Broken chocolate: visibility in cocoa supply chains

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Abstract

Purpose: This paper examines the potential of 'biomarkers' to provide immutable identification for food products (chocolate), providing traceability and visibility in the supply chain from retail product back to farm.

Design/methodology/approach: Research employs qualitative data collection, including fieldwork at cocoa farms and chocolate manufacturers in Ecuador and the Netherlands and semi-structured interviews with industry professionals to identify challenges and create a supply chain map from cocoa plant to retailer, validated by area experts. A library of biomarkers is created using DNA collected from fieldwork and the International Cocoa Quarantine Centre, holders of cocoa varieties from known locations around the world. Matching sample biomarkers with those in the library enables identification of origins of cocoa used in a product, even when it comes from multiple different sources and has been processed.

Findings: Supply chain mapping and interviews identify areas of the cocoa supply chain that lack visibility required for management to guarantee sustainability and quality. A decoupling point, where smaller farms/traders' goods are combined to create larger economic units, obscures product origins and limits visibility. These factors underpin a potential boundary condition to institutional theory in the industry's fatalism to environmental and human abuses in the face of rising institutional pressures. Biomarkers reliably identify product origin, including specific farms and (fermentation) processing locations, providing visibility and facilitating control and trust when purchasing cocoa.

Research limitations/implications: The biomarker 'meta-barcoding' of cocoa beans used in chocolate manufacturing accurately identifies the farm, production facility or cooperative, where a cocoa product came from. A controlled dataset of biomarkers of registered locations is required for audit to link chocolate products to origin.

Practical implications: Where biomarkers can be produced from organic products, they offer a method for closing visibility gaps, enabling responsible sourcing. Labels (QR codes, barcodes, etc.) can be swapped and products tampered with, but biological markers reduce reliance on physical tags, reducing the potential for fraud. Biomarkers identify product composition, pinpointing specific farm(s) of origin for cocoa in chocolate, allowing targeted audits of suppliers, and identifying if cocoa of unknown origin is present. Labour and environmental abuses exist in many supply chains and enabling upstream visibility may help firms address these challenges.

Social implications: By describing a method for firms in cocoa supply chains to scientifically track their cocoa back to the farm level, the paper shows that organizations can conduct social audits for child labour and environmental abuses at specific farms proven to be in their supply chains. The paper therefore provides a method for delivering supply chain visibility for firms serious about tackling such problems.

Originality/value: This paper provides one of the very first examples of biomarkers for agricultural supply chain visibility. An in-depth study of stakeholders from the cocoa and chocolate industry elucidates problematic areas in cocoa supply chains. Biomarkers provide a unique biological product identifier. Biomarkers can support efforts to address environmental and social sustainability issues such as child labour, modern slavery, and deforestation by providing visibility into previously hidden areas of the supply chain.

Keywords: Supply chain visibility, food security, biomarkers, DNA tracking, modern slavery, child labour, cocoa, quality management

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Joël Allainguillaume. Dr. Allainguillaume is an Associate Professor in Conservation Science (Molecular Genetics) in the Centre for Research in Biosciences at the University of the West of England, Bristol. To date, the majority of his research work has centred on the application of molecular and genomics approaches to address problems of agronomic, ecological and conservational importance. His areas of expertise focus in cacao improvement concerning the study of Cacao Swollen Shoot Virus (CSSV) and DNA barcoding, his interest here lay in the use of DNA barcodes for environmental, commercial and forensics applications.

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1. Introduction

Cocoa supply chains represent a $78bn industry beset by quality issues and threats to environmental and social sustainability for over a century (Hasian Jr., 2008). Reports suggest that the problems are worsening despite promises made by large focal firms. High demand and volatile global cocoa prices incentivize stakeholders to obtain beans from deforested regions and from lower quality 'bulk cocoa' cultivars, affecting established farmers and arresting sustainability gains (Fountain and Hütz-Adams, 2017). Commoditization of cocoa contributes to the challenge as supply traceability is routinely absent. A transnational organization, the International Cocoa Organisation [ICCO], was formed to protect growers' interests and an international standard – ISO 34101 Sustainable and Traceable Cocoa (ISO, 2017) - was developed. Despite industry self-regulation on child labour (ICI, 2020) widespread problems persist, leading executives to openly declare that "the cocoa supply chain as it works today is broken" (Ionova, 2018).

Supply chain management (SCM) is key to commercial success (Barratt and Oke, 2007), but increasing supply chain complexity has made monitoring inter-organizational activities more difficult (Williams *et al*., 2013). Supply chain visibility, defined by Francis (2008, p.128) as "the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events", enables managers to control key inputs and activities in these modern, fragmented supply chains.

Efforts to create upstream visibility have proliferated, with advances in technologies designed to enable greater supply chain visibility (SCV). Internet of Things (IoT) sensors can provide detailed contextual information (Parry *et al.*, 2016); radio frequency identification (RFID) provides product data and tracking; barcodes and quick response (QR) codes can provide links to external databases at reduced cost; blockchain-based solutions can be employed to provide data immutability. However, empirical research shows that issues remain to be overcome in delivering SCV, particularly linking physical and digital worlds, where digital infrastructures are lacking, or human input of data is employed (Rogerson and Parry 2020).

In this paper, we examine biological technologies that may provide a solution to the problematic digital-physical boundary. The use of biological markers ('biomarkers') for tracking food products is relatively novel. Biomarkers are unique chemical signatures derived from organic materials from either DNA, proteins, or isotopes. These signatures can identify an animal, plant, or even some

processing or storage stages where biological materials interact and are changed by their environment, e.g. fermentation, soil conditions or contamination (Knight *et al*., 2012). The approach shows promise for SCV as a library of biomarkers can be created to identify original source material and processing locations used. A product's biomarker readings may be taken and compared with library records, verifying a product's claimed source and potentially its routing through a supply chain.

To address the problem of visibility in cocoa we first examined the supply chain, ascertained the key areas of challenge, and developed a solution that employs novel biomarkers that can identify the origin of the cocoa from samples taken at any point in the supply chain. To develop understanding of the cocoa supply chain, interviews were conducted with industry professionals along the supply chain during a period of field work on cocoa farms in Ecuador and at a processing plant in the Netherlands. Interviewees gave detail on issues with visibility. We created novel biomarkers, a computer model of a unique DNA of a sample, from DNA collected from farms, processing locations, Bioversity International (an agricultural sustainability research organization), and 159 cocoa plant varieties from the International Cocoa Quarantine Centre located at the University of Reading (ICQC). ICQC holds the majority of known genetic resource of cocoa varieties around the world. This created a library of biomarkers against which to compare future samples. Biomarkers from cocoa taken either from samples within a supply chain or from finished products, can then be compared to the ledger of biomarkers created to identify origins. The paper proposes that biomarkers can provide enhanced traceability and facilitate SCV in food supply by offering a scientifically robust mechanism for proving cocoa provenance, allowing investigations of specific farms to demonstrate sustainable practices are in evidence on those plantations.

