To see and be seen: Technological change and power in deforestation-driving global value chains

Abstract

New digital tools for monitoring forest- and land-cover change have made it easier for civil society actors to call firms to account for deforestation. While there is much recent work on how shifting technologies within global value chains reshape dyadic power relations between firms, there has been less work on how technologies reshape diffuse power relations across global value chains. In deforestation-linked global value chains, technological changes linked particularly to increased production-area visibility affect both dyadic and diffuse power relations, and their interactions, simultaneously. Synthesizing work on transaction characteristics and power relations in global value chains to address this novel situation, we argue that monitoring technologies' effects on global value chains will likely depend on prevailing intellectual property regimes. Proprietary technologies favor large-scale operations and already established lead firms, while open technologies could support democratization. Treating forest- and value-chain information as a public good could support more inclusive, equitable, and sustainable value chains.

Keywords: Deforestation, global value chains, governance, technologies, power relations, palm oil

Introduction

Greenpeace Southeast Asia's 2020 exposé *Burning Issues: Five Years of Fires* doesn't pull its punches. Compiled using extensive satellite data, the report details the total burned area in the oil palm plantation holdings of the top ten offending firms across the Indonesian archipelago, which the Indonesian government has sanctioned minimally. Three of the top five offenders, Greenpeace Southeast Asia (2020, p. 12) observes, were linked to a single family controlling the massive Sinar Mas and Asia Pulp and Paper groups. For many firms, the report is a new iteration of ongoing campaigns. For example, in 2016 Mighty Earth, at the time a fledgling environmental nongovernmental organization (NGO), charged the South Korean-owned Korindo, a top-ten offender in the Greenpeace report, with violating its Forest Stewardship Council (FSC) certificate. The NGO presented satellite data indicating land clearance by fire on Korindo's oil palm concessions in Indonesia's Papua Province (Bellantonio et al., 2016). A further report from the University of London's Forensic Architecture Group used satellite imagery to demonstrate the fires in question were not spaced randomly, as would be expected if they were natural, indicating they were deliberately set (Jong, 2020).

Cases like these are sadly commonplace. Global value chains (GVCs), sequences of firms taking products from primary materials to finished consumer goods (Gereffi, et al. 2005), are significant deforestation drivers. Roughly a quarter of tropical forest loss between 2005 and 2013, and about a third of deforestation-related greenhouse gas emissions, are attributable to international demand for timber and deforestation-linked products (Pendrill et al., 2019a, 2019b, 2020).

Naming and shaming lead firms contributing to ecosystem destruction requires documenting forest cover change and linking changes to particular supply chains (zu Ermgassen, et al., 2020). NGOs now can use several monitoring technologies, by which we mean the assemblage of computational tools for information processing, satellite imaging, and cloud computing, for these purposes, reshaping power relations in deforestation-linked GVCs. While this confluence of big data, cloud computing, and machine learning are often discussed as harbingers of de-skilling and geographic restructuring in GVCs (Sturgeon, 2021), they have a further important impact in value chains with substantial land-use footprints: they make upstream production activities increasingly visible and monitorable. As one palm oil industry insider observed in the mid-2010s, "the days of going unnoticed as a 'black sheep' are over" (qtd. in Heng, 2015), though, as the Greenpeace Southeast Asia (2020) report makes clear, government sanctions may not be forthcoming. Widespread evidence of GVCs' complicity in tropical deforestation (Pendrill et al., 2019b) have led several firms to issue commitments pledging to achieve zero-deforestation supply chains (Garrett et al., 2019; Lambin et al., 2018; Weber & Partzsch, 2018). The palm oil sector accounts for the plurality of these pledges, followed closely by timber and paper pulp (Donofrio et al., 2017).

Zero-deforestation pledges and similar interventions are investigated in a number of GVC studies (Castro-Nunez et al., 2020; Dermawan & Hospes, 2018; Gardner, et al., 2019; Lyons-White & Knight, 2018). Here, we are particularly interested in how emerging monitoring technologies have helped motivate these pledges. Existing work documents several cases of technological change impacting dyadic power relations between firms, but new monitoring technologies in deforestation-linked GVCs are not only reshaping dyadic power relations, but also the more diffuse power relations connecting external actors with GVC practices. While deforestation-linked GVCs are a particularly clear place to observe these dynamics, there is reason to believe they might play out elsewhere. Numerous emerging tools are empowering downstream and civil society actors to remotely monitor some aspects of upstream production processes in analogous ways in other GVCs (e.g., Bakker & Ritts 2018; Helmerch et al., 2021), extending the potential for actors to use common strategies of leveraging environmental governance concerns as part of struggles to appropriate value (Havice & Campling, 2017; Ponte, 2019).

So how might novel monitoring technologies affect dyadic and diffuse power relations? To address this question, we build on existing accounts of power relations in GVCs. We argue that monitoring technologies' effects are heavily conditioned by the prevailing property rights regime under which they are managed, which determines the degree to which the technologies are relatively open for adoption and transformation, as opposed to proprietary, limited to a few users' purposes.

In the following section, we review literature on GVC power relations, articulating the conceptual toolkit that frames our analysis. We then outline the methods we use to catalog emerging forest monitoring technologies in deforestation-linked GVCs, with a particular focus on the palm oil sector. We use this case to illustrate how the framework helps identify situations where changing technologies can reshape GVC power relations. Finally, we use the framework and our analysis of the deforestation case to argue that government provision of forest monitoring capabilities as a public good could support more inclusive GVCs.

Transactions and power relations in global value chains

Governance of environmental and social externalities is a key concern in deforestation-linked GVCs. As Havice and Campling (2017) argue, however, the concept of governance in the GVC literature has tended to focus on relationships between lead firms and others in the value chain, while in the literature on environmental concerns it refers to a more diffuse process of state and non-state control. To avoid unnecessary confusion between these two important but distinct usages, we focus our discussion on the more general concept of power, which we believe effectively encompasses both senses of the term.

