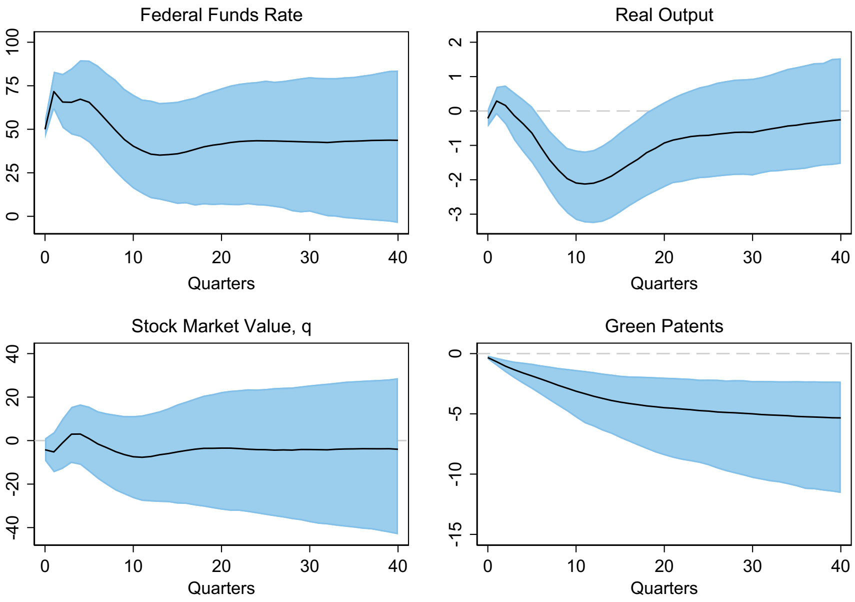

Figure 2. US monetary policy shock, 50 bps: impact on US economy.
Notes: This figure shows the percentage response of real output, q, and the green patent number for a temporary 50 basis point increase in the federal funds rate over a 10-year horizon. The gray horizontal dashed line shows the zero point.

With the monetary contraction, we see a fall in real output as demand contracts and financial conditions tighten. As interest rates rise, the aggregate stock market index and firms' valuations also fall. This is consistent with an inverse relationship between asset prices and yields, resulting from financial flows moving out of private equity, venture capital, and other funds to higher-yielding government bonds. Although this negative effect on q is only statistically significant in the very short run, we would nonetheless expect a pro-cyclical comovement of output and stock markets (noting that the effects on output are statistically significant).

Over time, these effects taper off to some degree although green patenting activity seems to undergo a more persistent reduction, monotonically falling to around 5% below baseline in the medium run. This accords with the stylized facts that R&D activity is highly pro-cyclical (e.g., Ouyang, 2011): in effect, firms in economically constrained times sacrifice such budgets more readily than other production costs (or price margins).[13]

4.1.1 Discussion

Accordingly, we can conclude that monetary policy changes *can* influence innovation activity and the incentives for adapting green technologies given that it impacts demand and profitability and funding sources (and perhaps firms' risk appetite). Our results however only give a flavor of the issues at play, and further research is needed to understand how monetary policy can affect the green transition.

To illustrate, a superficial conclusion from the above simulation is that whenever monetary policy (conventional or unconventional) is restrictive, green patenting activity will suffer. And indeed, in the European context, Grimm et al. (2022) suggest that quantitative easing (expansionary central bank bond buying programs) had a positive effect on participating firms' innovation rates.[14] However, from another perspective, the long regime of historically low interest rates and quantitative easing policies pursued by G7 central banks after the Great Financial Crisis from 2008 onward may have—consistent with some Schumpeterian endogenous growth theories—have kept