This study makes four contributions. First, the paper introduces one of the first examples of biomarkers to the supply chain literature and explains how the technique can help to solve stubborn traceability issues. Second, we add to the growing body of work on SCV where insufficient focus on social and environmental sustainability has left a gap in the literature (Williams *et al.*, 2013). Third, we build on the small but important literature on cocoa supply chains, where human deprivation and environmental destruction are rife and where extant research has neither mapped cocoa supply chains to effectively establish the root of these problems nor offered a viable solution. Finally, we contribute to institutional theory by demonstrating, using insights from within the cocoa industry, why the coercive and normative pressures on multinational chocolate firms have proven ineffective.

This paper begins with a literature review contextualizing the study in cocoa supply chains and their institutional pressures before reviewing literature on SCV. The science of biomarkers and examples from industry are then provided. Two research questions are developed. First, we contextualize the issue:

RQ1. What are the causes and impacts of SCV problems in cocoa supply chains?

We then expound a potential solution:

RQ2: How can biomarkers enable firms to overcome these issues of visibility in their supply chains?

The methodology section explains the mixed research approach, with qualitative analysis of primary data collected from interviews and secondary data. Results provide a map of cocoa supply chains, highlighting multinational chocolate brands' poor visibility and how biomarkers may provide a solution. The paper ends with a discussion of findings and the contributions and implications of the research.

2. Institutional theory and cocoa supply chains

Neo-institutional theory suggests that organizations adopt management practices which align themselves with their environments (DiMaggio and Powell, 1983). The coercive (i.e. legislative and regulatory), normative (i.e. stakeholder expectation), and mimetic (i.e. peer) pressures underpinning these processes have been shown to promote sustainable business practices as organizations seek legitimacy with their stakeholders (Adebanjo *et al.,* 2013).

However, though firms often send signals that reinforce their legitimacy with key stakeholders, there is also evidence that some firms take advantage of the information asymmetry between themselves and their consumers by signalling adherence to institutional expectations while failing (or refusing) to adopt sustainable practices (Gold *et al.,* 2017). This decoupling is illustrated in the cocoa industry, where the primacy of the profit imperative (McLoughlin and Meehan, 2021) means that decades of claims to protect children and the environment have not been matched by the actions necessary to improve conditions and explains why the industry has not produced sustainable supply chains (Carmagnac and Carbone, 2019).

Ninety percent of the world's cocoa is produced by smallholder farmers in geographically remote areas of tropical countries (Naranjo-Merino *et al.*, 2018), limiting the visibility of focal firms and therefore their ability to influence (i.e. coerce) upstream actors. Key growing regions in West Africa and eastern South America are in hard to govern areas (Moxham and Kauppi, 2014). Despite

government efforts, Ghana's centralized cocoa trade board, for example, has made limited progress in integrating supply chains and capturing downstream production processes (Ntiamoah and Afrane, 2008). A lack of visibility means there is no oversight for supplier codes of conduct. Assurance work is often left to third parties.

The persistent and pernicious harm of child labour has a long and documented history in cocoa supply chains and remains a significant issue in West Africa (LeBaron and Gore, 2020). In 1905 Cadbury sent an investigator to São Tomé and Principe to verify claims made by a journalist who had travelled in the Portuguese colony to inspect plantations (Nevinson, 1906). Joseph Burtt was so appalled by conditions, he lobbied for justice and for America to join Europe in boycotting São Toméan cocoa.

The cocoa supply chains still exploiting minors are also responsible for systemic environmental degradation in cocoa farming areas. Deep-rooted and long-standing problems persist with farming on deforested land (Ruf *et al.*, 2015) and in national parks (Odijie, 2019). Cocoa supply chains have been the subject of a small number of investigations over the last two decades, mainly exploring quality and process optimization (e.g. Saltini *et al.*, 2013). Gains have been made with regards to farmers' income and empowerment, but sectoral transformation has not materialized.

Consumer demand for sustainability has provided normative institutional pressure, which the industry has reacted to with the proliferation of sustainability certification options, making certifiers themselves vulnerable to market pressures (Bostrom *et al.,* 2014). While these certifications themselves help to drive institutional pressures (Kauppi and Hannibal, 2017), criticism of certifiers includes lack of financial reward for farmers, inability to remediate child labour, and uncertainty around compliance with standards (Lemeilleur *et al.*, 2015). Standards have imparted a degree of legitimacy to chocolate manufacturers, but the intractability of the industry's problems has meant that child labour and environmental concerns have not subsided (Ingram *et al.*, 2018).

While cocoa supply chains have received attention in the literature, including from an institutional theory perspective, there is a widespread acceptance of the difficulties focal firms claim to face in being unable to evaluate conditions on the ground in growing areas (Wiese and Toporowski, 2013). Fundamentally, focal firms are unable to establish the provenance of the crop they are buying because the commodification of cocoa, geographical remoteness of the farms, and 'mass balance' nature of its upstream trading. Sustainable certified cocoa traded on 'mass balance' means that the

amount of output sold as certified must be equivalent to the amount sourced as certified, taking account of production yields and losses. While this enables the rapid adoption of certified practices, it means purchasers cannot be sure of the provenance of their specific product because the method relies on matching volumes rather than tracking products through the supply chain (Gassler and Spiller, 2018).

Identifying where supplies come from and conducting targeted social audits is extremely difficult (Thorlakson, 2018). There are claims in the literature that multi-stakeholder initiatives brought about by normative pressures on firms have improved the cocoa industry's sustainability performance (Gold *et al.,* 2015). Such claims are contrary to reports that point to no change in child labour rates over the previous six years, with 1.5 million child labourers, about half of West Africa's 5-17-year-olds, working on cocoa farms (NORC, 2020). The literature offers little explanation of why the various institutional pressures on cocoa supply chains and chocolate-producing focal firms have failed to produce the results that might be anticipated given the scale of the industry's abuses and pressures for reform.