In a seminal contribution, Gereffi et al. (2005) place power relations at the heart of GVC studies, asking how actors like lead firms can shape suppliers' behavior without vertical integration. This initial formulation of GVC power as the capacity to shape others' conduct directly or indirectly has led to numerous examinations of how power relations are a central factor in value distribution (Bartley, 2007; Helmerch et al., 2021; Ponte, 2019; Dallas et al., 2019; Raj-Reichert, 2020).

In one of the most systematic recent typologies of GVC power relations, Dallas et al. (2019) present a two-dimensional model (see Table 1). Their first dimension considers the number of parties involved in a power relation. Dyadic relations involve only two parties, while collective relations encompass many. The second dimension considers whether parties exercise power via direct interactions or broader structures. In the first case, one party immediately constrains another's actions, while, in the second, one party's actions change the overall environment, reshaping others' strategies. Combining these dimensions yields four ideal types of power: bargaining (dyadic-direct), in which two actors negotiate over the distribution of value; demonstrative (dyadic-diffuse), in which socially powerful actors establish informal norms others must follow; institutional (collective-direct), in which actors create formal rules of conduct; and constitutive (collective-diffuse), in which collective norms set the scope of acceptability.

	Direct	Diffuse
Dyadic	**Bargaining** Lead global value chain firm demands suppliers report on forest impacts Firms negotiate over prices that reflect costs of internalizing environmental externalities	**Demonstrative** Prominent social media influencers raise concerns about the impacts of palm oil on forests A large manufacturer commits to zero-deforestation supply chains, forcing others to compete
Collective	**Institutional** The Forest Stewardship Council (FSC) establishes new standards for genetically modified timber plantations The European Union passes legislation requiring proof of legal harvest for all timber imports	**Constitutive** Social license to operate comes to be understood to include more rigorous environmental protections Consumers' tastes change to favor recycled and reclaimed timber products

Table 1. Examples of four forms of power theorized in Dallas et al. (2019).

Oliveira, et al. (2021) and Foster and Graham (2017) point out that there remains a good deal to be done in the GVC and global production networks literature to study the intersection between digital technologies and power. To be sure, there is extensive research on how technology affects GVC production processes, reshaping some of the power relations outlined in Table 1. Work on digital technologies, for example, considers how firms can use them to control labor (Gerber, 2021; Rani & Furrer, 2021), expand sourcing location options (Butollo, 2021), or even create novel market structures with distinct power relations, as, for example, through the creation of platform ecosystems (Foster et al., 2018; Grabher & van Tuijl, 2020; Hartmann et al., 2020; Humphrey, 2018; Lee & Gereffi, 2020; Parker et al., 2014; Rehnberg & Ponte, 2017). There also have been numerous analyses of how changing technologies shape market entry and upgrading opportunities (Coe & Yang, 2022; Dauvergene, 2020; Hartmann et al., 2021; Li et al., 2018; Humphrey et al., 2018; Lee & Gereffi, 2020; Sako & Zylberberg, 2019).

Despite this rapidly growing literature, Oliveira et al. (2021) and Foster and Graham (2017) argue there remains a good deal to be done in the GVC and global production networks literature to study the intersection between digital technologies and power. While the above-cited studies, among very many others, have substantially expanded our knowledge of how digital technologies might affect the distribution of value in GVCs, they generally address only the upper-left-hand corner of Table 1. In other words, the existing literature on digital technologies and power focus almost exclusively on dyadic relationships, most often between lead firms and suppliers. Oliveira et al.'s (2021) concept of "digital power," for example, describes the shift in bargaining power of suppliers vis-a-vis lead firms in more or less fully digitalized value chains.

And yet, as Foster and Graham (2017) argue, digital technologies do not simply alter the balance of bargaining power but can reshape relationship patterns throughout a production network. There are three more quadrants in Table 1, and digital technologies have the potential to affect each of them, as well.

Several studies suggest that a key impact of digital technologies is likely to be a substantial shift in transaction costs (Deng et al., 2022; Lehdonvirta et al., 2019; Oliviera et al., 2021), and we argue that this is a key mechanism by which they might reshape GVC power relations. Gereffi et al. (2005) characterize GVC transactions by their complexity, which is how much information exchanges require, and codifiability, how easy it is to standardize information exchanges, using these characteristics to make predictions about likely value-chain structures. Digital technologies affect both these factors.

First, as technology makes it easier for distant actors to observe problematic elements of the production process, this new visibility can increase civil society or other actors' power to demand better behavior (Havice & Campling, 2017; Raj-Reichert, 2020). In the case of deforestation-linked GVCs, for example, there are several examples of civil society organizations using satellite monitoring tools, Mighty Earth, the NGO with whose work we started our discussion, has been particularly active in this regard (Mighty Earth, 2020). Capabilities like these make downstream firms' purchases increasingly risky and, therefore, complex.

Second, these increased requirements require more complex transactions, as it becomes necessary to demonstrate that upstream production processes meet new expectations about the production process (Strange & Humphrey, 2019). This might mean providing evidence, for example, that livestock in a firm's supply chain were not grazed on areas that were until recently part of the Amazon rainforest.

Third, affected downstream firms will need to respond to this increased complexity, which will entail some transaction costs (Acquier et al., 2017; Strange & Humphrey, 2019), as well, potentially, as some upgrading opportunities (Lehdonvirta et al., 2019). Firms might respond by seeking certification under one of the many commodity roundtables or similar ecolabels or by trying to exploit blockchain technologies to provide rigorous proof of their own sustainability bone fides. However, the same technologies that make it easier to police suppliers' forest cover, however, monitoring technologies also make transactions more codifiable. In 2018, for example, the Roundtable on Sustainable Palm Oil (RSPO) adopted a new model for identifying forests for conservation on member plantations that uses satellite data and automated processing to simply and formalize the private standard's requirements (RSPO, 2018).