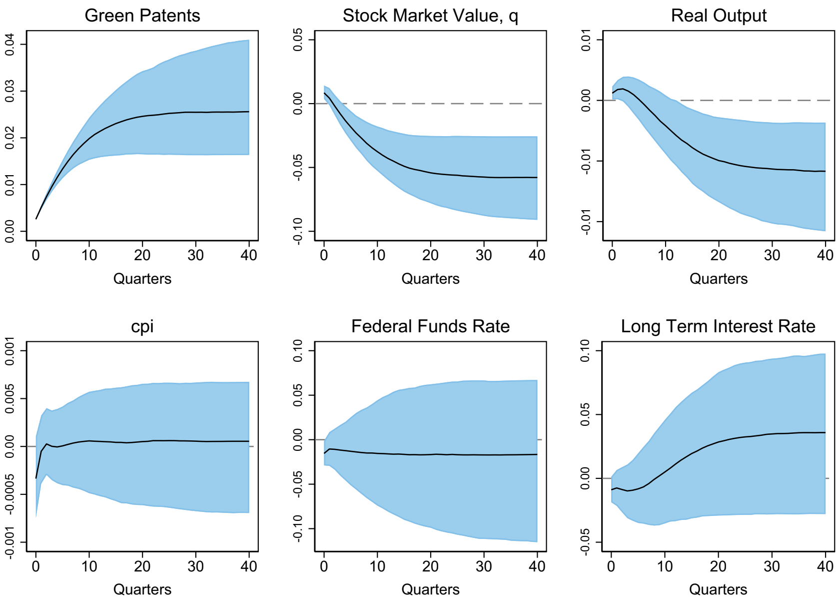

Figure 3. Green patent shock: impact on US economy.
Notes: The figure shows the generalized impulse response of stock market values to a one standard deviation US patent shock. The dark solid line is the median response, and the blue shaded areas represent 68% confidence intervals. The zero line is given by the gray dashed horizontal. The reporting horizon is 10 years.

"zombie" firms alive longer than would normally be the case, strengthened their market power, and delayed the entrance of new, potentially greener firms (see Aghion et al., 2018; Liu et al., 2022).

4.2 Green patent shocks

Now, we consider a one standard deviation shock to the US *green* variables. Figure 3 presents the impacts of selected US variables, and Figure 4 shows the impact of that same shock on G7 stock markets.

4.2.1 Home shock

We turn first to consider the home (US) effect. The expansion of green patents has some features of a supply shock in that (at least initially) real output rises (reflecting the higher amount of resources available) and aggregate prices fall. Interest rates react very little. As discussed earlier, the literature has reported both positive *and* negative effects of green patenting on output and financial returns. In our case, we have *both* effects operating, albeit at different horizons. The behavior of the stock market is—as in the simple model—consistent with that of output: initially, q rises reflecting the improved profitability and future prospects of green firms. But this effect turns out to be short-lived, and aggregate output and stock returns fall after about one year.

We might initially view this as a curious result. Endogenous growth theory emphasizes that new patenting and R&D activities are positive drivers of per-capita output. In our case, though, there are a few considerations to bear in mind when assessing this result. First, as implemented here, the impact on stock market valuations from patenting activity is specific to green patents and not *total* patents: the introduction of green technologies will ultimately improve social outcomes but may involve significant adjustment costs for both green and brown firms, thus affecting private valuations.

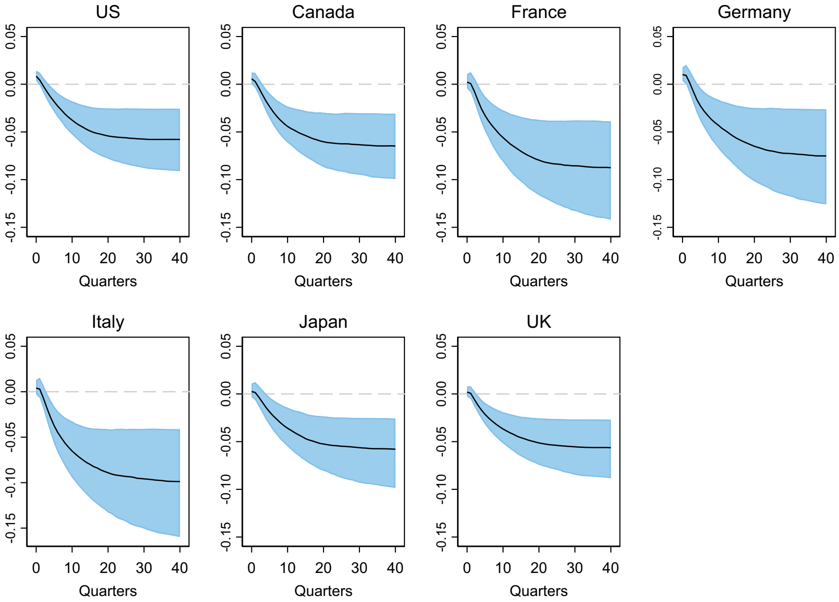

Figure 4. Green patent shock: impact on G7 stock markets values.
Notes: The figure shows the generalized impulse response of stock market values to a one standard deviation US patent on G7 stock markets. The dark solid line is the median response, and the blue shaded areas represent 68% confidence intervals. The zero line is given by the gray dashed horizontal. The reporting horizon is 10 years. All y-axis ranges are the same in the panels to facilitate cross-country comparisons.