3. Supply chain visibility

Little research has been conducted on SCV in the context of cocoa despite the scale of the problems inherent in the industry. Gold *et al.* (2015) highlight the need for SCV metrics, and SCV has been found to improve socially responsible supply chain practices (Awaysheh and Klassen, 2010). SCV facilitates sustainability assessment in food supply chains (Hannibal and Kauppi, 2019) and is a key factor in achieving sustainability goals in agricultural supply chains (Kamble *et al.*, 2020). A lack of visibility has been found to reduce focal firm ability to manage sustainability of its raw materials (Karaosman *et al.,* 2018), introducing significant environmental and reputational risks, and reducing firms' ability to oversee non-compliant suppliers. Where farm data are not available, differentiation based upon sustainability practices, which would empower farmers, is lost (Haynes *et al.*, 2012). SCV-derived sustainability is demonstrably profitable in some contexts. In cocoa, certified sustainable chocolate commands a price premium and holds significant market share (Vecchio and Annunziata, 2015). Whilst firms offer guarantees of sustainability to increase profit margin, given the ubiquity of cocoa certification, claims may lack rigour (Haynes *et al.*, 2012).

Quality data is one of the most important factors in enhancing SCV. SCV brings integration of decision making, improved efficiency (Bartlett *et al.*, 2007), facilitates action and improves supply chain performance (Delen *et al.*, 2009). Technology-empowered SCV can create data availability,

improving perceived trust through reduced monitoring (Johnson *et al.*, 2013). SCV-enabling technologies such as internet of things (IoT), radio frequency identification (RFID), quick response (QR) codes and barcodes are used to link physical artefacts to digital worlds (Parry *et al.*, 2016). As cocoa from various farms is often mixed before fermentation, tagging and tracing technologies are powerless to assure provenance. Blockchain systems have contributed data immutability, helping create trust in data for visibility in food supply chains, but these systems rely on digital connectivity and often require human data input that can lead to error or fraud (Rogerson and Parry 2020). While research exists on various methods for delivering SCV, biomarkers are a novel approach that has yet to receive adequate attention in the literature.

4. Biomarkers for SCV

Food products are not digital, so provenance relies on packaging labels. Digital connectivity is not ubiquitous across food supply chains and the digital/physical interface is open to abuse (Rogerson and Parry, 2020). The development of effective forensic techniques to verify claims of provenance is required (Dormontt *et al.*, 2015). The biochemistry of natural products provides unique chemical traits that can be employed to distinguish them through the extraction and analysis of DNA, a natural biological barcode[1] (Jeanson *et al.*, 2011). DNA is extracted directly from the raw or processed food product by chemical methods. This DNA is then purified to isolate the ingredient, plant or microorganism DNA of interest (Özgen Arun *et al.*, 2013). Biomarkers derived from this DNA are particularly useful as they can determine whether a mix of species, such as fish or crop-based raw ingredient is present in a processed food product (Warner *et al.*, 2013). Biomarkers can change due to environmental factors such as chemical exposure or temperature change, but they are hardy and resistant to many industrial processes. This makes them potentially useful for SCV because samples can be taken at various nodes of a supply chain, allowing samples to be traced back to source by comparative analysis against a library of known biomarkers (Zolg and Langen, 2004). The use of DNA meta-barcoding in food has been developed in a number of cases, for example, conservation projects to identify fraudulent honey mixtures or to track contamination outbreaks (Hawkins *et al.*, 2015), but has yet to be applied in the chocolate industry to solve a supply chain problem.

The DNA of a cocoa tree is mirrored in the beans it produces and survives processing such that the biomarkers are identifiable in the final chocolate product. The DNA of cocoa plants differs from farm

[1] The review of the literature, methodology and findings on biomarkers here is written to be accessible to supply chain experts. For a full scientific and technical description of the proposed system, please see: https://uwe-repository.worktribe.com/output/6642792

to farm because of the unique local micro conditions, even between neighbouring farms (Lafargue, 2020). Cocoa plantations generally retain the same trees for over 25 years, meaning biomarkers registered in a library will be long lasting. Biomarkers can be created to identify the dominant bacteria from a cocoa fermentation process site as during the fermentation process local microorganisms such as bacteria and yeast populate the pulp (Papalexandratou *et al.*, 2011). These bacteria remain inside the cocoa bean even after later processing stages, providing additional identifying biomarkers that are unique to fermentation locations (Lafargue, 2020).

While there is a growing scientific literature on biomarkers, little research has been published on their use in supply chains. Extant papers focus on the science rather than broader SCM application or implications (e.g. Dormontt *et al.*, 2015). Both the limited evidence of the use of biomarkers and need for enhanced SCV found in the literature provide an opportunity to investigate them further.

5. Methodology

The three parts of our methodology – data collection, fieldwork, and the DNA testing – were conducted concurrently. A diagram demonstrating the various stages of these research processes is shown in Figure 1, below.

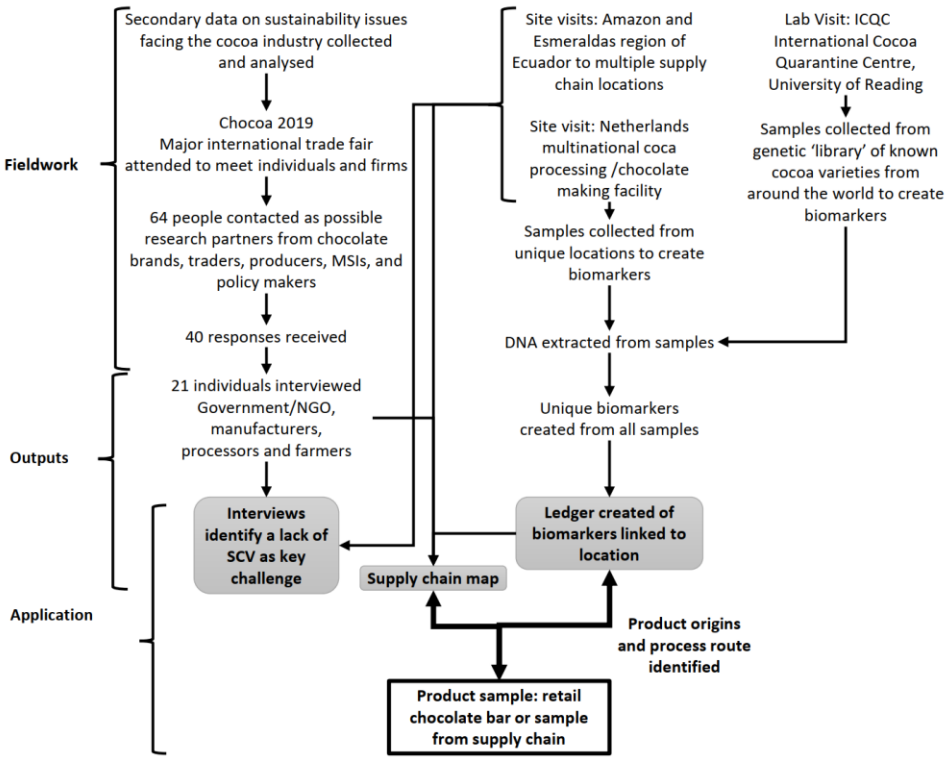


Figure 1. Research methodology in concurrent 3 parts: data collection, fieldwork, & DNA testing

The nature of the research necessitated care being taken to ensure the reliability, objectivity, and validity of our data. We achieved these important aspects by employing widely used methods from the literature. We adopted a semi-structured interview approach, asking broad, open questions, and allowing respondents to lead interviews to determine their experiences of issues with SCV. We used multiple sources from different geographies and stages of the supply chain to confirm our findings using triangulation through, for example, checking our supply chain map with respondents once it was complete (Eisenhardt and Graebner, 2007). Finally, we established transparency in our research design, including who was approached, who was interviewed and about what, and how we conducted our analyses, to be clear about how our data were collected and conclusions drawn through offering detailed, step-by-step insights into our process below (Aguinis *et al.,* 2018).