How shocks to the structure of a GVC's transaction costs are likely to play out will necessarily be contextually contingent (Havice & Campling, 2017). One consideration is what Havice and Campling (2017) call "interfirm strategies" - the localized solutions firms take when faced with specific challenges. Strange and Humphrey (2019) argue that firms' strategies for addressing risks arising from complex and hard-to-codify transactions will depend on the power asymmetry they enjoy vis-a-vis other value-chain actors (though we should note that technological changes may mean that asymmetry is at times uncertain or unstable). On the one hand, lead firms, or, sometimes, coalitions of mid-tier firms, enjoying high power asymmetry can impose requirements through stringent contracts. This approach would remain firmly in the realm of bargaining power as outlined in Table 1. On the other hand, downstream firms might opt for Table 1's lower-left-hand quadrant, adopting institutional solutions either because power relations are more balanced, because institutions like certification standards provide more brand credibility in external audiences' eyes (Potoski, 2017; Potoski & Prakash, 2005, 2013), or because they want to economize on transaction costs.

Whether they select a bargaining or institutional strategy, downstream firms can still use these approaches to push compliance costs onto suppliers (Acquier et al., 2017; Havice & Campling, 2017; Gibbon, 2003; Ponte, 2019; Strange & Humphrey, 2019). Should this happen, a second factor, relating to prevailing digital technologies' institutional characteristics, becomes relevant. This has to do with the extent to which the technologies available to help codify the more complex transactions are open (meaning publicly available for use, transformation, and reuse), versus closed (meaning proprietarily available only to certain users at cost). While there are some legal lines between open and closed technologies in different legal systems, in practice it is better to think of the distinction as a sort of continuum between, on the one hand, an ideal type open technology, the techniques for whose use are freely available to anyone, and the physical resources for whose use are publicly provided, and, on the other, an ideal type closed technology, the techniques for whose use are a closely guarded secret, available only to a select few at high cost. Something close to the ideal-type closed technology might be the formula for Coca-Cola. If there were ever a recognized and publicly supported right to Internet access, then maybe Wikipedia or OpenStreetMap would be an ideal-type open technology.

More open technologies are more likely to affect constitutive power, as they facilitate diffusion and reuse (Laplume et al., 2016; Rehnberg & Ponte, 2018) and can innovate at lower cost than proprietary sources, due to volunteer labor and distributed expertise (Hemmi & Graham, 2014; Laplume et al., 2016). Constitutive power, recall, is the power resulting from the creation of novel norms. A good example of how openness can contribute to constitutive (as well as bargaining) power is the Earth Defenders Toolkit (https://www.earthdefenderstoolkit.com/home/), a suite of geographic information science (GIS) tools created by Digital Democracy intended to facilitate community mapping in areas without Internet access. Backed by a coalition of NGOs focused mostly in the Amazon, Earth Defenders Toolkit relies primarily on JavaScript, and all the underlying code is freely available on GitHub. The suite's main app, Mapeo, is designed to support geospatial data collection with mobile phones even without an Internet connection. It uses OpenStreetMap (https://www.openstreetmap.org), a crowdsourced global geospatial database similar to Google Maps, which, as its name suggests, is also open and freely available. The freely available, open software packages upon which it rests allows the team of workers and volunteers that support Mapeo and the Earth Defenders Toolkit as a whole to use geospatial technology to facilitate indigenous communities' efforts to make recognition of traditional land rights a more generally respected norm.

Closed technologies, conversely, should boost demonstrative power, as more affluent or branding-motivated firms are more likely to be early movers. Recall that demonstrative power is the power a firm enacts when its practices set new standards that other GVC players must follow in order to remain competitive. A good example of this mechanism at play is the chocolate firm Tony's Chocolonely's use of the supply chain traceability firm ChainPoint's proprietary blockchain-based platform to trace cacao beans from its source cooperatives (Pannekoek, 2018). The firm explicitly frames its market strategy as an effort to use traceability as a means to raise awareness and challenge other chocolate firms to eliminate modern slavery from their supply chains (Tony's Chocolonely, 2022).

If downstream firms are able to shift transaction costs upstream, the characteristics of the available technologies for GVC governance become doubly relevant. To the extent that a technology is open and relatively easy to adopt, it could be a boon for smaller upstream operations. Effective and accessible signalling mechanisms can help lower information asymmetries, potentially empowering producers to signal the quality of their work and capture more value (Lehdonvirta, et al., 2019). Granted, as Foster, et al. (2018) demonstrate in the case of information technologies' impacts on African GVCs, technological uptake capacity can be an important constraint on producers' capacity to take advantage of these opportunities. Nevertheless, as the Earth Defenders Toolkit example demonstrates, even in this case more open technologies are more likely to be of help, as other actors can generate more accessible tools from less accessible open ones. Conversely, if the technology is proprietary and costly to access, larger, more well-resourced, operations are the likely beneficiaries.

We provide a schematic summary of these considerations in Figure 1, focusing on the case of advances in digital monitoring technologies. While the diagram uses a series of arrows to connect the different components of the framework, this is not meant to imply that these relationships are straightforwardly deterministic. Rather, they are simply intended to help guide the reader through a schematic of the possible implications of the conceptual analysis undertaken in this section, considered as a whole. We use this framework to structure our discussion of applications of novel monitoring technologies in deforestation-linked GVCs.