Second, like standard VARs, the GVAR model is essentially a reduced-form framework built to capture data co-movements and data coherence, with a relatively loose theoretical underpinning. While this gives us confidence in the empirical reliability of the results, it leaves open their mapping to theory. In that respect, we might do best to consider these GVAR patent shocks as not exclusively an increase in the share of green patents as such but also as a shock embodying greater application of environmental regulations, increased stockholder pressure for ESG measures, more widespread adaption of the available green technologies, and so on. This broader interpretation is arguably more useful in our context since it precisely reflects the multifaceted nature of the ESG agenda.[15]

Seen in that light, the results become easier to rationalize. We already noted that pollution abatement costs deplete current profits since they shift resources away from the production of goods. Those costs in the small model are assumed to be convex, implying that the more the adjustment the steeper the costs (in terms of production foregone). The ESG agenda will therefore push brown firms to clean up, thus cutting into their profit and stock market evaluations. Moreover, if those firms had higher purely private returns to capital, and the share of such firms are large, then indeed, overall stock returns will be depressed. Analogously, if the private returns to green patenting are low and deferred (e.g., Brynjolfsson et al., 2021), and the output share of such firms is low, then these positive effects may not be sufficient to boost the overall stock market.[16]

Ex ante, the overall effect is unclear, although the result that green patenting activity does not lead to a permanently higher level of stock returns in the medium run is robust to the case where the shock is implemented in a structural recursive fashion, further giving us confidence in its empirical validity (see subsection 4.4.1 and Section A).

A final point to note is that the GVAR, or any empirical model, is estimated on historical data; its parameters are given. In our context, arguably the model captures demand interactions better than supply. If the ESG framework were to become a more pervasive feature of the corporate landscape, it might lead firms to change their production framework (and thus lower their abatement costs), shift more earnestly toward cleaner technologies, and adapt the complementarity between dirty and clean factors of production.[17] A critical mass of firms doing so, would potentially paint a more favorable picture of stock market returns under the green transition.

However, the possibility that such a transition implies at least over some horizon negative returns and may require a complementary policy response (e.g., subsidies) is a reasonable conclusion to draw.

4.2.2 Impact on G7 stock markets

Interestingly, this dynamic for stock market plays out in a similar manner for the G7 economies in their reaction to the US shock, Figure 4. The profile is initially positive then more persistently negative. Another interesting feature is the asymmetric effect of the US shock across the G7. For instance, the effect of the shock have essentially the same impact on the economies of Canada, the UK, and Japan but larger than the home effect for the European nations. However, there is still marked uncertainty (as characterized by the width of the confidence intervals). The following section decomposes G7 stock markets into their drivers in more detail.

4.3 Decomposition of stock market influences

After showing the impulse responses, we now investigate the quantitative importance of green patents on the stock market using the generalized forecast error variance decomposition (GFEVD). This procedure decomposes a given domestic variable into domestic and external determinants. Consequently, we can capture spillover effects. We incorporate this possibility by adding the US green patents in all GFEVD. We normalized each row of the GFEVD table to a sum of 100%.

We explore the spillover effects of US patents on domestic stock markets in Table 2, which illustrates the GFEVD of stock markets for all economies. The table is organized into seven blocks, with each block capturing the influence of domestic variables (y, q, r, l, e, cpi) on the domestic stock market. The second part focuses on the impact of green patents on stock markets. In this segment, we analyze the effects of both domestic and US green patents. The US green patent illustrates the spillover effect on domestic stock markets.

