I. INTRODUCTION

The economic fallout from the COVID-19 crisis resulted in a sharp decline in global carbon emissions (Figure 1, panel 1).[2] Daily emissions in early April 2020 fell by about 17 percent compared with 2019 levels, though most of this decline has reversed since then as economic activity has picked up across countries. Such a reversal in emissions is in line with what turned out to be only a temporary decline in the price of carbon emission allowances in March 2020 (Figure 1, panel 2). Overall, recent studies forecast a reduction in annual emissions of about 4 to 7 percent in 2020, and that emissions will rebound in 2021 (Le Quéré and others 2020; IEA, 2020).[3] As such, the temporary drop in emissions will not yield the large and sustained decrease in emissions required under the Paris Agreement to limit the increase in global temperature to well below 2°C.

On top of these trends, there is a possibility that the transition to a low-carbon economy could be delayed if the economic scarring from the pandemic crisis runs deep, inducing economic agents and policymakers to sideline environmental objectives. Heightened economic uncertainty and corporate balance sheet vulnerabilities may result in a reduction in investments and research in long-horizon, capital-intensive green projects. In addition, subsidies or economic rescue packages aimed at softening the impact of the crisis may slow the transition; for example, by supporting firms or activities not compatible with long-term climate mitigation goals.

Nevertheless, the current crisis could also present an opportunity for a transition to a low-carbon economy by inducing structural shifts in consumer and investor preferences toward environmentally friendly goods and services as economic agents may change their beliefs about the likelihood of other catastrophic events, such as those linked to climate change. Indeed, survey evidence suggests that voters have become more worried about other global threats, such as climate change, after experiencing the COVID-19 pandemic (Geman, 2020).[4] More generally, an increased awareness of the benefits of long-term disaster prevention could facilitate implementation of green policy measures such as carbon taxes and "green recovery" packages.[5]

The large drop in oil prices that coincided with the COVID-19 pandemic could also impact the climate transition by affecting firms' incentive structure and their financial constraints. The effect is, however, theoretically ambiguous. On the one hand, a decline in oil prices may relax firms' financial constraints and reduce the incentives for businesses to improve their energy efficiency and shift away from fossil fuels, while also hindering the development of clean energy sources by making investments in renewable energy projects relatively less

[2] In the short term, there is an almost one-to-one relationship between economic growth and emissions (Hale and Leduc 2020).

[3] UNEP (2019) estimates that emissions need to decline by 2.7 percent annually in order to reach the 2°C goal by 2030.

[4] However, optimal policy choices when confronted with multiple large catastrophes are complex and do not necessarily imply investments in all mitigation efforts with a positive net present value (Martin and Pindyck 2015).

[5] Calls for implementing green recovery packages in the aftermath of the COVID-19 crisis have come from different quarters, including the private sector. For example, in June 2020 more than 100 global investors called for a green European Union (EU) recovery plan. The EU coronavirus recovery package earmarks about 30 percent of the funds (some €550 billion over 2021–27) for climate protection.

profitable.[6] On the other hand, low oil prices could benefit the energy transition, by hurting the profitability of the oil sector, leading to lower investment and production in the fossil fuel sector, thereby making it easier for clean energy firms to compete.

In general, the effect of an oil price shock on firm environmental performance is likely to depend on the underlying source of the shock—that is, whether it is a demand or supply driven shock. For instance, a negative global demand shock that reduces economic activity and oil demand could lead to lower corporate environmental performance as investments into cleaner energy sources may be delayed because of tight financial conditions for firms. Conversely, a drop in oil prices due to an oil supply shock can trigger an increase in global economic activity (Baumeister and Hamilton, 2019), thereby easing firms' financial constraints and allowing them to improve their environmental performance.

Against this backdrop, in this paper we aim to address the following key questions: (1) How has the COVID-19 crisis affected green investments so far? (2) What can be learned from past economic crises about the likely behavior of the corporate sector in the near and medium terms with respect to the greening of the economy? (3) What do developments in the oil market imply about firms' environmental performance?