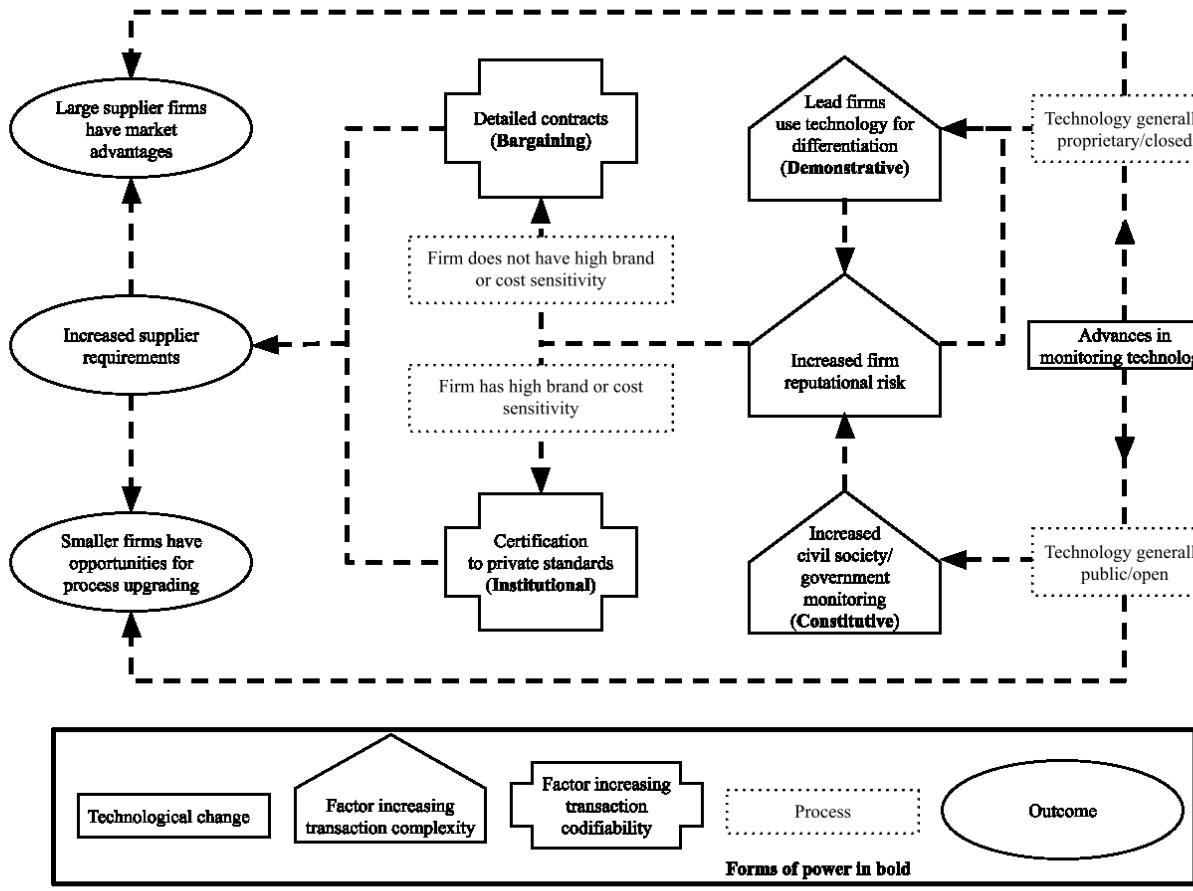

Figure 1. Schematic representation of conceptual framework. The chart reads from right to left, starting with the "Advances in monitoring technology" box.

Methods

Our interest in deforestation-linked GVCs emerged from our own experiences working on aspects of sustainability certification in the palm oil GVC, in which novel digital monitoring technologies were being applied, over the past seven years. In the summer of 2017, the first author began an interview project focusing on everyday work in transnational environmental certification organizations focused on land use. As part of this ongoing project, interviewees were asked to consider any recent or upcoming technologies that made their work easier or they anticipated being transformative. These interviews, 16 in number at the time this analysis was conducted, were conducted via Skype or Zoom and, with the interviewees' permission, recorded and transcribed. From February - August 2020, the second author conducted 21 interviews with

26 representatives of palm oil producer companies, consumer goods manufacturers, retailers, investors, NGOs and palm oil sustainability consultants as part of a project examining transparency and traceability tools and platforms. Interviews were recorded and transcribed. We thematically coded both sets of interviews to identify which and how digital forest-monitoring technologies were used by different GVC actors.

While the interviews addressed a range of technological tools for issues such as supply-chain traceability, client management, and communications, we focus in this analysis on satellite-based monitoring technologies. We chose this focus for two primary reasons. First, satellite monitoring technologies are a particularly unique aspect of GVCs that are tied to large-scale land use. Second, these technologies have clearly been the most politically important in deforestation-linked GVCs, allowing us to examine the connections between technological change and a wide range of power relations.

Based on technologies raised in the interviews and encountered in our previous experience, we consulted newsmedia, organization websites, and gray and academic literature to compose a list of primary technologies being developed and deployed and to collect case examples of how they were being used in deforestation-linked value chains. Here again, our analysis focused on the palm oil sector due to our prior experience and because, as the palm oil sector accounts for the plurality of zero-deforestation commitments, it is here that the applications of monitoring technologies were most advanced. Using these lists, we consulted academic literature on the technologies more generally, conducting individual literature searches for supply chain and zero deforestation applications using Google Scholar, Web of Science, and JSTOR databases. After assembling these sources, we examined cases to identify features of emerging technologies that could affect transaction codifiability and complexity.

These secondary materials allowed us to cross-check interviewees' assessments of the role of different technologies by assessing their actual applications, as well as the ways in which they were framed. However, we should note that the aim of this work was to identify the ways in which different actors were using these different technologies to affect power relations, and we cannot make claims about specific causal impacts of any of these technologies, per se.

Monitoring deforestation-linked value chains

Many stakeholders in deforestation-linked GVCs like palm oil suggest digital technologies are changing their work. One UK-based retailer, for example, expected that “technology is going to revolutionize the way we manage supply chains.” Another interviewee working for a carbon offsetting organization was more circumspect: “[R]emote sensing [satellite-based monitoring] is still hugely powerful, but we've not yet seen what it really can do, but it's definitely starting to play a role. [...] It's not quite there yet, but I think it's getting there and it's pretty exciting.” A recent Greenpeace International (2019, p. 23) report argues that “it has never been easier for companies to understand who produced their commodities and whether those suppliers are destroying forests," implying laggers are shirking an emerging norm. In this section, we take stock of the monitoring technologies to which these interviewees refer. We first consider the assemblage of technologies that underpin these possibilities and how this assemblage has been turned to the task of land-cover monitoring. We present a summary of these technologies in Appendix 1.