5.1 SCV interviews

An understanding of sustainability issues facing the cocoa industry began by reading reports published by major chocolate manufacturers, from multi-stakeholder initiatives (MSIs) such as ICCO and ICI, and the ISO 34101 Sustainable and Traceable Cocoa standard. National public bodies were approached, including Ecuador's National Research Institute for Cocoa, to understand government positions. Having identified the industry's major stakeholders, we attended the industry's Chocoa conference in February 2019 to meet individuals and firms.

Following this research, 45 people were approached representing chocolate brands, traders, producers, MSIs, and policy makers. Responses were received from 41 individuals from which 23 interviews were conducted. Twelve interviews, including eight conducted during the fieldwork, detailed in the next section, involved both face-to-face and telephone conversations. Two interviews were conducted solely in-person, and nine were conducted by email. Table 1 consists of an anonymized list of respondents for this paper.

Table 1. Interview Respondents

Respondents	**Organization type**	**Size**	**Respondent role**	**Date of collection**
Respondent 1	Cacao Farmer	Commercial	Cacao Producer	14/12/2018
Respondent 2	Trading and quality control	SME	Trader	13/03/2018
Respondent 3	Governmental	International	National research cacao coordinator	12/09/2018
Respondent 4	Governmental	International	Embassy Counsellor	16/05/2018
Respondent 5	Governmental	International	Trade Commissioner	23/08/2018
Respondent 6	Cooperative trader	Small-scale	Trader	07/08/2018
Respondent 7	Cacao Farmer	Small-scale	Cacao Producer and cooperative representative	23/08/2017
Respondent 8	Cacao Farmer and chocolate trading	Small-scale	Cacao Producer	07/08/2018
Respondent 9	Cacao Farmer	Commercial	Cacao Producer	12/04/2018
Respondent 10	Chocolate manufacturer	FMCG	Cacao and sustainability researcher & development	19/12/2018
Respondent 11	Chocolate manufacturer	FMCG	Technical supervision and quality assurance cocoa and chocolate	27/04/2018
Respondent 12	Chocolate machinery and products	SMEs	Director and sales manager	15/04/2018
Respondent 13	Research and Development - NGO	International	Research Coordinator	24/04/2018
Respondent 14	Policy making	International	Policy Director	25/02/2018
Respondent 15	Post-harvest and trading	SMEs	General Manager	19/12/2018
Respondent 16	Chocolate trader	Small	Chocolate trader - chocolatier	29/05/2018
Respondent 17	Chocolate trader	Small	Partner and Co-Founder	24/02/2018
Respondent 18	Consultancy and research	Multiple	Chairman - Director	22/02/2018
Respondent 19	Chocolate manufacturer	FMCG	Global Head Agronomy	14/12/2019
Respondent 20	Chocolate maker	SMEs	Director - Chocolate Maker	11/04/2018
Respondent 21	Consultancy	Multiple	Consultant – Chief chocolate correspondent	25/02/2018
Respondent 22	Research and academy	Multiple	Researcher - Director	18/12/2018
Respondent 23	Chocolate maker	SMEs	Founder – Chocolate maker	04/10/2018

To maintain independence, interviews were conducted by one researcher and analyzed by another (Weston et al., 2001). Interview data were used to produce a map of the cocoa supply chain to be used to understand visibility limits and their implications. The map was edited and validated during fieldwork described below.

5.2 Fieldwork

Fieldwork was divided into two stages: supply chain analysis and collection of biological samples. Fieldwork was carried out in Ecuador with Tree of Wisdom Chocolate Ltd., Cayapas Cooperative and the National Institute for Agricultural Research (INIAP). Farm visits were undertaken in the Amazon and Esmeraldas regions that produce premium quality native varieties. An Ecuadorian SME chocolate maker was visited to gain insight to regional supply chains, including bean origin, processing, facilities available, and local SCV difficulties. Finally, a grinding facility in the Netherlands belonging to a multinational firm was visited. The facility refines cocoa for use in the manufacture of various chocolate products. The visit provided insight to international supply chains, their mapping, blends of cocoa origins, quality drivers and sustainability requirements. Research identified process flows from bean to product, how beans are classified at each stage, how traceability of the supply chain is assessed, and SCV issues. Fieldwork allowed identification of traceability protocols employed and further characterization of factors that limit visibility.

We collected samples of beans and chocolate along the supply chain from unique locations in Ecuador in order to create biomarkers. Further DNA was collected from 159 reference samples from ICQC in Reading. The unique biomarkers derived from these samples provided the library of location of growth, fermentation, and production.

5.3 Analysis

An inductive approach to interview data analysis was taken, identifying generalizable themes as they emerged from the data (Abbasi, 2017), leading to initial categorization (Strauss and Corbin, 1998), and contradictions and outlier responses identified (Laughlin, 1995). Braun and Clarke's (2006) qualitative data analysis process was followed. To maintain the link between original data and emergent analysis, early levels of analysis were titled with direct quotes before grouping them together into codes (Layder, 1998) which became the first level of analysis. Themes not sufficiently supported by data were removed or merged with similar codes until two dominant themes emerged. The process was repeated three times to ensure consistency in coding and confidence in the analysis. The two major aggregate themes were: 'a break in the chain' and 'outsourced negligence'. The process by which these aggregate constructs emerged can be seen in Figure 2.