Focusing on a sample that extends from 2002 to 2019 and comprises 62 countries, we document that the COVID-19 crisis has not led to a sustained decline in green financing so far. In fact, flows into sustainable funds and the performance of sustainable assets has been robust throughout the crisis. However, there is a real risk that the COVID-19 crisis may adversely affect the transition to a low-carbon economy, notwithstanding the possibility that it induces a structural shift in preferences that leads to a greater focus on climate-related risks by firms than in the past. Specifically, our results show that tighter financial constraints as well as economic downturns are associated with weaker environmental performance and lower levels of green investments by firms.

In addition, the analysis also shows that shocks to oil prices have ambiguous effects on firms' environmental performance. Predominantly demand-driven negative oil price shocks, as has been the case during the COVID-19 crisis, are likely to be detrimental for firms' environmental performance. Instead, oil supply shocks that lower the price of oil are associated with higher environmental performance, pointing to a mechanism where a lower oil price relaxes firms' financial constraints, and hence allows firms to invest in green technologies.

Overall, these results suggest that adverse financial and economic shocks, which limit real activity and tighten firms' financial constraints, could reverse progress in corporate environmental performance by several years. Therefore, in the current context, public policies and recovery packages that boost green investments are warranted to support the

[6] Acemoglu and others (2019) discuss the long-term effects of the shale gas boom, which reduces carbon dioxide emissions from coal in the short term, while increasing aggregate production and directing energy innovation to shift away from clean energy to fossil fuels.

transition to a low-carbon economy.[7] Fostering growth of the sustainable finance sector through better disclosures, the development of green taxonomies, and product standardization may further help to mobilize green investments (IMF, 2019).

Our findings are related to a growing literature on corporate social responsibility (CSR) and firm-level performance. The paper most closely related to ours is Hong and others (2012) who focus on the United States and argue that less financially constrained firms have higher corporate social responsibility scores. Looking at the determinants of CSR, Ferrell and others (2016) find that firms with fewer principal-agency problems engage more in CSR.[8] Our results support the findings of Hong and others (2012), while specifically focusing on firms' environmental performance and extending the analysis to a broad panel of countries. Moreover, our analysis contributes to the literature with a novel analysis of the effects of aggregate shocks—global financial stress, real economic activity and oil market shocks—on firms' environmental performance.

The rest of the paper is organized as follows. Section II discusses the development of the sustainable finance sector at the onset of the COVID-19 crisis. Section III provides an overview of the data and econometric framework to analyze how past economic, financial and oil market shocks have impacted firms' environmental performance. Section IV concludes with possible policy implications.

II. THE COVID-19 CRISIS AND FINANCING THE ENERGY TRANSITION

The COVID-19 crisis does not seem to have led to a sustained decline in green financing. The issuance of green corporate bonds, which has trended up over the past decade, declined in March 2020 during the peak of the financial market turmoil resulting from the crisis, but stayed well within the range of historical deviations (Figure 2, panel 1). Issuance has picked up since then, with the share of green bonds in total corporate bond issuance more than doubling between March and June 2020. In the syndicated loan market, loans to firms with an above-median score in environmental performance have increased over the past decade compared with loans to firms with a below-median score.[9] Lending to both types of firms dropped slightly in the first quarter of 2020 (Figure 2, panel 2).

Investment funds, especially fixed-income funds, with a focus on sustainable or environmental investments have continued to attract investment throughout the crisis, with

[7] As noted in IMF (2020), an initial green investment push combined with steadily rising carbon prices could deliver the needed reductions in emissions to reach net zero emissions by 2050.

[8] In another related study, Lins, Servaes and Tamayo (2017) find that firms with high CSR outperformed firms with low levels of CSR during the global financial crisis and argue that the effect is related to the positive impact of firms' social capital.

[9] Firm-level environmental, social, and corporate governance data come with several caveats. First, the data cover only publicly listed firms, so the results do not necessarily carry over to the entire economy, which includes unlisted small- and medium-sized enterprises. Second, there is a lack of standardization and transparency across data providers. Hence, environmental scores from different providers may capture different features of environmental performance. Third, as some scores are self-reported by firms, accuracy may vary across the sample.

only a small drop in aggregate inflows in some asset classes (Figure 2, panel 3).[10] A possible driver for the good performance of sustainable and environmental funds may have been the relatively high returns that green investments have generally experienced during this crisis (Figure 2, panel 4).