After outlining some of the most relevant technologies and applications, we present examples of the diverse ways firms and civil society organizations deploy these technologies in GVC power struggles. The interfirm and activist strategies that have emerged in the process are contextually complex, and it remains to be seen the dominant ways in which these technological changes may affect deforestation-linked GVCs. Nevertheless, our analysis demonstrates that these technologies are being used to reshape all four types of power relations outlined by Dallas, et al. (2019), not simply interfirm bargaining power.

The land-cover monitoring technological assemblage

The transformation in the capacity to monitor land-cover change at a distance hinges on the confluence, in the past few years, of publicly available satellite imagery, machine learning, and cloud computing. For several years, satellite systems have provided daily or weekly global imagery (Dubayah et al., 2020), and at smaller scales, light detection and ranging (LiDAR) observations, which use laser pulses to penetrate forest canopy cover, have helped researchers monitor forest degradation and carbon stocks (Leijten et al., 2020). While data availability has improved substantially, different image sources serve different purposes, and would-be users must be aware of significant tradeoffs. As an interviewee from a carbon offsetting organization explained, satellite monitoring "[S]eems a simple solution. But the level of resolution needed to get to a carbon credit, which has to be within certain confidence values," requires "trying to dial that in." In other words, while lower resolution data are sufficient for mapping tree cover, estimating carbon stocks requires higher resolution data, covering multiple wavelengths with frequent imaging. An interview from another carbon-market organization had a similar assessment: "we're pretty much limited in what we can use [satellite monitoring] for. If we can apply it for things like greater tree canopies or using it for proxies of biodiversity, I think that would be super powerful."

In order for satellite data to be useful, however, it is necessary to translate the wavelengths detected by remote sensors into meaningful estimates of carbon density or land-cover classifications. Machine-learning algorithms like regression trees, neural networks, and support vector machines have proven effective in these tasks, but they are computationally expensive (Hansen & Loveland, 2012).

Widely available cloud computing has made these algorithms more widely applicable. Google Earth Engine, launched in 2010 with the express purpose of supporting deforestation monitoring (Moore, 2010), is a prime example. Google Earth Engine users with some coding skill can process satellite images in the cloud, and the system underpins several platforms designed for non-experts. Users can conduct analyses with imagery and other scientific datasets from various sources (Kumar & Mutanga, 2018).

Applications

The technological assemblage described above has been applied in a variety of ways by organizations active in deforestation-linked GVCs. Some of these applications rely primarily on bespoke in-house solutions using at least some proprietary technologies. Others are intended to facilitate more general use mostly based on open technologies.

Applications relying heavily on proprietary technologies often use them to provide precision monitoring for firms' supply bases, particularly in the palm oil sector. For example, palm oil firm Golden Agri Resources uses satellite data alongside drone photography for land-cover monitoring and participatory mapping (Carbon Disclosure Project, 2019), and Airbus's Starling provides high-resolution forest surveillance services to help firms such as Nestlé and Ferrero monitor suppliers (Airbus, 2018). One civil society interviewee reported combining high-resolution land-cover data with intensive half-day on-farm visits as part of their work on a landscape-scale sustainability in Colombia.

Other organizations have been working to develop tools applicable and publicly accessible to a wide user base. Hansen et al.'s (2013) global high-resolution forest cover dataset, for example, is probably the most influential cloud computing application in the forest sector. It is a crucial component of the World Resource Institute's Global Forest Watch (GFW; http://www.globalforestwatch.org/), a platform that allows users to analyze forest change, fire occurrence, and other land-cover measures at no expense. Both civil society and private sector actors take advantage of the service. An interviewee from one oil palm firm, for example, reported "using [GFW] to follow deforestation to make sure that all our estates are keeping forest."

While useful for monitoring forest cover, current tools are less suited to assessing forest quality than applications that rely on more proprietary tools. Some platforms currently under development, however, rely on other satellite sources to facilitate advanced analyses. Radar Alerts for Detecting Deforestation, a project currently being developed for Indonesia and Malaysia, is intended to be a publicly available forest monitoring system using Sentinel-1 satellite data (World Resources Institute, 2019). The Sentinel-1 satellite system's frequent coverage and ability to penetrate cloud cover, the project participants argue, will encourage more rapid responses to deforestation events (Environment News Network, 2020). Backed by a substantial Bezos Foundation grant, the World Resources Institute (2020) is currently working to develop a similar system at a global scale.

Forms of power

As these assemblages of technologies and applications emerge, organizations active in deforestation-linked GVCs have been actively mobilizing them in various power struggles. There are several examples of firms' turning to these technologies as a resource to boost bargaining power, as a case involving Nestlé demonstrates. In June 2018, the firm was briefly suspended from the Roundtable on Sustainable Palm Oil (RSPO) due to reporting violations. Nestlé's immediate response claimed there were "fundamental differences in the theory of change that Nestlé and [the] RSPO [we]re employing to realise the ambition of a wholly sustainable palm oil industry," specifically around the firms' vision of "achieving traceability to plantations [. . .] through interventionist activities instead of solely relying on audits or certificates." These differences in approach can be traced back to the firm's partnership with The Forest Trust (now Earthworm Foundation), a response to the realization that Nestlé's RSPO certification provided them insufficient reputational protection. With Earthworm Foundation, Starling, and other on the ground partners, Nestlé conducts supplier assessments and maintains a transparency dashboard, giving the firm more direct leverage with its supply chain, and, at least some in the firm thought, making it possible to avoid using institutional power for reputational protection.

Approaches like these can be attractive because they can empower lead firms to monitor and control suppliers. An oil palm producer interviewee reported, "using automatic NASA fire hotspot [alerts] for all our estates [...]. at least you know and you can go and talk with the people [smallholders] and understand why it happened and how to avoid it." Dr. Gotz Martin of Golden-Agri resources, similarly, noted the firm would "now be able to see the real-time picture from above while working with our suppliers on the ground" (qtd. In Lyons, 2019). Following an analysis of proprietary data from Starling, Nestlé (2019b) determined forest loss to be driven by small-scale farming alongside "a decrease in deforestation led by large-scale plantation companies," redirecting deforestation concerns to these operators. Investors are also beginning to leverage these tools to monitor their debtor firms. One interviewee, for example, expected their satellite monitoring work to "be very helpful to do much better, much quicker checks for deforestation issues [. . .] to have more evidence of these types of breaches of our policy and being able to more quickly discuss that with the companies."