We start our analysis in Canada. In the first period, GDP influences the stock market by 2.58%, the interest rates, the exchange rate, and domestic green patents all contribute around 5%, prices by 0.35%, and the stock market itself explains 77% of its own fluctuations. These values denote the extent of the Canadian stock market's fluctuation attributed to *domestic* factors. The column pertaining to US green patents reveals that a mere 1.1% of first-period stock market fluctuations result from spillover effects. Over time, however, the influence of green patents grows. In the last period, Canadian green patents affected the stock market by 17.6%, while US green patents contributed to a 35.57% impact. The increasing importance of green patents in the fluctuation of domestic stock markets is not exclusive to Canada. The table suggests a growing influence of green patents over time, including spillover effects from the US green patents.

In the remaining economies, US green patents present an increasing impact on domestic stock markets over time. In the last period, the spillover effect amounted to 21.91% in France, 31% in Germany, 14% in Italy, 24.19% in Japan, and 33.81% in the UK. This suggests the existence of relevant spillover effects of US green patents in the G7 economies. Additionally, similarly to the impact of US green patents, domestic green patents demonstrate relevance in explaining fluctuations in stock markets. The exceptions are France, Japan, and the UK, where domestic green patents displayed lower values (ranging from 0% to 1%).

Table 2. GFEVD of stock markets to domestic variables and the US green patents

Horizon	Country						Green patents	
	Canada							
	y	*q*	*r*	*l*	*e*	*cpi*	Canada	USA
1	2.58	77.01	4.51	5.08	4.52	0.35	4.84	1.12
12	2.56	41.02	7.09	9.26	1.65	0.40	17.46	20.55
24	1.93	29.68	6.25	7.17	1.62	0.18	17.60	35.57
	France							
	y	*q*	*r*	*l*	*e*	*cpi*	France	USA
1	0.38	70.32	1.00	19.85	0.67	7.02	0.59	0.17
12	0.32	45.54	4.47	26.40	0.43	9.12	1.83	11.90
24	0.27	39.23	4.83	23.31	0.53	8.04	1.89	21.91
	Germany							
	y	*q*	*r*	*l*	*e*	*cpi*	Germany	USA
1	5.06	68.34	2.81	3.92	0.07	2.68	12.65	4.46
12	2.93	19.84	8.84	17.97	5.49	0.34	27.82	16.77
24	1.69	13.34	4.28	13.53	6.01	0.22	29.95	31.00
	Italy							
	y	*q*	*r*	*l*	*e*	*cpi*	Italy	USA
1	5.39	69.65	4.15	13.00	0.78	3.04	3.61	0.39
12	3.53	10.43	18.09	34.29	4.61	6.06	13.74	9.24
24	2.78	6.93	18.13	29.72	5.62	8.52	14.24	14.05
	Japan							
	y	*q*	*r*	*l*	*e*	*cpi*	Japan	USA
1	0.06	98.49	0.21	0.32	0.37	0.22	0.15	0.18
12	0.69	81.22	1.34	2.32	1.60	2.45	0.16	10.22
24	1.07	65.90	1.86	2.52	1.41	2.92	0.12	24.19
	UK							
	y	*q*	*r*	*l*	*e*	*cpi*	UK	USA
1	0.02	66.21	6.12	18.15	2.44	6.23	0.68	0.16
12	0.65	49.03	3.78	20.12	5.64	1.86	0.27	18.66
24	1.01	39.36	2.81	15.75	5.82	1.13	0.31	33.81
	USA							
	y	*q*	*r*	*l*	*e*	*cpi*	USA	USA
1	6.99	88.39	1.12	2.14		0.17	1.18	
12	4.36	69.64	2.94	5.48		1.26	16.32	
24	2.80	48.37	6.75	3.68		0.58	37.81	

Notes: This table decomposes the determinants of home stock markets into home variables and US patents over three different quarterly horizons. Each row sums to 100.

In short, we found that the US green patents affect international stock markets, provoking their falls. Thus, we provide evidence of persistent spillover effects from green technology innovation on financial markets. The subsequent subsections test our main results by changing the model's configuration.

4.4 Robustness

4.4.1 Robustness: the structural GIRF

One limitation of the GIRF is that it does not identify shocks in a structural manner. We overcome this limitation by using the structural GIRF (SGIRF) with a given causal ordering. The SGIRF identifies shocks in one economy: here, the USA. In this case, we adopt the order:

$$green \rightarrow y \rightarrow cpi \rightarrow r \rightarrow l \rightarrow q$$

where → indicates the presumed direction of causation. In other words, we treat green patents as the most exogenous variable. A shock to green patent affects production, causing changes in prices. The credit markets react to short- and long-term interest rate fluctuations. These movements, in turn, affect the stock markets. The results are shown in Figure A.1 and Figure A.2 in the appendix. As can be seen, the results are essentially invariant to those of the GIRF.