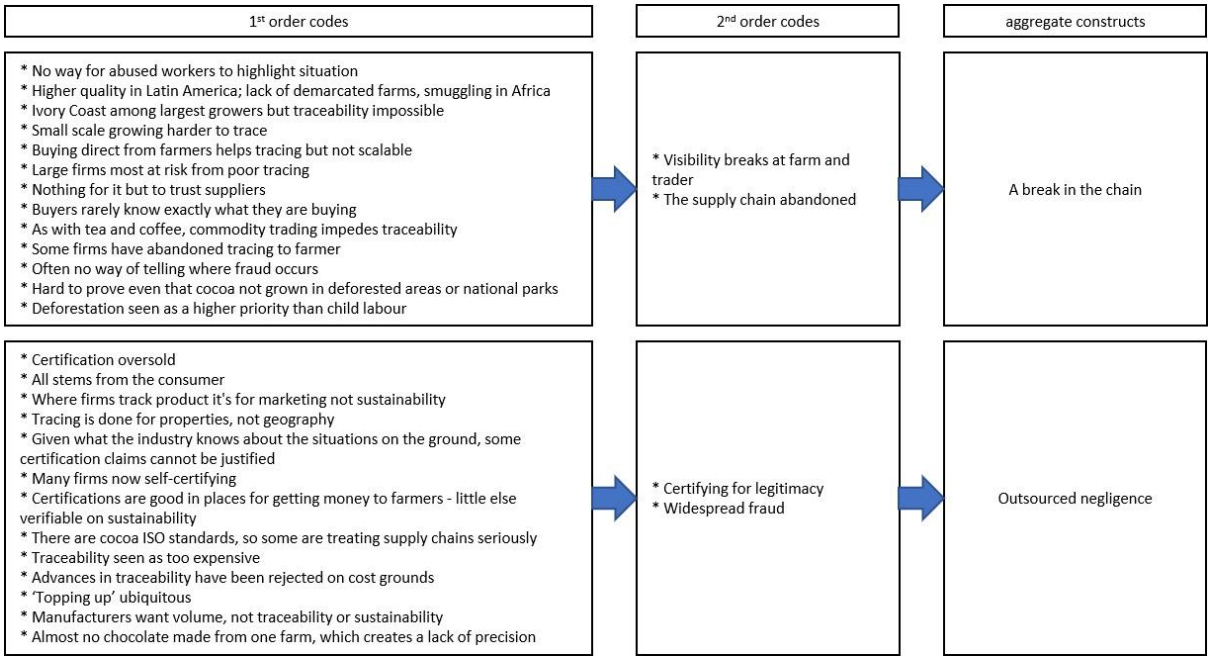


Figure 2. Inductive research process to create aggregate constructs

5.4 DNA extraction and method testing

We extracted DNA from fieldwork samples to create biomarkers and generated further biomarkers from DNA extracted from 159 leaf samples collected from ICQC, creating a global library of biomarkers (Lafargue, 2020). This reference set acted as a control, so that we could compare biomarkers in the reference set and the biomarkers we created from chocolate products. Generation of DNA sequencing data was performed by Exeter Sequencing Services. All downstream analysis, models and a biomarker database were processed through the open-source data analysis software Quantitative Insights into Microbial Ecology 2 version 2017.2.

We obtained chocolate samples including Nestlé© KitKat and Mars© Mars bar in duplicate from shops in Bristol and Reading in the UK. In addition, Bioversity International, Tree of Wisdom Chocolate Ltd., and Cocoa Hunters (a Colombian chocolate producer) supplied us with 45 samples of single-origin chocolate from known origins. The single origin samples were accompanied with metadata from the farm and fermentation areas used (farm name, type of genetics, type of analysis, machine that used for sequencing, etc.). We used the reference samples and fieldwork samples to create an extended library of unique biomarkers linked to location for audit purposes (Bolyen *et al.*, 2019). We used samples of single-origin chocolate from known origins to validate the biomarker matching method. We used retail samples to test the method on chocolate of unknown origin. Matches of biomarker and origins confirmed the methodology was sound and the process demonstrated traceability.

6. Findings: SCV challenges in cocoa

Our first research question, "what are the causes and impacts of SCV problems in cocoa supply chains?", is addressed through the insights gained into SCV challenges in cocoa supply chains and the reasons for the failure of institutional pressures to force change into the industry. We conceptualize the main themes of our findings as *a break in the chain*, which represents the discrete nature of points of failure in cocoa supply chains which prevent SCV, and *outsourced negligence*, which characterizes the nature of focal firms' abandonment of upstream operations and the problems that creates.

6.1 A break in the chain

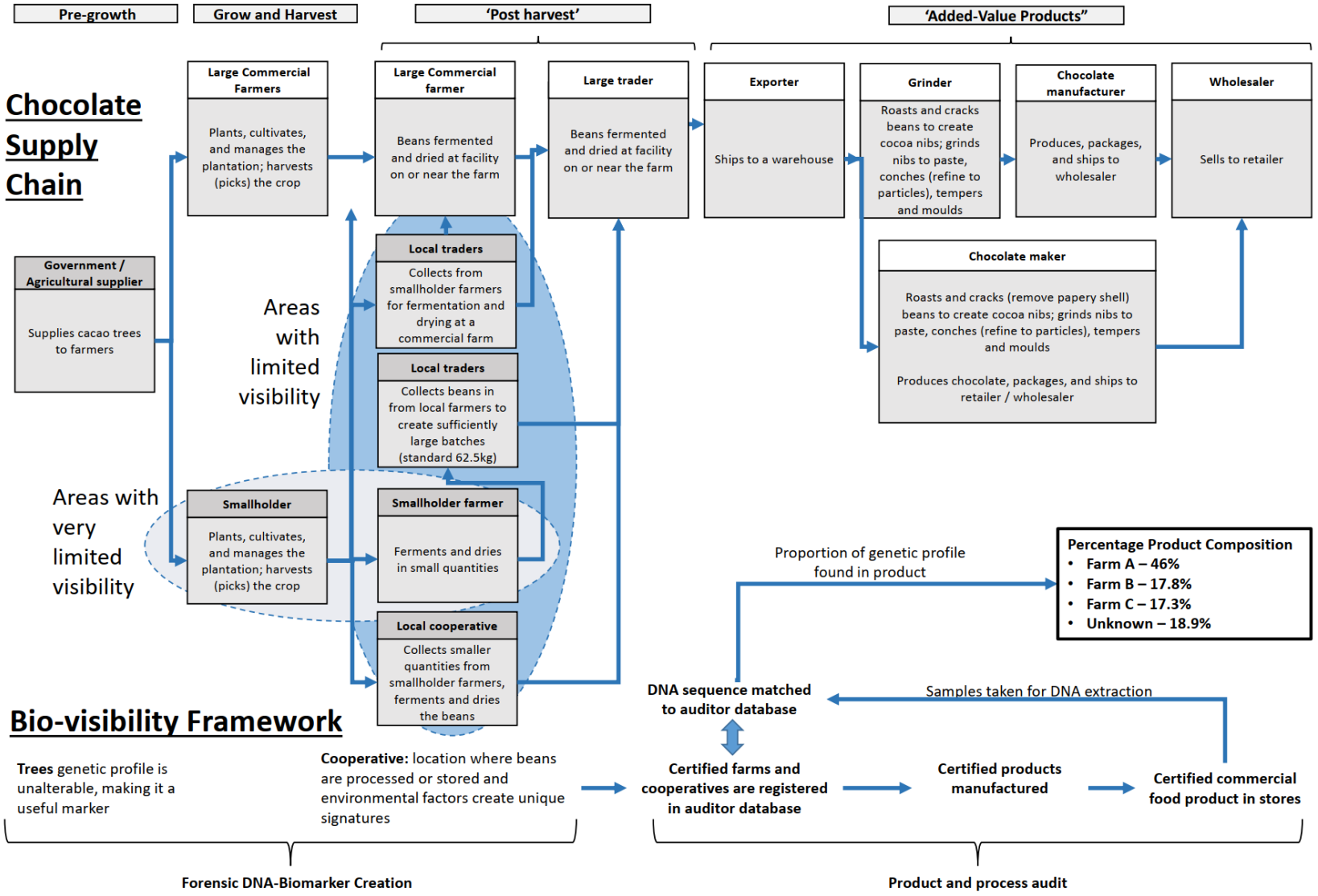
6.1.1 Visibility breaks at farm and trader