Forest monitoring technologies, however, are being employed far beyond standard bargaining struggles. They are also useful for enacting constitutive power. As the quotation from the Greenpeace International report with which we began this section demonstrates, the mere availability of these technologies empower NGOs to call on firms to make transparent forest monitoring a norm. Lead firms in the palm oil value chain are already responding to reputational risks by pushing for more monitoring (Gallemore et al., 2018), and investors are also concerned about civil society's growing capacity to name and shame particular firms. One investor interviewee, for example, explained their firm's interest in satellite-based monitoring as a way to determine if their debtors were causing deforestation "instead of waiting for the NGO reports to come out [...]."

Supporting these efforts to pressure firms to make good on emerging zero-deforestation norms, several organizations track and score firms' activities. The Zoological Society of London's Sustainability Policy Transparency Toolkit (SPOTT) benchmarking platform, for example, tracks sustainability reporting commitments in the palm oil, timber, and rubber sectors and includes satellite monitoring as a normative feature of sustainability management. Supply Change, an online database managed by ForestTrends, similarly, provides publicly available resources monitoring firms' commitments and progress toward reduced-deforestation supply chains (Donofrio et al., 2017).

In response to growing normative pressure, some firms turn to the institutional power of private standards. These standards, in turn, are actively investigating ways to use emerging technologies to make their activities more efficient. Our interviews indicate that secretariat members in some sustainability certifications have begun discussing using digital technologies to automate inspection or on-farm monitoring procedures, concerns that have become more urgent amid the COVID-19 pandemic (Castka et al., 2020). Several interviewees working for environmental certification organizations hoped public data and cloud-based platforms would make it easier to monitor certified operations or, perhaps, go beyond certification as currently practiced. Yet they are also pragmatic. One interviewee working for an organization focused on agricultural certification, for example, pointed out that many remote technologies that could be useful for tracking actual on-farm activities would at least rely on mobile phone service and that face-to-face interactions remain central to effective assessments.

An alternative response is to turn to proprietary tools and data in an attempt to garner demonstrative power. When announcing the Radar Alerts for Detecting Deforestation system, for example, Benjamin Ware, the Nestlé's Global Head of Responsible Sourcing, declared that "no longer can anyone claim to be unaware of the deforestation risks around their supply chains" and that the new system would "bring accountability and transparency across the industry" (qtd. in Nestlé, 2019a). Larger firms may opt for more exclusive and cutting-edge technologies, distinguishing themselves from competitors. Starling's service, used by firms like Nestlé and Ferrero, for example, features 1.5-meter-resolution data. Though impressively precise, such detail is unnecessary for practical forest-cover monitoring. One palm oil supply chain and sustainability consultant interviewee echoed this point, noting clients' interest in "radar technology, which is often better, because it can cut through the cloud cover and [provide] daily monitoring," despite not really knowing what to do with the resulting data.

In short, new forest monitoring technologies are being used as resources for all of Dallas et al.'s (2019) forms of power. As these technologies (and deforestation-linked GVCs) are rapidly evolving, it is difficult to discern a general direction in this complex system. However, it is possible to reflect more broadly on how these different interfirm strategies might affect one another and what this might mean for future sustainability efforts in deforestation-linked GVCs.

Emerging pathways for forest monitoring

Digital technologies seem poised to reshape power relations in deforestation-linked GVCs, but just how is highly contingent. Our stocktaking provides several examples of the processes outlined in Figure 1. In contrast to Weber and Partzsch's (2018) fear that traceability on its own might empower more well-resourced GVC actors vis-a-vis marginalized ones, we suggest the outcome depends heavily on the extent to which technologies are public and open, as opposed to proprietary and closed to many.

Figure 2 revisits our initial framework as applied to deforestation-linked GVCs, highlighting the implications of the proprietary path. While we present the open and closed paths separately, our empirical analysis shows they unfold simultaneously as activists and interfirm strategies rely on aspects of the forest monitoring technology assemblage in attempts to leverage different forms of power. Such a pattern would prevail if, for example, only very high resolution monitoring or bespoke digital tools came to dominate the space. That technological arrangement would be likely to favor lead firms' demonstrative and bargaining power, potentially raising entry barriers for smaller operations. Furthermore, as Figure 2 highlights, in a scenario in which proprietary technologies dominate, there may be less scope for civil society organizations to pressure firms. That is, if accepted tools are very costly and proprietary, they will also be more likely to be beyond the reach of all but relatively well-resourced civil society actors. Such an outcome would enhance lead firms' capacity to extract value from increased sustainability demands, a phenomenon observed in several GVCs (Havice & Campling, 2017; Ponte, 2019).