4.4.2 Bilateral financial flows

We change the variable that connects economies (equation 23, term w_{ij}). Specifically, we now use bilateral financial flows. Figure A.3 presents the results of a US green patent shock. All stock markets decrease to the shock, taking around four periods to present statistically significant values.

4.4.3 Varying bilateral trade

Another robustness check is to use varying bilateral trade. Figure A.4 shows the results of a US green patent shock. The only difference compared to the past results is that the German stock market takes a longer period to present statistically significant values. Except for this difference, the estimates follow our previous results.

4.4.4 Model with 33 countries

The database of Mohaddes and Raissi (2020) incorporates 33 countries. However, due to the reasons described in Section 3.1, we used data from only seven countries. Given the weak-exogeneity hypothesis, it is advisable to include a larger number of countries in the sample. To validate our findings, we conducted tests using all 33 countries from the database of Mohaddes and Raissi (2020). While the G7 countries represent approximately 25% of the world's GDP, the inclusion of all 33 countries covers 90%, thereby enhancing the representativeness of the world economy in the GVAR. Figure A.5 depicts a US green patent shock and the responses of the stock markets across these countries. The results support our primary conclusion: stock markets exhibit a decline in response to a US green patent shock, demonstrating the spillover effects of green patents on international financial markets.

5. Concluding remarks

We examined the interplay between climate change policies and firms' valuations. This is important since how successful the ESG agenda will be rests in large part on how well firms' returns fare.

To understand these interactions better, we first built a small dynamic IS-LM model to incorporate greening activities in an open-economy framework. Importantly, the model features the

Green Tobin's q that reflects variables associated with the development of green technologies and pollution abatement efforts. The model highlighted that while greening has first-order impacts on real and financial variables, its intertemporal impacts on stock returns are ambiguous.

Informed by this analysis, we analyzed patent and monetary policy changes in a large empirical global VAR model to quantify the channels of influence and international spillovers. Monetary policy changes were shown to have impacts on patenting activity and home and foreign stock markets. However, while monetary policy impacts green innovation, the question arises as to whether it is advisable to utilize this instrument to influence green innovation.

As regards green patent shocks, results suggest that a tension exists over time between promoting pollution reduction and energy efficiency and the profitability of (green and brown) companies in the aggregate. This nuanced result provides something of a challenge to the literature and calls for more research effort to understand the various channels that might explain this dynamic—and in turn whether any particular policy recommendations follow. Given the sometimes large international spillovers from US-centric shocks, there may also be a role for international cooperation or countries adapting their own policies in response to those spillovers.

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Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S1365100524000348

Notes

1 As regards policy effects, specifically monetary policy effects on greening activity, some studies find monetary policy can a have large effect on environmental metrics (Attílio et al., 2023, Ullah et al., 2020), and others have rather weak effects (Chan, 2020). Other studies assess policy under different environmental shocks (Annicchiarico and Di Dio, 2017) and carbon taxes. For specific monetary perspectives on climate change, see Coeuré (2018), Mersch (2018), Olovsson (2018), NGFS (2019), Rudebusch (2021a, 2021b), and Boneva et al. (2023). For a theoretical analysis, see Faria et al. (2023).

2 This has also been reflected in public communications. For example, " . . . *Climate change is an emerging risk to [..] the economy, and we are, as so many others are, in the very early stages of understanding what that means, what needs to be done about it and by whom. . .*", Powell (2020).

3 This is an interesting result since it would appear to mirror the performance over time of ESG funds as noted by some market watchers (e.g., Master and Temple-West, 2023; Shifflett, 2023).

4 The IS-LM model is a common framework used in macroeconomics. IS stands for *investment-saving* and LM stands for *liquidity preference-money supply*.

5 The only modification we did in Faria et al. (2022) is to assume that the adjustment costs are associated with the firm's capital stock k, rather than its rate of change $\dot{k}$.