A map of the generic cocoa supply chain created from interviews and used to identify areas with limited SCV can be seen in Figure 3. Following the cocoa through the supply chain is challenging. Each organization has its own process depending on the variety of product to manufacture. However, most of these tiers have two variables in common. Both certified and uncertified cocoa are mixed during collection, with mass balance trading from this point creating another break in the chain.

Figure 3 shows the process flow of the supply chain of cocoa, from the farm to the retailer. The areas most lacking visibility are highlighted. Primarily, visibility is missing at farms, but it can also be missing for smaller traders. Below the supply chain we present the biomarker process, described in section 7.

From a SCV perspective, we find cocoa supply chains are fundamentally broken, and conceptualize this as *a break in the chain*. Interviewees at all stages of the supply chain said that other parts of the chain they work with suffer problems caused by a lack of visibility. Primarily, cocoa supply chains lack visibility at the farm level, where key problems of child labour, deforestation, and fraud occur. This makes determining the provenance of the raw product – a key factor in sustainable production – extremely difficult. A central aspect in broken cocoa supply chains are differences in the quality of infrastructure in cocoa growing regions. Not only does this severely limit SCV, the opacity of these parts of the supply chain precludes the development of effective SCV mechanisms, preventing local stakeholders from raising sustainability concerns.

Figure 3. Cocoa supply chain, from farm to retailer



We were told that, "*it is too expensive and too difficult to get people to places*" in the supply chain by a professional who summed up visibility in West African cocoa growing:

> "*The way that Ivory Coast works is not that traceable. There is a group of collectors called pisteurs [a middleman who travels between villages collecting the crop]. Some arrive on motorbikes, others in pick-up trucks with a 5-tonne capacity.*"
>
> 14/12/2018, Director, chocolate manufacturer

This method of crop collection speaks both to the physical and market infrastructure challenges for visibility. Some farms are so inaccessible they are most easily visited by motorcycle. Access is physically difficult and established groups who collect the harvest wish to protect their status. It is not in the pisteurs' interests to allow external oversight that might bring institutional pressures to bear at this key point in the supply chain. The costs and barriers to monitoring these farms are therefore significant. Such structural issues have a clear impact on SCV as to gain basic information on what is happening on the ground, firms "*need to specify the field where the cocoa is being harvested*" [respondent 14].

SCV failure caused by fragmentation of the early stages of the supply chain means a level downstream of the farm classifies the product. One respondent highlighted this nonsensical situation, stating "*a processor can show that the cocoa that was bought is sustainable; the buyer can see that it was sustainable; but not the farmer that produces the cocoa*." [respondent 14]. The post-harvest stage is as far into the supply chain as most interview respondents perceive current SCV achieves.

6.1.2 The supply chain abandoned

The starkest result of this break in the chain is that focal firms have effectively abandoned farm-level traceability. While this does not necessarily mean that farmers and their farms have been abandoned – the corporate social responsibility programmes of the largest chocolate producers continue to work with communities in poor cocoa-reliant areas – it does mean that those firms cannot know which farms their inputs come from, and therefore cannot carry out targeted social audits to uncover child labour and environmental degradation caused by their raw materials. A researcher at an international NGO asserted that, "*traceability starts at the moment the cocoa leaves the farmer*" (respondent 13). We also heard limited examples from Ivory Coast where firms

were abandoning traceability at the later trading phase of the supply chain, largely because of "*a lack of delimited farms and… smuggling*" [respondent 19], further limiting focal firms' ability to manage the social and environmental sustainability of their inputs.

The inability of focal firms to drive visibility down to farms has led to their effective surrender of this part of the supply chain. This means that firms do not have data from which to take decisions linking product to raw material. There appears to be a widespread withdrawal from sustainability efforts beyond third party certification of cultivation as companies trace the product only from the post-harvest phase where bean crops have been consolidated into fewer, larger pools. Many of our respondents spoke of "*abuses in the supply chain*," that "*there is child labour*," and that buying from deforested land is a problem. We found an industry aware of the fact that certification schemes are either not aimed at solving or cannot solve these problems. This points to the need for new solutions that provide visibility into supply chains so firms can highlight problems and begin to solve them.

6.2 Outsourced negligence

6.2.1 Certifying for legitimacy

Focal firms' lack of SCV has led to a reliance on certification schemes, meaning sustainability outcomes remain beyond the direct control of the large chocolate manufacturers. Firms are aware that certifiers have little additional visibility, but they offer legitimization as a trusted 'partner', absolving the focal firm of (at least some) responsibility. We were told that, "*There are literally tons and tons of Fairtrade certified cocoa on the market – that's not a special thing*" [respondent 19]. In outsourcing sustainability assurance, focal firms may have simply handed control and knowledge to certifiers in exchange for a legitimising mark on their products. Firms offer assurances to customers that what they are eating is sustainable. A Director at an NGO engaged in industry research told us "*there is more cocoa that is certified than consumers that want certified cocoa*" [respondent 13]. In their rush to certify rather than take meaningful action, firms have created an oversupply of 'certified' cocoa that may or may not actually be produced sustainably.

There was a tendency among interviewees to blame the consumer for the lack of diligence in the process. As one respondent explained "*tracking is more about storytelling [than genuine upstream visibility]*" [respondent 16]. Describing their firm's approach to SCV, one interviewee claimed that they are simply responding to customers.

