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CLIMATE SCIENCE

A climate intelligence arms race in financial markets

Public policy grapples with private "black box" models

By **Jesse M. Keenan**

Global financial markets are using applied science to measure, and to guide investments in response to, phenomena attributed to climate change, which influence supply chains, production capacity, and fundamental aspects of supply and demand. Such science and technology, and their integration into markets, are critical for shaping behavior and extending discipline over carbon consumption and excessive risk-taking. There is thus a technology arms race among climate services providers to develop capacity for understanding market, transition, and physical risks across a broad spectrum of asset classes. But the lack of transparent scientific validation and public oversight over rapidly advancing, and often proprietary, "black box" technologies are causes of concern, both for the integrity of science and for the potential impacts on consumer behavior and public policy. This paper explores potential pathways for public-sector consumers to extend review authority over such products and services that may be operating outside of the bounds of scientific merit, to balance demands for public transparency, scientific integrity, intellectual property, and commercial enterprise in the broader adaptation of market economies.

Market participants, primarily insurance and reinsurance firms, have long relied on catastrophe (CAT) modeling to focus on exposure to physical risk and to evaluate near-term loss (e.g., return frequency of losses from flooding to an insured factory). But more recently, climate services firms have been developing advanced technology focused more broadly on evaluating vulnerability (i.e., exposure, but also sensitivity and adaptive capacity) across a broader range of time horizons and climate stresses and shocks (e.g., hazards). For instance, exposure of physical assets to sea level rise, and corresponding

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Workers engage in coastal construction in Dubai. Climate services technology is increasingly utilized to manage investment and construction risks.

estimated declines in local economic output, are used to underwrite commercial real estate loans where income-producing collateral may be impaired within the term of the loan. Beyond physical risks, many firms also seek to analyze transition risks accrued in the course of decarbonization (e.g., stranded assets) (See the table).

To understand this rapid development of climate services technology (CST), it is critical to understand the policy and market context driving the demand. Firms and entire sectors are being pressured by investors and underwriters with a variety of motivations, such as social and environmental responsibility or self-interested transparency of physical and transition risks. Public-sector concerns (e.g., credit ratings of municipal bonds; asset and portfolio management decisions) are driven either by a desire to get ahead of financial markets or at the behest of underwriters and credit rating agencies. In the financial sector, the Network for Greening the Financial System (NGFS), a global network of central banks established during the 2015 Paris climate accord negotiations, is developing a system for measuring and reporting climate risks and uncertainties to guide the supervision of regulated banks and investment institutions (*1*). With this emerging work of central banks through NGFS, as well as the European Commission's sustainable finance rule-making and the Financial Stability Board's Task Force on Climate-Related Financial Disclosures (TCFD), the demand for CST among regulators, private enterprises, shareholders, and investors is shaped by emerging guidelines and the impetus for standardized assessment and reporting.

Assisted by CST, public and private stakeholders are united by an ambition to measure (i) material degradation of physical assets, (ii) life cycle analysis and cost accounting of assets, (iii) operational thresholds of supply chains, and (iv) macroeconomic impacts of climate change. The first in this race in the private sector to deploy services to manage risk and value asset impairment will develop—or maintain—market share, and the last in the race runs the risk of failure. The stakes for public consumers of CST are arguably greater, given the increased reliance on CST to inform long-term capital investments. The primary concerns are that investment decisions might underestimate physical risk in a manner that reduces the performance of an asset so that anticipated benefits are undercaptured or not captured at all. Maladaptive path dependencies may have greater impact for long-term capital allocations (public-sector investments are often multigenerational) than for short-term investment cycles that dominate most private-sector capital allocations in liquid or semiliquid assets. There are also public-sector consequences associated with opportunity costs, political legitimacy, or the institutionalization of bad science within public-sector entities that drives them to ask the wrong questions.

As such, the accessibility and quality control of the underlying proprietary technology is central for long-term fiscal stewardship. This arms race goes beyond the commodification of climate data to the very heart of a policy discourse struggling to define the regulatory limits of data as public and private goods.

GROUND-UP INNOVATION

The methodological advancement of CST has been tremendous, albeit uneven, often driven by the proliferation of data. For real estate, infrastructure, and commodity asset classes, distributed, low-cost measurement hardware and sensors are being integrated with the rule-based Internet of Things to manage systems as various as stormwater drainage, energy infrastructure, and pollution control (*2*, *3*). Increasingly inexpensive, high-quality measurement hardware synced with conventional, capital-intensive public data collection has engaged public, private, and civic stakeholders to develop networks that integrate environmental data in an open-source format for such applications as demand management and parametric insurance (*4*, *5*). Benefiting from these streams of open data, blockchains are positioned to reduce compliance costs and further the diffusion of capital for mitigation and adaptation by enabling authentication between parties concerning verifiable carbon emissions, distribution of green investment funds, and climate risk disclosures broadly (*6*, *7*). What unites these technological developments and ambitions is a common infrastructure based on open, accessible, and often public data (*8*).