6 Note in the model presented in this paper, for simplicity the only form of R&D investments are assumed to be in green technologies. In the richer model of Faria et al. (2022) they show that the standard Tobin's q is a special case of the Green Tobin's q. For example, if we consider that the firm can use its investment funds to accumulate conventional capital stocks, $\dot{k}$, as well as green R&D expenditure, $\mathcal{R}$ (assuming zero depreciation), we have:

$$I = \dot{k} + \mathcal{R}$$

then the resulting q is (see their equation (6))

$$q = \aleph[1 + AC'(I - \mathcal{R})]$$

where A is as above and $C(\cdot)$ is a generalized adjustment cost function predicated on the level or rate of change of capital. Accordingly, in the absence of green R&D expenditures, $\mathcal{R} = 0$, we would retrieve the conventional Tobin's q:

$$q = 1 + C'$$

7 Or expressed more compactly:

$$y_{ss} = \frac{bh\left(m-p\right) + \sqrt{\left[bh\left(m-p\right)\right]^2 + 4abc\varphi}}{2bc}$$

$$q_{ss} = \frac{\varphi}{\left(2b\right)^{-1}\left[bh\left(m-p\right) + \sqrt{\left[bh\left(m-p\right)\right]^2 + 4abc\varphi}\right] - h\left(m-p\right)}$$

8 The average quarterly 10-year US real rate (as provided by the FRED data source over 1982q1 to 2023q3) is 2.4% with a standard deviation of 1.9 and a max and min of 7.5 and −0.4, respectively. The latter reflected some temporarily negative values in 2012 and 2020.

9 Or, alternatively, on the nominal exchange rate and price levels, domestic and foreign.

10 See Papadopoulos (2022) for an analysis of environmental data indices and their comparability across data providers.

11 These economies represent almost all global spending in R&D. We tried to include China because of its international importance, but Chinese data on relevant variables such as green patents were largely unavailable.

12 For specific monetary perspectives on climate change, see Coeuré (2018), Mersch (2018), Olovsson (2018), NGFS (2019), Rudebusch (2021a, 2021b), and Boneva et al. (2022). For a theoretical analysis, see Faria et al. (2023).

13 For example, with the beginning of the tightening in the federal funds rate from 2022q1 onward, venture funding fell sharply (see National Venture Capital Association, 2023), which tends to be viewed as more powerful than traditional R&D spending in stimulating patent activity (see Kortum and Lerner, 2000).

14 We tested whether the monetary shock is symmetric by implementing the same shock as in Figure 2, but with a negative monetary shock: a 50 basis point decrease in the federal funds rate. The responses showed that real output increases and green patents increase. Importantly, the values are similar to those in Figure 2, differing only in the direction of change. Thus, the monetary shock is symmetric. Results are available upon request.

15 Although, the structural variant of the shock, note, behaves, qualitatively similar.

16 Indeed, in so far as green and brown firms' stock returns are correlated, the heightened uncertainty may play a role (see Li et al., 2023).

17 See León-Ledesma et al. (2010) and Schulte (2017) for a discussion of these concepts.

References

Aghion, P., E. Farhi and E. Kharroubi (2018). *Monetary Policy, Product Market Competition, and Growth*. mimeo: Harvard University.

Alessi, L., E. Ossola and R. Panzica (2021). What greenium matters in the stock market? The role of greenhouse gas emissions and environmental disclosures. *Journal of Financial Stability* 54, 100869.

Alessi, L., E. Ossola and R. Panzica (2023). When do investors go green? Evidence from a time-varying asset-pricing model. *International Review of Financial Analysis* 90, 102898.

Ambec, S. and P. Barla (2002). A theoretical foundation of the porter hypothesis. *Economics Letters* 75(3), 355–360.

Annicchiarico, B. and F. Di Dio (2017) GHG emissions control and monetary policy. *Environmental and Resource Economics* 67, 82300851.

Attílio, L. A., J. R. Faria and M. Rodrigues (2023). Does monetary policy impact CO_2 emissions? *Energy Economics* 119, 106559

Barro, R. (1990). The stock market and investment. *Review of Financial Studies* 3, 115–131.

Bettendorf, T. (2017). Investigating global imbalances: empirical evidence from a GVAR approach. *Economic Modelling* 64, 201–210.

Bettendorf, T. and M. A. León-Ledesma (2019). German wage moderation and European imbalances: feeding the global VAR with theory. *Journal of Money, Credit and Banking* 51(2-3), 617–653.