Overall, the impact of the COVID-19 crisis on environmental finance thus seems to have been modest and short-lived. However, given the persistence and severity of the shock—in terms of the decline in output, the extent of potential scarring, and the heightened economic uncertainty, which are straining corporate balance sheets—it is difficult to say whether such trends will continue and what the overall impact of the crisis will be on firms' actual environmental performance and on their ability to contribute sufficiently to global climate change mitigation efforts in the near and longer terms. In view of this, and to draw implications for the current pandemic crisis, the following analysis examines firms' environmental performance during previous episodes of financial and economic stress.

III. Lessons from Past Economic Crises for the Energy Transition during the COVID-19 Crisis

A. Financial Constraints and Firms' Environmental Performance

Drawing on Hong and others (2012) and Dyck and others (2019), we estimate the following baseline specification to evaluate the linkages between financial constraints and firms' environmental performance (environmental score):

$$E_{i,s,c,t} = \alpha_s + \gamma_c + \delta_t + \beta_1 Constraints_{i,t-1} + \mu' X_{i,t-1} + \varepsilon_{i,s,c,t}, \quad (1)$$

where $E_{i,s,c,t}$ indicates the environmental score for firm *i* in sector *s*, country *c*, and time *t*. α_s, γ_c and δ_t are sector, country and time (year)-fixed effects, respectively. $X_{i,t-1}$ are firm-level controls such as the logarithm of total assets and earnings before interest and taxes. The variable $Constraints_{i,t-1}$ is a firm-level financial constraint measure, which following the literature is defined in several alternative ways outlined below:[11]

[10] Sustainable funds explicitly indicate all kinds of sustainability; impact; and environmental, social, and corporate governance (ESG) strategies in their prospectus. Environmental funds invest in environmentally oriented industries. See IMF (2019) for a discussion of sustainable finance and financial stability.

[11] There is an extensive literature evaluating how financial constraints affect firm behavior, using firm size, firm payout, ratings, or indices based on linear combinations of observable firm characteristics as measures of financial constraints (Almeida, Campello, and Weinback 2004; Duchin, Ozbas, and Sensoy 2010). However, Farre-Mensa and Ljungqvist (2016) argue that listed firms classified as constrained by standard financial constraint proxies have no difficulties in raising debt, suggesting that results on the link between financial constraints and environmental performance should be interpreted cautiously.

- Firm size: captured by the logarithm of firm's total assets, with large firms expected to be less financially constrained than smaller firms;[12]
- Dividends: a dummy variable equal to one if a firm does not pay dividends, and is therefore considered as financially constrained, and zero otherwise;
- Ratings: a dummy variable equal to one if a firm with a positive debt-to-asset ratio is not rated according to Standard and Poor's, and hence may not have easy access to capital markets (indicating that it is financially constrained), and zero otherwise;[13]
- Interest Coverage Ratio (ICR): a dummy variable equal to one if a firm's earnings before interest and taxes are below interest expenses, indicating that it is financially constrained, and zero otherwise;
- KZ score: a dummy variable equal to one if the Kaplan-Zingales score, an aggregate measure of financial constraints (Kaplan and Zingales, 1997), is above the median of the Kaplan-Zingales score distribution; and zero otherwise.

Our dataset comprises about 7,000 listed firms—for which information on environmental performance is available—corresponding to 69 industries (as per the Global Industry Classification Standard) from 62 economies. The data is at annual frequency and covers the period 2002 to 2019.[14] Information on environmental scores $E_{i,s,c,t}$ is obtained from Refinitiv and is based on 68 metrics covering three environmental categories: Resource use, Emissions, and Innovation. Category scores are calculated using a rank scoring methodology to evaluate firms' environmental performance relative to all other firms each year, firms' overall environmental scores are then calculated from a weighted average of the category scores, where the category weights vary by industry. We use the proprietary environmental aggregate scores as our main dependent variable. These scores range between 0 (low performance) and 100 (high performance).[15]

The estimation results, reported in Table 2 (panel A), show that tighter financial constraints are associated with worse environmental performance. The environmental performance of financially constrained firms for each measure is significantly weaker than that of unconstrained firms. Specifically, environmental performance falls by 10 points when firm size drops from the median to the 25th percentile of the firm size distribution. When a firm does not pay dividends or when it is not rated, its environmental score is 4 points and 3

[12] In the estimations, the sign of this variable is reversed such that higher values indicate smaller firms. The rationale for using size as a measure of financial constraints is that small firms are typically young and less well known, hence more vulnerable to capital market imperfections (Almeida and others (2004)).