CST providers and CAT modeling firms that support the financial services industry consume large amounts of public data and augment those data with proprietary databases. For example, there are databases that track not only the location and exposure of a firm's assets, but also the near-entirety of the firm's supply chain. Analysis can be run to simulate sensitivity to extreme events or absolute constraints on production inputs and logistical outputs from a combination of shocks and stresses. Recent advances seek to model the flattening of tail risks as they reverberate across industries and sectors.

In recent years, CST providers have been quickly outpacing the first-generation CAT modeling firms, which have been less able to integrate the wider range of scientific disciplines engaged in climate change modeling and market analysis because of their focus on near-term exposure. Whereas a CAT modeling firm in a commercial lending context might simply estimate an average annual loss of the collateral, a CST provider may go a step further and contextualize the loan within a broader portfolio of analysis to understand the market share and value impairment implications associated with a variety of compounded climate impacts. Today, leading firms have advanced the idea of "benevolent intelligence" for addressing the demands of various sectors (*9*). Some firms' proprietary technology is attracting substantial investment from Wall Street and Silicon Valley.

The commercial merits of the first generation of CST service providers will be determined by their customers in the private market. But what expectations should the public sector have? Although public policy in many countries promotes open access to

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government climate and meteorological data, and most public bodies have processes to promote transparent review of public analyses, public climate services providers (e.g., Met offices) have not yet engaged deeply in asset-level measurement and modeling as a service in the context of financial market activity. With the public sector thus largely dependent on proprietary CST, what if these models are fundamentally misaligned with the best available science and otherwise inform maladaptive decisions? How might the public lose control of or access to public data once it goes into the black box?

There are many laudable models in the CST industry, but there are also inferior models being misapplied to inform maladaptive decisions and investments within the private and public sectors. For example, some CST providers are commonly criticized by scientists for overselling their capacity to downscale physical exposure assessments, which can drive long-term capital planning by local jurisdictions. The downscaling may suggest a measure of uncertainty that is beyond current scientific consensus. As such, some providers pitch certainty in quantitative models that is unwarranted or not soundly "complemented with qualitative approaches to capture the full complexity [of] tangible and intangible aspects of vulnerability in its different dimensions" (*10*). Much better are those CST firms that provide largely nonprobabilistic decision support within scenario planning that explicitly acknowledges the limitations of the technology.

Climate-related risks and financial impacts

Modified from Recommendations of the Task Force on Climate-Related Financial Disclosures (2017), http://bit.ly/2kIzf7l

Transitional risks

CLIMATE-RELATED RISKS	POTENTIAL FINANCIAL IMPACTS
Policy and legal	
• Increasing pricing of GHG emissions • Enhanced emissions-reporting obligations • Mandates on and regulation of existing products and services • Exposure to litigation	• Increased operating, insurance, and compliance costs • Write-offs, asset impairment, and early retirement • Reduced demand for products and services from litigation • Increase in fines and penalties
Technology	
• Substitution of existing products and services with sustainable options • Unsuccessful investment in new technologies • Costs to transition to lower-emissions technologies	• Write-offs and early retirement of assets • Reduced demand for products and services • Research and development (R&D) and capital investment in technologies • Costs to adopt new processes and practices
Market	
• Changing consumer behavior • Uncertainty in market signals • Increased costs of raw materials	• Reduced demand based on changing consumer preferences • Increased production costs • Unexpected shifts in energy costs • Repricing of assets (e.g., fossil fuel reserves, land and securities valuation)
Reputation	
• Shifts in consumer preferences • Stigmatization of sector • Increased stakeholder concern and negative feedback	• Reduced revenue from decreased demand • Reduced revenue from decreased production capacity • Reduced productivity and human capital investment • Reduced capital availability

Physical risks

CLIMATE-RELATED RISKS	POTENTIAL FINANCIAL IMPACTS
Acute • Increased return occurrence of extreme events • Increased severity of extreme events **Chronic** • Changes in variability in weather patterns (e.g., precipitation) • Rising mean temperatures • Rising mean sea levels	• Reduced production capacity and supply chain disruption • Higher costs from negative impacts on workforce Write-offs and early retirement of assets • Increased operations and capital costs • Reduced revenues from lower sales • Insurance availability and pricing pressures