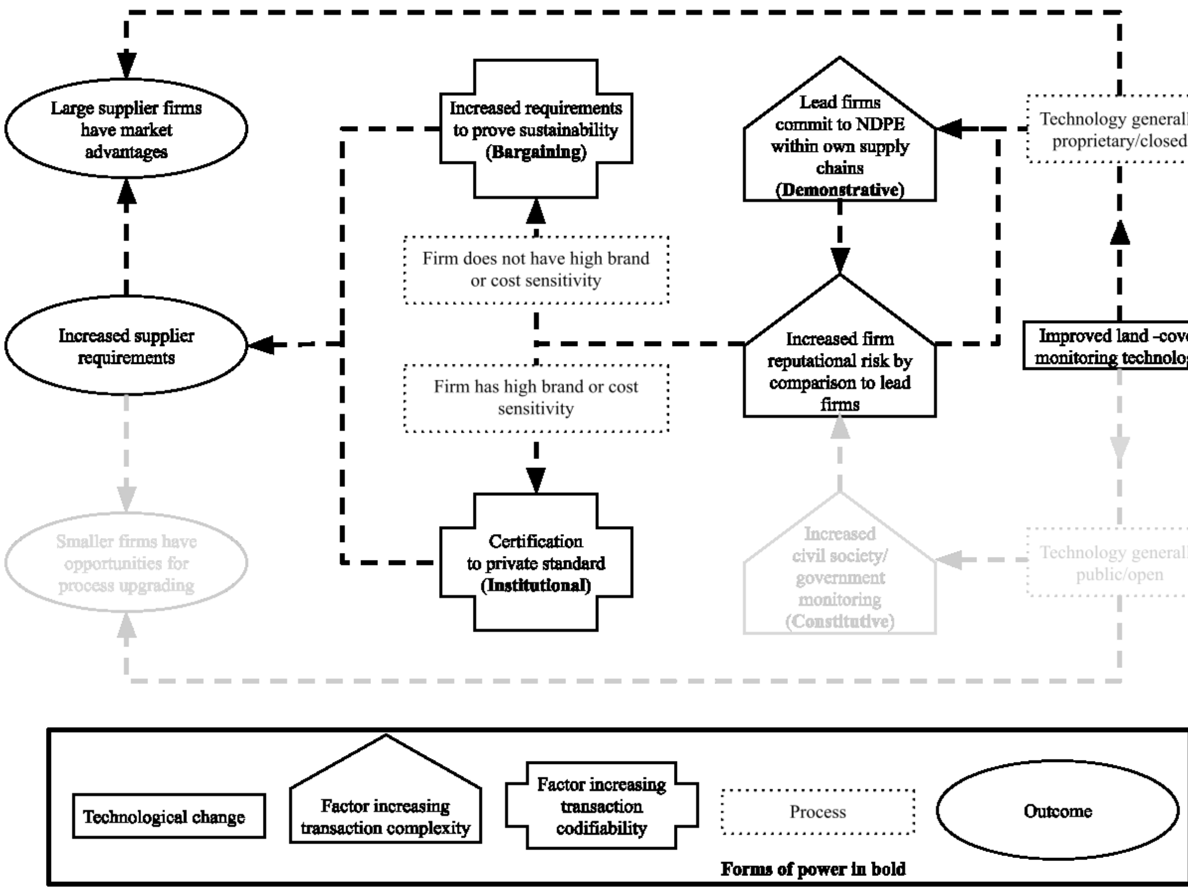

Figure 2. Conceptual framework, highlighting likely causal mechanisms in the case that dominant monitoring technologies are primarily proprietary.

Fortunately, open-access technologies currently form the core of most of the most influential monitoring technologies we have discussed, As the examples above illustrate, they are generally sufficient for civil society and advocacy purposes. To the extent that such technologies continue to be the core of deforestation monitoring and, ideally, become more user-friendly and widely accessible, we might see a situation more like that highlighted in Figure 3.

Figure 3's highlighted pathway suggests more open technologies might be less exclusionary while still providing opportunities to hold firms accountable. Participatory mapping, for example, has been incorporated into sustainability certification standards to recognize rights to land for local communities, as part of requirements for Free, Prior and Informed Consent processes (RSPO, 2018: 36), and in dealing with land disputes (RSPO, 2018: 41), though important questions remain about who is empowered and who disempowered under what conditions, and who gains and who loses. If they are sufficiently open and available, communities can use cloud, drone, and satellite technologies to document and stake their own claims to conservation and land management (Millner, 2020). Global Forest Watch and similar open-access resources also provide valuable resources for civil society actors, investors, and supply chain members to engage in monitoring.

Furthermore, open development of new code and apps for cloud-based platforms allows tools to be reused and transformed, potentially democratizing geospatial analyses (Kumar & Mutanga, 2018). As one interviewee noted, most actors need something more than "a system that needs a group of high-cost PhD-level advisors." Still, there are examples of actors upstream in value chains banding together to create their own institutions and technologies to help capture value (Havice & Campling, 2017), again illustrating the potential for public goods provision to support struggles over value distribution. The Earth Defenders Toolkit discussed previously is a good example of the potential for open technologies to be remixed to facilitate use by people for whom the underlying technologies were not designed. In this more optimistic scenario, accessible technologies might help level the playing field for communities and smaller operators, for whom sustainability strategies like certification are often inaccessible (Watts et al., 2021).