[13] This approach is akin to Duchin and others (2012), who consider firms as unconstrained if they have zero debt and no rating.

[14] Table 1 provides the summary statistics on our key variables of interest. A full list of data sources and variable definitions is provided in Annex A.1.

[15] Using a logarithm transformation of the environmental scores in the estimations leads to qualitatively unchanged results compared with using the raw environmental scores.

points lower, respectively, than the score of dividend-paying and rated firms. The environmental score is 1 point lower when a firm's interest coverage ratio is below 1 or when the Kaplan-Zingales index is above the median of the sample distribution.[16]

It is conceivable that firms with high levels of environmental performance also happen to be less constrained. For example, well-governed firms may both be less likely to become constrained and may also be more likely to invest in corporate social responsibility (Ferrell and others, 2016). To control for such time invariant firm-level characteristics we also consider firm fixed effects. Similarly, to control for macroeconomic conditions that could be a driver of both CSR and financial constraints (such as accommodative monetary policy or strong economic growth), we include country-time fixed effects. Our original conclusions are robust to these changes (columns (6) and (7) of panel A, Table 2). [17]

Similar results are obtained when considering two sub-categories of the environmental score directly related to climate change, firms' emissions and their resource use (Table 3). For example, for a firm that does not pay dividends, its emissions and resource use scores drop by 6 points. Moreover, for a firm that is not rated, its emissions and resource use scores drop by 3 and 4 points, respectively, compared with 3 points for the overall environmental score.[18]

B. Financial Constraints and Firms' Investments in Green Technologies

A key channel through which financial constraints can affect firms' environmental performance is through investments in green technologies, as constrained firms may postpone or reduce such investments if they do not directly contribute to revenue generation. Moreover, financially constrained firms may face difficulties in borrowing against future profits to invest in research and development, consequently postponing investments in intangibles that could potentially improve their environmental performance.

We test this hypothesis using the following Probit model:

$$P(I_{i,s,c,t} = 1) = \Phi(\alpha_s + \gamma_c + \delta_t + \beta_1 Constraints_{i,t-1} + \mu' X_{i,t-1}), \quad (2)$$

[16] The results are robust to alternative definitions of the financial constraint variables, such as defining a firm as constrained if its total assets are below the median of the firm size distribution by total assets, the KZ score as a continuous variable, whether a firm's long-term issuer rating is below investment grade according to Standard and Poor's, and the long-term issuer rating defined as a continuous variable. Using firm age as a measure of financial constraint (older firms face lower financial constraints) also indicates that financially constrained firms have lower environmental performance. The use of a balanced panel of firms, starting from 2010 does not qualitatively change the results either. See Online Annex Table A2.

[17] For brevity, the specification with firm and time fixed effects, as well as country-time fixed effects, is presented only for one measure of financial constraint (rating status). The results with firm fixed effects are qualitatively robust when using alternative measures of financial constraints (except for the interest coverage ratio where the results are not statistically significant).

[18] The effects of financial constraints on the third environmental score category (environmental innovation) are typically not statistically significant. However, the underlying metrics used to calculate that category score—e.g., whether a company is involved in animal testing for cosmetics, or in developing new products that are marketed as reducing noise emissions—are not directly related to climate change, and thereby less relevant for the transition to a low-carbon economy.

Where Φ is the cumulative distribution of the normal function and $I_{i,s,c,t}$ is a binary variable that indicates whether a firm *i*, in sector *s*, economy *c* undertakes environmental investments in year *t*.[19] α_s, γ_c, δ_t are sector, country and time fixed effects. $Constraints_{i,t-1}$ is one of the five firm-level financial constraints defined above, and $X_{i,t-1}$ are the same firm-level controls as in the previous analysis to control for observable firm characteristics.