STANDARDIZING CLIMATE RISK

In the summer of 2019, U.S. lawmakers and politicians stepped up their assertions that the Federal Reserve Bank (FRB)—as a notable holdout—should join NGFS on the grounds that climate change represents a fundamental risk to the stability and growth of the economy. Among the policy ambitions of NGFS is the standardization for defining the "greening" and "browning" of assets and asset classes (with greening broadly meaning that an investment is less exposed to climate risk and/or otherwise represents an acceptable greenhouse gas footprint). NGFS cites data from the China Banking and Regulatory Commission (CBRC) showing that "green" loans had a lower nonperforming loan ratio than did conventional loans (*1*). The FRB's absence puts the United States at a strategic disadvantage if it cannot participate in fundamental NGFS negotiations, such as the not-so-simple task of defining what is green and what is brown.

Any such definitions must be supported by empirical evidence, including from the CST industry. Validating and legitimizing the policies would require monitoring of asset performance to capture weaknesses in underwriting criteria for investors, borrowers, and asset-level performance. For example, in the CBRC observations, is it the environmental and economic performance of the assets, or the superior credit quality of borrowers who can afford to invest in green assets, that is driving loan performance?

Harmonizing definitions for assets across sectors and countries will require major investments in not only CST, but also institutions that define enterprise reporting, accounting, and disclosure (e.g., the U.S. Securities and Exchange Commission). With the evolution of climate impacts and asset sensitivity over time, climate intelligence must support evolving empirical justification for oversight. As such, NGFS argues that a standardized taxonomy for macro-financial supervision based on asset-level quantitative analysis is partially dependent on bridging data gaps and making such data "publicly available in a data repository" (*1*). For global regulators to do their jobs, they need standardized, consistent, and transparent access to data and assessment methodologies.

FIRM-LEVEL DISCLOSURES

TCFD's guidance for private-sector climate risk disclosure is an important contribution that is supported by more than 800 private- and public-sector organizations managing more than $118 trillion in assets (*11*). Complementing the Carbon Disclosure Project (CDP), which collects and benchmarks data on carbon footprints and adaptation, TCFD provides guidance for analyzing transition and physical risks and opportunities. Given wide-ranging uncertainties, the guidance provides frameworks for both probabilistic modeling and nonprobabilistic scenario planning. One core limitation is the inherent flexibility of any given firm to subjectively exclude information that it feels may not be particularly important, but which may in fact be material to regulators or the sector. In this context of subjective ambiguity, NGFS has

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positioned itself to advance assessment and reporting standardization. However, standardization may require a measure of methodological continuity and transparency that may conflict with proprietary techniques and data sources; this represents a substantive challenge to NGFS's public data repository recommendations.

An additional challenge with integrating disclosure systems (e.g., CDP and TCFD) and public data repositories is that participating firms are reluctant to be publicly benchmarked because the consequences of falling behind may outweigh the benefits of being ahead. Despite coordinated guidance by CDP for TCFD integration, some firms have dropped out of the CDP system in favor of the flexibility afforded within TCFD. One could argue that NGFS' ambition for standardization is effectively analogous to benchmarking, in that metrics for the greening and browning of asset classes are dependent on changing empirical thresholds that lead to binary determinations of value through legislated definitions. In either case, firms cede market influence to the judgment of third parties.

Although this does not mean that public authorities could not exert oversight over sector-wide assessment methodologies, such as in the energy sector, this is less likely across other sectors for two reasons. First, the wide range of sector-specific activities is likely beyond the capacity of public authorities to fully operationalize, especially in light of the limited authority for regulation among NGFS members. Even with public securities regulation, climate disclosure policies are largely deferential to subjective determinations of whether information is relevant and are not prescriptive as to method and scope of assessment. Second, oversight to standardize sector-specific methodologies would be in part dependent on data and information, which could incentivize firms to limit their contribution of data to the public realm. Even well-intentioned firms desire predictability, and moving targets fundamentally challenge that predictability.

Comprehensive assessment and reporting standardization across a wide range of sectors may not be optimal, at least initially, given the behavioral disincentives, the lack of institutional capacity, and the broad scope of the challenge. It may be more practical to begin with standardization of asset-specific and asset class–specific assessment methodologies, starting from the ground up and following the technology. In this sense, nonparticipation of any given firm would be unlikely to impair a macro view of the performance of an entire class.