Blanchard, O. J. (1981). Output, the stock market, and interest rates. *American Economic Review* 71, 132–143.

Boneva, L., G. Ferrucci and F. P. Mongelli (2022). Climate change and central banks: what role for monetary policy? *Climate Policy* 22(6), 770–787.

Brynjolfsson, B., D. Rock and C. Syverson (2021). The productivity J-curve: how intangibles complement general purpose technologies. *American Economic Journal: Macroeconomics* 13(1), 333–372.

Bussière, M., A. Chudik and G. Sestieri (2012) Modelling global trade flows: Results from a GVAR model, *Globalization Institute Working Papers 119*, Federal Reserve Bank of Dallas, 1–34.

Bussière, M., A. E. Karadimitropoulou and M. A. León-Ledesma (2021). Current account dynamics and the real exchange rate: disentangling the evidence. *Macroeconomic Dynamics* 25(1), 28–58.

Cæuré, B. (2018). Monetary Policy and Climate Change. In: Speech at the Conference Scaling up Green Finance: The Role of Central Banks, Organized by the Network for Greening the Financial System. November.

Chan, Y. T. (2020). Are macroeconomic policies better in curbing air pollution than environmental policies? A DSGE approach with carbon-dependent fiscal and monetary policies. *Energy Policy* 141, 111454.

Compact, G. (2004). Connecting financial markets to a changing world, Available at https://www.unepfi.org/fileadmin/events/2004/stocks/who_cares_wins_global_compact_2004.pdf (accessed 10 June 2024).

Dasgupta, P. (1982). *The Control of Resources*, Harvard University Press.

Dees, S. (2020). Assessing the role of institutions in limiting the environmental externalities of economic growth. *Environmental and Resource Economics* 76,429–445.

Dees, S., F. Mauro, M. Pesaran and L. V. Smith (2007). Exploring the international linkages of the euro area: a global VAR analysis. *Journal of Applied Econometrics* 22,1–38.

Fama, E. (1981) Stock returns, real activity, inflation and money. *American Economic Review* 71, 545–565.

Fama, E. (1990). Returns, expected returns, and real activity. *Journal of Finance* 45, 1089–1108.

Faria, J. R., G. Tindall and S. Terjesen (2022). The Green Tobin's *q*: theory and evidence. *Energy Economics* 110, 1–15.

Faria, J. R., P. McAdam and B. Viscolani (2023). Monetary policy, neutrality, and the environment. *Journal of Money, Credit and Banking* 55(7), 1889–1906.

Gente, K., M. A. León-Ledesma and C. Nourry (2015). External constraints and endogenous growth: why didn't some countries benefit from capital flows? *Journal of International Money and Finance* 56(C), 223–249.

Gillingham, K. and J. H. Stock (2018). The cost of reducing greenhouse gas emissions. *Journal of Economic Perspectives* 32(4), 53–72.

Growiec, J. (2012). The world technology frontier: what can we learn from the US states? *Oxford Bulletin of Economics and Statistics* 74(6), 777–807.

Hall, S. G., G. S. Tavlas and Y. Wang (2023). Drivers and spillover effects of inflation: the United States, the euro area, and the United Kingdom. *Journal of International Money and Finance* 131, 102776.

Hansen, L. P. (2022). Central banking challenges posed by uncertain climate change and natural disasters. *Journal of Monetary Economics* 125, 1–15.

Haščič, I. and M. Migotto (2015). Measuring environmental innovation using patent data.*OECD Environment Working Papers*, Paris: OECD Publishing. 89, 1–58.

Hulshof, D. and M. Mulder (2020). The impact of renewable energy use on firm profit. *Energy Economics* 92, 1–10.

Keller, W. (2001). The geography and channels of diffusion at the world's technology frontier. *NBER. Working paper* 8150.

Kilian, L. and H. Lütkepohl (2018) *Structural Vector Autoregressive Analysis*, Cambridge Books, Cambridge University Press.

King, A. and M. Lenox (2002). Exploring the locus of profitable pollution reduction. *Management Science* 48,289–299.

Kortum, S. and J. Lerner (2000). Assessing the contribution of venture capital to innovation. *RAND Journal of Economics* 31, 674–692.

León-Ledesma, M. A., P. McAdam and A. Willman (2010). Identifying the elasticity of substitution with biased technical change. *American Economic Review* 100(4), 1330–1357.