Table 2 (panel B) shows that financially constrained firms are indeed less likely to make investments that reduce future environmental risks, such as treatment of emissions or installation of cleaner technologies. For example, the probability that a firm will make an environmental investment falls by 6 percentage points when firm size drops from the median to the 25th percentile of the firm size distribution. Similarly, a firm unable to pay dividends has a 3 percentage points lower likelihood of making a green investment.[20]

C. Firms' Environmental Performance and Macro-financial Shocks

Adverse macro-financial shocks that increase uncertainty and dampen economic activity can amplify firms' financial constraints and significantly impede their ability to invest in green projects, thereby weakening their environmental performance.[21] To assess the impact of macro-financial shocks on firms' environmental performance, two types of shocks are analyzed here: (1) a global financial stress shock (proxied by the Chicago Board Options Exchange Volatility Index, VIX) and (2) a real economic activity shock capturing a sudden drop in domestic output.[22]

The following model is estimated to evaluate the dynamic responses of firms' environmental performance to these shocks:

$$E_{i,s,c,t+h} = \alpha_s^h + \gamma_c^h + \beta^h shock_t + \delta'^h Firm\ controls_{i,t-1} + \gamma'^h Macro\ controls_{t-1} + \in_{i,s,c,t+h}, \qquad (3)$$

Where *i* is a firm, *s* is a sector, c is the economy and *t* is time (year). h denotes the horizon of the projection. $E_{i,s,c,t}$ is the environmental score from Refinitiv. α_s^h and γ_c^h are sector and country fixed effects. $X_{i,t-1}$ are firm-level controls: the logarithm of total assets and earnings

[19] Specifically, it is the answer to the following question that is one of the metrics of the Emissions category of the Refinitiv's environmental score: "Does the company report on making proactive environmental investments or expenditures to reduce future risks or increase future opportunities? (i) investment made in the current fiscal year to reduce future risks and increase future opportunities related to the environment; (ii) investments made in new technologies to increase future opportunities; (iii) treatment of emissions (e.g., expenditures for filters, agents); (iv) installation of cleaner technologies.

[20] Several robustness checks have been performed to assess the robustness of this analysis. These include: i) alternative definitions of the financial constraint variables such as defining a firm as constrained if its total assets are below the median of the firm size distribution by total assets, the KZ score as a continuous variable, whether a firm's long-term issuer rating is rated below investment grade according to Standard and Poor's, and the long-term issuer rating; ii) country fixed effects are replaced by climate policies: country-specific environmental policies obtained from the OECD's environmental policy stringency index or information from the World Economic Forum survey regarding the strictness and enforcement of environmental laws; iii) to circumvent the incidental parameters problem that may arise in non-linear panel data models, replacing fixed effects by macroeconomic and financial control variables: the lagged country-specific output gaps, the lagged price of oil (the logarithm of the WTI) and the lagged VIX; iv) the use of a balanced panel of firms, starting from 2010. The original conclusions are robust to these changes.

[21] For example, Gulen and Ion (2016) document the negative effect of aggregate uncertainty on firm-level investment. There is also an extensive literature evaluating the effects of uncertainty on macroeconomic activity rekindled by Bloom (2009). For example, Caggiano and others (2014) find that uncertainty shocks lead to a contraction in economic activity and that the effects of uncertainty on economic activity are stronger in recessions than expansions, while Rossi and Sekhposyan (2015) propose new measures of uncertainty based on forecast error distributions, which have significant effects on the macroeconomy.

[22] Defined as the change in the annual output gap obtained from the World Economic Outlook database.

before interest and taxes. The macroeconomic controls include the price of oil (logarithm of the WTI), country-specific output gaps, and the VIX.[23]

The analysis shows that a sudden jump in the VIX, comparable to that observed during the first half of 2020 in the context of the COVID-19 pandemic, would lead to a persistent drop in firms' environmental performance by up to 5 points, with the pre-shock performance level not attained for at least three years after the shock (Figure 3).[24] Absent policy actions and behavioral changes, this would imply that average corporate environmental performance would return to the levels that prevailed in 2006.