> "*Consumers understand certifications; they don't understand assurance. It's too complicated for them to understand, so we have to make what our customers ask for. I don't believe in UTZ, I certainly don't believe in Fairtrade. I also think organic [status] in cocoa, hmm, I don't believe in organic in cocoa. I don't believe that farmers are better able to produce [sustainably], but that's what the customer wants so that's what we have to make*."
>
> 19/12/2018, General Manager, trader

The firms in our sample were focused on gaining third-party logos to satisfy consumers, but there was scepticism about what these schemes offer. A consultant at a trading firm told us that within certification there remained "*scope for fraud, confusion, losing traceability*" and noted that current certification schemes are not easily scalable and reliance on them would not reform the industry.

> "*I think most people now believe traceability via certification is maybe not the best. In general, certification was over-sold, but people realize that certification is not going to tackle these big issues at scale. Remember all of these certifications were niche activities, and the industry is trying to apply them at scale… None of the certification schemes are going to solve the poverty, deforestation, child labour and issues that need to be solved*."
>
> 25/02/2018, Consultant

One senior industry consultant stated that "*Western values*" represented by certification and traceability are important to 'us' but that the market is further distorted by pushing the cost burden of visibility onto the farmer. The farmer, as the economically least capable member of the supply chain, is required to have certification before they can trade with certain suppliers. In cases where farmers themselves do not pay, NGOs do so on their behalf. This creates a race to the bottom, with a market for cheap certification, "*but what that does is to disrupt an already distorted market*" [respondent 18].

Not only is the cocoa supply chain broken, but the industry is aware that the organizations tasked with assuring stakeholders of the ethical nature of the commodity offer little more than a legitimating stamp for which some charge the very stakeholders they claim to be protecting. This amounts to the abandonment of at-scale commodity traceability because SCV is too problematic to drive into upstream operations.

6.2.2 Widespread fraud

Focal firms' effective abandonment of early nodes in their supply chains has left those key regions open to widespread fraud, which reduces the ability of current traceability systems to ensure the provenance of cocoa inputs. Attempting to track the commodity only after it leaves the farm means that focal firms cannot understand issues at farms. The result is that, in the less-developed growing area of West Africa, rudimentary issues such as "*a lack of delimited farms and a lot of smuggling*" (respondent 14) are accepted as extensive.

One specific issue pertains to the shipment of harvests. As cocoa is collected in bags of a uniform weight, farmers are able to 'top up' bags of supposed higher quality varieties of cocoa with beans of an inferior quality, simultaneously threatening quality and pretending traceability to specific farms.

> "*Fraud starts with the farmers. If a farmer has both CCN-51 and Nacional cacao on his land, he has a financial incentive to mix the CCN-51 with the Nacional cacao, especially if he's getting paid a price based on Nacional cacao. In this way, he increases the volume that he sells at the higher price. This is the first point of contamination, and the hardest to control, because there are thousands of growers, and the mixing happens in the privacy of their own farm*."
>
> 07/08/2018, Director, farmer and trader

At a trader level, the issue becomes more acute. A policy Director informed us that "*many cooperative owners travel around the countries to buy non-sustainable cocoa to complete the yield. In Africa it would be necessary to delimit the farms, count the trees, and then to develop the [genetic] markers [in order to overcome this]*" [respondent 14]. As the number of intermediaries is lower than the number of farms, monitoring at the intermediary level is lower cost, which explains the abandonment of the farm as a unit of investigation. However, fraud is not restricted to the local level. One respondent informed us that fraudulent activity can occur cross-border due to price differences between cocoa with different country of origin:

> "*If you claim [that your product is from a certain] country – there are specific issues about Ecuador and Peru, or Ghana and Ivory Coast – you will have cocoa smuggling from one country to another one*."
>
> 19/12/2018, industry consultant

Without SCV at farms, physical contamination of qualities is rife. Without the ability to guarantee single farm provenance, focal firms and certifiers cannot know which farms to conduct social and environmental audits on, and abusively cultivated cocoa will continue to thrive. Fraud is a potentially endemic problem that cannot be solved without visibility at all levels of the supply chain. Infrastructure differences, tracing only from the trader level, and cross-border fraud describe a supply chain which we consider fundamentally broken.

The two major themes of broken supply chains and outsourcing certification could be portrayed as primarily issues beyond firm control. The locations in which cocoa is grown, particularly in Africa, are often remote and lack the local institutional strength or governance that might assist with tackling supply chain problems. The harvest's status, as a commodity traded in a similar way to tea, coffee, and other commodified products, makes markets opaque. However, the major chocolate firms are multinationals with the power to bring about transformational change. Many of our respondents stated that sustainability and public image are important to firms who buy most of the cocoa from these supply chains. However, the work and the costs involved in monitoring hundreds of thousands of different farms creates a barrier to ethical supply chain behaviour that requires significant executive attention. Our data demonstrate that SCV would be a step towards understanding these problems in depth and addressing them effectively.

7. Findings: Biomarkers as a solution

SCV analysis answers the first research question, identifying that the main visibility gaps in cocoa supply chains are during harvest, trade within farms, and when beans are gathered at cooperatives. This section seeks to examine the second research question, "how can biomarkers enable firms to overcome these issues of visibility in their supply chains?" We developed two novel types of DNA biomarkers to each provide a unique 'fingerprint' identity, one from cocoa trees at the farm and one from the bacteria which grow during cocoa bean fermentation. We identified a specific bacterium that was always present at fermentation. This was used to create biomarkers for different fermenter locations, corroborated with the visited cooperatives in Ecuador. Different sites have different processes and microorganisms, but a sufficient level of DNA sequence variation allowed us to distinguish unique patterns to identify each fermentation site. We found the bacterial biomarkers year on year in the same locations, giving longitudinal visibility of the microbial conditions of the facility. All biomarkers were recorded against locations, providing a register of the area of production.

When examining cocoa, we captured biomarkers and compared them to the auditable database, with matches identifying the source of the sample, hence giving location data. Our sample analysis also indicates the percentage of a biomarker (and hence group of cocoa trees) in a chocolate bar. As chocolate bars usually contain cocoa from many different sources, multiple biomarkers are detected, and an unsupervised machine learning model was constructed to identify the proportion of different groups in a chocolate sample. In tests, we identified biomarkers from a fermentation stage in Ecuador in finished products, including highly processed derivative cocoa products such as cocoa butter. Through biomarker analysis, we were also able identify specific beans from known trees in Ivory Coast that matched the biomarkers found in the chocolate in Kitkat (93.38%[2]) and Mars bars (81.73%) as it mirrored the genetic profile with high similarity.