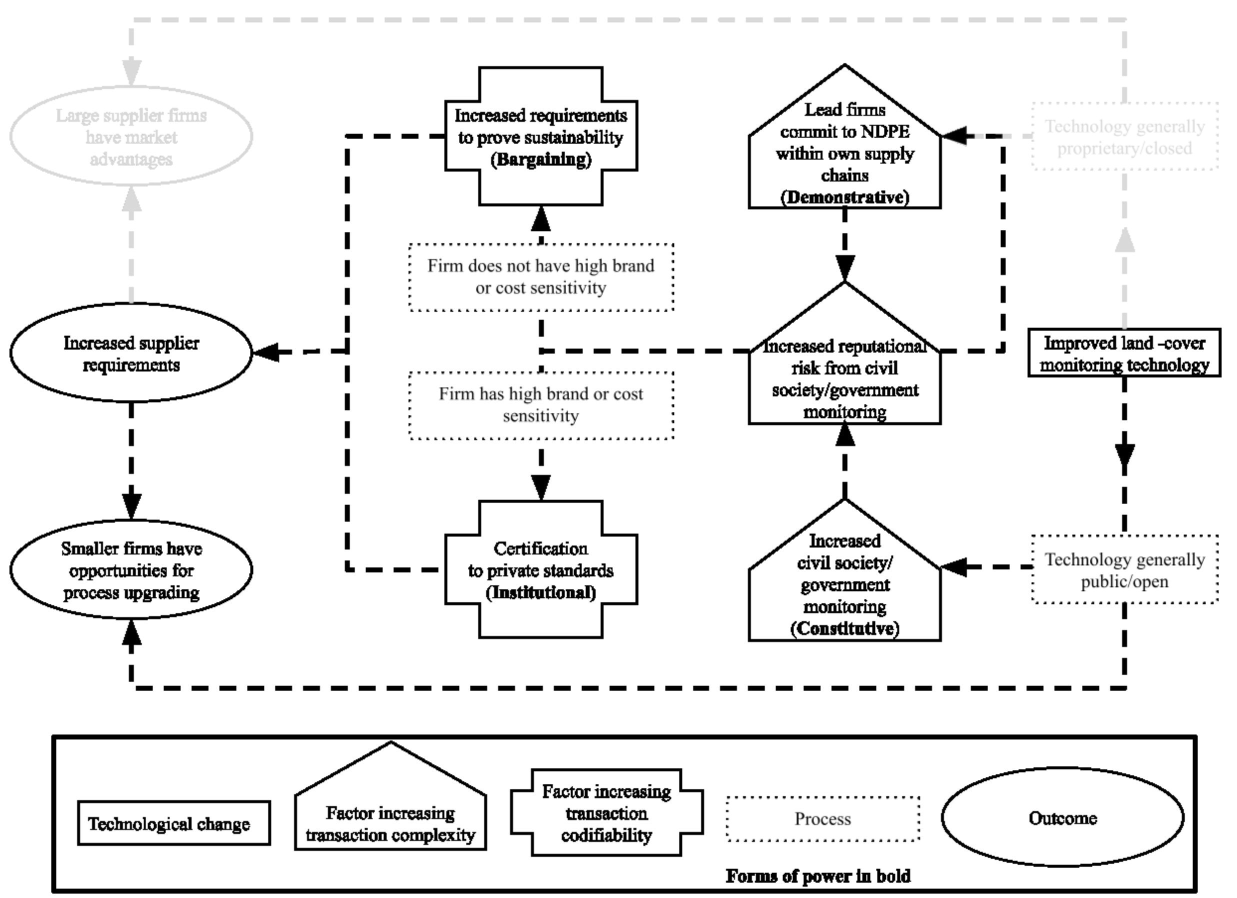

Figure 3. Conceptual framework, highlighting likely causal mechanisms in the case that dominant monitoring technologies are primarily proprietary.

It is important to be clear that the difference between open and proprietary technologies is institutional, not technological. That is, very, very similar technologies might be either open or proprietary, depending on how they are situated within property regimes. This point leads to two key threats to the open monitoring technology path, which would rely on institutional power to support public goods.

First, governments must continue to provide open satellite data. While much existing satellite data were produced by and held in the Global North, governments in the Global South can also play important roles. One interviewee from an NGO working on traceability reported that in their experience "the Indonesian government is very excited about big data [...]. It has a lot of excellent data itself, but a lot of [...] isn't easily accessible, so they see the technology behind [traceability tools] as something that would really enable them to move forward." Further capacity building and data accessibility from these sources could help combat the risks that North interests could dominate forest monitoring.

Second, the reliance on Google Earth Engine places the open technological assemblage at a single firm's whim. Beyond Google Earth Engine, these technologies are generally dominated by actors in the global North (Weber & Partzsch, 2018), which could privilege their concerns over those of tropical forest countries' residents.

Some stakeholders are already advocating such a public goods model. An NGO interviewee reported a chief investment officer of an insurance firm "saying on the number of occasions that ESG [environment, social, and governance] data should be treated as a common good." Unfortunately, they went on, data often are "privatized and marketed and [...] that increases the disparities, unless you consider that the market left on its own will magically integrate all of this data [. . .]." Our interviews suggest even well-resourced investors often rely heavily on openly available materials such as SPOTT. Reflecting on these sources' benefits, one investor interviewee noted, "What would be very helpful is to have more and more freely available information."

Conclusions

Our analysis points to some important considerations for research and practice. For researchers, forest-monitoring technologies highlight the need to extend GVC analysis from governance of technology to also encompass technologies for governance. From a more practical perspective, our analysis highlights the strengths and vulnerabilities of the emerging constellation of forest monitoring technologies, as well as how they might affect and be affected by diverse GVC stakeholders. Our review reveals a wide range of digital technologies used to support zero deforestation efforts in the palm oil sector and beyond. Despite the promise of "digital transformation," however, how these different technologies might affect deforestation-linked value chains is highly uncertain and, we argue, contingent on the degree to which open versus proprietary technological approaches come to dominate.

Of course, monitoring technologies on their own will not lead to sustainability in deforestation-linked GVCs. One supply chain consultant interviewee also reflected on this problem, explaining that when they asked their clients what they might do with daily forest cover updates, "they don't really know, and they will privately admit that they're not going to take action on the updates - they don't have the capacity [. . .]." Furthermore, applying pressure on bad actors requires being able to identify who owns what and from where materials are ultimately sourced, a challenge subject to an institutional and technological assemblage of its own.

Certainly, new digital forest monitoring technologies make it easier for external actors to hold firms to account for deforestation in their supply chains. Should the costs of being visible be pushed upstream, however, not only the environmental and social impacts of deforestation-linked global value chains, but also the distribution of costs and benefits accruing from monitoring these impacts, must be central ethical, policy, and private governance considerations. Based on our analysis of power dynamics within deforestation-linked value chains, we believe a critical variable will be the degree to which different technologies are openly accessible as opposed to proprietary and exclusive. Without directly addressing these considerations, the application of new technologies may risk (re)producing marginalizations in GVCs while also failing to address the urgent issue of deforestation.

While our empirical interest focuses firmly on somewhat unique deforestation-linked GVCs, we nevertheless believe this analysis points to a more general lesson for GVC studies interested in technology. Put simply, while the literature's current focus on technologies' impacts on dyadic bargaining relationships is understandable, there are three more forms of power to investigate (Dallas et al., 2019). While the distribution of value is more clearly at stake in dyadic bargaining relationships, transformations in constitutive, demonstrative, and institutional power relations may have the potential to reshape GVC structures and struggles as a whole. The ways organizations' strategies take advantage of emerging technologies in these power struggles could be a very beneficial avenue for future research.

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