Moreover, to test the conjecture that financial stress weakens corporate environmental performance when firms are financially constrained, we augment equation (3) by interacting VIX with a financial constraint measure. The results show that the adverse effect of global financial shocks on environmental performance is magnified when firms are financially constrained (Table 4, panel A). For example, for firms not paying dividends or for unrated firms in 2019, the global financial stress shock observed thus far in 2020 is estimated to lower environmental performance by 1 and 2 additional points, respectively, compared with dividend-paying or rated firms. As above, the findings are robust to the inclusion of firm fixed effects to control for time invariant firm-level characteristics.

Turning to the analysis of a sudden drop in economic activity, a large decline in the output gap (10 percentage points, about 50 percent larger than that observed in the Group of Seven (G7) economies during the global financial crisis), would lead to a 3 point decline in firms' environmental performance in the medium term (Figure 4, panel 1).[25] Similarly, firms' carbon intensity—captured by their total carbon emissions relative to revenue—could increase by up to 8.5 percent in the medium term after such a decline in the output gap (Figure 4, panel 2), even though the initial response of carbon intensity to economic shocks may be small because of the cyclical dynamics of carbon dioxide emissions observed amid recessions (Figure 1, panel 1; Hale and Leduc 2020).

D. Firms' Environmental Performance and Oil-market Shocks

To assess the impact of oil price changes on firms' environmental performance, oil supply and oil demand shocks are obtained from the structural VAR model of Baumeister and Hamilton (2019). The shocks are derived from the median of the posterior distribution of the relevant parameters and aggregated at an annual frequency by taking an average of the monthly values over the calendar year. We exclude from this analysis the oil inventory

[23] When the shock is defined in terms of the change in output gap, the variable is not included in levels as a control variable.

[24] The analysis is robust to using alternative definitions of financial stress shocks: An autoregressive model of order one for the monthly VIX is estimated over the period extending from January 1990 to December 2019 instead of using directly the VIX. The monthly residuals of that regression are aggregated at an annual frequency by taking an average of the monthly values over the calendar year;

[25] Other more global measures of economic activity shocks such as the forecast error for the current-year global GDP growth relative to the April WEO or the global economic activity shock from Baumeister and Hamilton (2019) also suggest a fall in corporate environmental performance in the medium term.

demand shock (also referred as a "speculative demand shock" in the oil market literature), since this shock plays a limited role in explaining oil price fluctuations in the VAR model of Baumeister and Hamilton (2019).[26]

Our econometric analysis suggests that the source of the oil price fluctuation is indeed key to understanding firms' environmental response to a shock. Historically, when oil prices have fallen due to demand-side factors, environmental corporate performance has been weaker. By contrast, when oil prices have declined due to an oil supply shock, environmental performance of firms has generally improved (Table 4, panel B). To the extent that the COVID-19-induced oil price shock is largely a demand-driven shock—as evident from the decomposition of the oil price shock in March and April 2020 (see Online Annex Figure.1)—firms' environmental performance is likely to suffer significantly.

Overall, these results indicate that tighter financial constraints are associated with weaker corporate environmental performance. Adverse global financial and output shocks that increase uncertainty and amplify firms' financial constraints also weigh significantly on their environmental performance. Furthermore, a reduction in oil prices against the backdrop of a decline in global economic activity is unlikely in itself to lift corporate environmental performance. Thus, absent strong supportive policy actions, tighter financial constraints and weaker economic activity related to the COVID-19 crisis may act as a drag on firms' environmental performance in the future.

IV. CONCLUSION

The COVID-19 crisis has resulted in a temporary decline in global carbon emissions, but the long-term impact of the crisis is uncertain. While the crisis may increase awareness of catastrophic risks and bring about a major shift in consumer preferences, corporate actions, and investor behavior, the analysis presented in this paper suggests that there is a real possibility that, barring policy interventions, investment by firms to improve their environmental performance may decline in this time of macro-financial stress.

To achieve the reduction in emissions needed to keep global warming below 2°C, an increase in green investments, in combination with steadily rising carbon prices, is critical (IMF, 2020). Public policies and green recovery packages to support firms' environmental performance during the COVID-19 crisis are therefore warranted.

In addition, to alleviate firms' financial constraints and to aid green investment, it would be key to put in place policies that support the sustainable finance sector, such as better disclosure standards, development of green taxonomies, and product standardization (see IMF, 2019).

[26] Including the world economic activity shocks from Baumeister and Hamilton (2019) in this specification does not qualitatively change the results.