Levine, P., P. McAdam and J. Pearlman (2008). Quantifying and sustaining welfare gains from monetary commitment. *Journal of Monetary Economics* 55(7), 1253–1276.

Li, H., E. Bouri, R. Gupta and L. Fang (2023). Return volatility, correlation, and hedging of green and brown stocks: is there a role for climate risk factors? *Journal of Cleaner Production* 414, 137594.

Liu, E., A. Mian and A. Sufi (2022). Low interest rates, market power, and productivity growth. *Econometrica* 90(1), 193–221.

Masters, B. and P. Temple-West (2023). The real impact of the ESG backlash. *Financial Times*, 4th December. https://www.ft.com/content/a76c7feb-7fa5-43d6-8e20-b4e4967991e7 (accessed 1 June 2024).

Mersch, Y. (2018) Climate change and central banking. In Speech at the Workshop discussion "Sustainability is becoming mainstream," Frankfurt am Main, November (vol. 27).

Mohaddes, K. and M. Raissi (2020). *Compilation, revision and updating of the global VAR (GVAR) database, 1979Q2-2019Q4.* Judge Business School (mimeo): University of Cambridge.

Mohr, R. D. (2002). Technical change, external economies, and the porter hypothesis. *Journal of Environmental Economics and Management* 43(1), 158–168.

National Venture Capital Association. . (2023-2023). Venture monitor Q2. *2023*, Technical report

NGFS. (2019). A Call for Action. Climate Change as a Source of Financial Risk.*First Comprehensive Report of the Network for Greening the Financial System*, Banque de France Publications.

Nordhaus, W. (2021). *The Spirit of Green*, Princeton University Press.

Olovsson, C. (2018). Is climate change relevant for central banks? *Sveriges Riksbank Economic Commentaries* 13, 1–8.

Ouyang, M. (2011). On the cyclicality of R&D. *Review of Economics and Statistics* 93(2), 542–553.

Papadopoulos, G. (2022). *Discrepancies in corporate GHG emissions data and their impact on firm performance assessment*, Joint Research Centre, European Commission..Working Papers 2022-12.

Pesaran, M., T. Schuermann and S. Weiner (2004). Modeling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business & Economic Statistics* 22, 129–162.

Popov, A., N. Grimm and L. Laeven (2022). *Quantitative Easing and Corporate Innovation, CEPR Discussion Papers 17280.* London: CEPR.

Porter, M. (1989). *The Competitive Advantage of Nations*, Palgrave MacMillan.

Powell, J. H. (2020). Transcript of Chair Powell's Press Conference Available at https://www.federalreserve.gov/mediacenter/files/FOMCpresconf20201216.pdf (accessed 10 June 2024).

Rassier, D. and D. Earnhart (2010). Does the porter hypothesis explain expected future financial performance? The effect of clean water regulation on chemical manufacturing firms. *Environmental Resource Economics* 45, 353–377.

Rudebusch, G. D. (2021a). Climate change and the federal reserve. *FRBSF Economic Letter* 25, 1–5.

Rudebusch, G. D. (2021b).Climate change is a source of financial risk. *FRBSF Economic Letter* 3, 1–06.

Schulte, P. (2017). Substitution between clean and dirty energy inputs: a macroeconomic perspective. *Review of Economics and Statistics* 99(2), 281–290.

Shifflett, S. (2023) Wall street's ESG craze is fading investors pulled more than $14billion from sustainable funds this year. *Wall Street Journal*, 14th November

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*, Cambridge University Press.

Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of Money, Credit, and Banking* 1, 15–29.

Truelove, H. B., A. R. Carrico, EU. Weber, K. T. Raimi and M. P. Vandenbergh (2014). Positive and negative spillover of pro-environmental behavior: An integrative review and theoretical framework. *Global Environmental Change* 29, 127–138.

Ullah, S., N. Apergis, A. Usman and M. Z. Chishti (2020). Asymmetric effects of inflation instability and GDP growth volatility on environmental quality in Pakistan. *Environmental Science and Pollution Research* 27(25), 31892–31904.

Zhang, Y., S. Zeng, Q. Wu, J. Fu and T. Li (2023). A study on the impact of the carbon emissions trading policy on the mining industry based on porter hypothesis. Resources. *Policy* 87, 104349

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