PUBLIC POLICY IMPLICATIONS

In light of this impetus for standardization of assessment, reporting, accounting, and disclosure of climate risks, what is the role of the public sector in overseeing quality control and ensuring some measure of consumer, civic, and scientific transparency? With far fewer resources for developing their own in-house capacity or for questioning the underlying assumptions of private-sector CST products and services, public-sector consumers are particularly vulnerable.

Climate services contracts themselves often offer little protection or recourse for bad science. For instance, some provisions assert proprietary dominion over publicly developed data and license these data back to the contracting public entity. Many of these contracts disclaim liability and provide no warranties. In many ways, the marketplace is operating on blind faith in model validation and the professional competence in applying those models (*12*). There is a tremendous demand for training workforces to understand what science can and cannot do within the realm of adaptation science and management.

The challenges of finding a trusted CST provider are substantial. The public sector can critically examine climate services procurement contracting to better understand and push back on intellectual property imbalances, particularly as this relates to data developed by public and civic entities. These efforts may parallel institutional learning emerging in other contexts, such as technology-contracting practices associated with "smart cities" investments. Public entities could develop procurement protocols that require confidential review of trade secrets associated with black box models prior to bidding or contracting. These efforts may require development of peer review advisory committees and technical support staff to maintain quality control.

However, because of the perennial lag between technology and regulation, it may be advisable to create standards development organizations (SDOs) that can develop protocols and compliance certifications for products and services that affect critical infrastructure at the intersection of national security and public safety (e.g., energy, potable water, communications). For example, there has been some standardization for various threats and hazards for critical infrastructure led by the U.S. National Institute of Standards and Technology (NIST) and handed off to SDOs. These activities should be informed by a broader strategic position that speaks to a clearer division between the public domain and data derived from CST. As recently called upon by the American Meteorological Society and others, national governments and multinational organizations could memorialize public data policies based on consensus-based principles from which independent assessment and reporting standardization may rely (*13*, *14*).

Whether it is market efficiency or consumer transparency, both the private and public sectors are incentivized to disclose climate risks in the long term, even if doing so is painful in the short term. Standardizing the process across asset classes will rely on publicly available data and proprietary technology that, in some cases, is subject to the rigors of scientific review and public scrutiny. CST offers many hopes but may also create maladaptive path dependencies based on poor-quality science and negligent professional services (*15*). It is critical that policy-makers and public-sector consumers assert a claim to the fundamental principles of the public domain—of science and data—to advance society's collective mitigation of, and adaptation to, climate change. ■

REFERENCES AND NOTES

1. Network for Greening the Financial System, *A Call for Action: Climate Change as a Source for Financial Risk* (NGFS Secretariat/Banque de France, April 2019).
2. S. Howell, Y. Rezgui, T. Beach, *Environ. Model. Softw.* **102**, 94 (2018).
3. H. N. Saha *et al.*, in *2017 8th Annual Industrial Automation and Electromechanical Engineering Conference (IEMECON)* (IEEE, 2017), pp. 65–68; https://ieeexplore.ieee.org/document/8079563.
4. Environmental Sensor Map (Integrated Ocean Observing System, National Oceanographic and Atmospheric Administration, 2019); https://sensors.ioos.us.
5. Stroud Water Research Center, *EnviroDIY* (2019); www.envirodiy.org/.
6. A. Lockley, Z. Mi, D. Coffman, *Front. Eng. Manag.* **6**, 38 (2019).
7. A. Marke, Ed., *Transforming Climate Finance and Green Investment with Blockchains* (Academic Press, 2018).
8. R. Hamaker *et al.*, *Analysis of Existing Data Infrastructure for Climate Services* (2019); http://eu-macs.eu/wp-content/uploads/2016/12/EUMACS-D1.3_revision.pdf.
9. D. Cusick, "Tech Offers a Virtual Window into Future Climate Change Risk" (23 April 2019); www.scientificamerican.com/article/tech-offers-a-virtual-window-into-future-climate-change-risk/.
10. R. Swart, *Clim. Serv.* **14**, 15 (2019).
11. Financial Stability Board, *Task Force on Climate-Related Financial Disclosures: 2019 Status Report* (2019).
12. B. van den Hurk *et al.*, *Clim. Serv.* **12**, 59 (2018).
13. American Meteorological Society, *Full, Open and Timely Access to Data: A Policy Statement of the American Meteorological Society* (18 July 2019); www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/full-open-and-timely-access-to-data/.
14. M. D. Wilkinson *et al.*, *Sci. Data* **3**, 160018 (2016).
15. H. Nissan *et al.*, *Wiley Interdiscip. Rev. Clim. Change* **10**, e579 (2019).

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