Traditionally the design and testing of biomarkers is performed in a laboratory, where assessing the mix of beans in a cocoa bag can take months and a cost over £40 per sample. The novel approach described here utilizes next generation sequencing, decreasing the time of assessment to two weeks and the cost to less than £5 per sample. The main challenge with the process is having the specialist skills to understand and perform the whole the process.

8. Discussion and conclusions

In this article we ask what the causes and impacts of SCV problems are in cocoa supply chains and how biomarkers can enable firms to overcome these issues. We answer our first research question through interviews and fieldwork along global cocoa supply chains. We find that a *break in the chain* occurs where products are amalgamated to produce economic quantities of goods, making visibility of supply opaque before this point. Due to mass balance trading, those specifically wishing to consume only certified chocolate may likely be consuming cocoa from unsustainable sources. The second research question is addressed by providing an example application of biomarkers as a potential solution for cocoa provenance that reliably traces cocoa from farm to bar, giving visibility of supply such that physical audits may be made on relevant farms. While it is currently possible to audit farm practices in many areas, we explain why linking the farm audit directly to a final product is currently often not possible. We offer evidence that the supply chain visibility afforded by biomarkers established the link between the farm audit and specific products downstream. The method we outline here offers focal firms the opportunity to repair the *break in the chain* and address the *outsourced negligence* that we find in our data. We find that biomarkers can drive

[2] Bray–Curtis similarity; a statistic quantifying compositional similarity between samples.

genuine visibility into the supply chains of multinationals' products, allowing them to highlight – and therefore mitigate and remediate - child labour and environmental abuses at source.

Our study makes four contributions. We introduce one of the very first examples of the use of biomarkers for tracing processed food products and providing visibility of the supply chain. Biomarkers, as an intrinsic property of the product, overcome the particular challenge that physical tags of a product can be switched. Biomarkers held in a database also provide a secure link between the physical product and the digital world (Rogerson and Parry, 2020). We demonstrate a novel application of biomarkers from fermentation, where they are shown to be unique to particular locations and be persistent throughout later food manufacturing processes. Therefore, we extend the use of biomarkers for food conservation (Hawkins *et al.*, 2015) to show that it is possible to analyse a chocolate bar sold as 'sustainable', identify the farm on which the cocoa in the bar was harvested, some of its processing stages, and check that farm's working and environmental conditions.

Second, in explicating biomarkers, we add to the conversation on the importance of SCV. We supplement the literature with specific details on the causes and effects of a lack of SCV in the context of cocoa supply chains, a clear concern for SCM (Francis, 2008) and risk to supply chain performance (Mani et al., 2018). The reduction in uncertainty offered by SCV would be a clear benefit to chocolate manufacturers (Rao Tummala *et al.,* 2006). The inability of firms to see into their supply chains limits their ability to improve their performance on issues from child labour to raw material quality (Barratt and Oke, 2007). While firms in some sectors have spent significant sums driving visibility into previously obscured areas of their supply chains (Rogerson and Parry 2020), chocolate manufacturers rely on third-party certifiers. The friction in supply chains, particularly where actors have vested interests in preventing visibility, is a key obstacle to trust (Shapiro and Rosenquist, 2004), making visibility appear difficult to implement. In this respect, the method we explain in this paper also helps to solve issues of fraud, such as 'topping up', which have not been thoroughly investigated in the literature. Where Carter *et al.* (2015) postulate that distance attenuates SCV, we demonstrate a niche technique to overcome this problem. In doing so, we show that focal firms can better manage suppliers beyond their normal visibility boundary, alleviating the need to cascade standards by bypassing problematic areas of the supply chain (Gold *et al.,* 2020).

Third, we bring the SCV conversation into the small but important cocoa supply chain literature by using visibility to elucidate upstream problems in the cocoa industry. We present evidence from

global cocoa supply chains, where studies have previously been confined to single geographies. We supplement prior findings on the regional nature of major sustainability issues such as deforestation and forced labour (Odijie, 2019; LeBaron and Gore, 2020) while adding that many of the underlying problems causing these issues exist across regions. Respondents from all areas of the supply chain refer to 'child labour abuses', and much of the child labour in cocoa supply chains is on family farms (Berlan, 2013). Our evidence suggests that child labour appears to be a widely known and serious issue in cocoa supply chains, more broadly accepted within supply chains than previously acknowledged in the literature.

Finally, we contribute to institutional theory, which suggests that firm behaviours will be shaped by their contexts, and in particular by pressures within those contexts. Using insights from within the cocoa industry, we posit potential boundary conditions by explaining that the coercive and normative pressures on multinational chocolate producing focal firms have not resulted in successful efforts to end child labour and environmental degradation in cocoa supply chains. In finding widespread fatalism about these issues, we explain a condition to the theory espoused by DiMaggio and Powell (1983), demonstrating a passivity to institutional 'evasion' by suppliers (Soundararajan *et al*., 2018). We provide an example to corroborate Adebanjo *et al.'s* (2013) assertion that normative institutional pressures are more difficult to bring to bear in product supply chains in institutionally weaker regions. In this respect we show how the industry to some extent rejects normative consumer and coercive legislative pressures (Konstantas *et al.*, 2018) and, in doing so, explain how the profit imperative tends to dominate other pressures (McLoughlin and Meehan, 2021). Our data calls into question the role of MSIs, showing how little credence is given to, for example, Fairtrade, and other organizations whose remit is to demonstrate acquiescence to institutional norms (MSI Integrity, 2020).

There is evidence from over 100 years of failures to trace chocolate back to cocoa farms and address sustainability and slavery issues (Nevinson, 1906; LeBaron and Gore, 2020; Tomasella v. Nestlé USA Inc., 2020). A lack of SCV goes some way to explaining the persistence of pernicious supply chain issues such as modern slavery in supply chains highlighted by Crane (2013). However, chocolate firms could now investigate biomarkers and potentially implement full SCV. Responsibility for the suffering and damage caused by their supply chains, which they have known of for over a century, rests with the Boards of these firms. Despite decades of talk on child labour and environmental destruction, firms have failed to meet even their own targets, let alone eliminate the abuses from

which their profits derive. This paper proposes biomarkers as a cost-effective, scientifically robust method to accelerate work in this area.

8.1 Limitations and future work

There are limitations inherent in our study. The solution proposed identifies origin or highlights where origins are unknown. To produce visibility and sustainable production free from child labour requires audits of the farms of origin and creation of a database of DNA from those farms. The institutional pressure required from upstream producers and consumers, and subsequently funding, in order to pay for such audits remains uncertain, though the method may allow third parties to conduct their own tests. Though we have engaged with actors along cocoa supply chains, we have not interviewed key employees representing all the major chocolate manufacturers. We welcome greater engagement to gain further insights into the challenges and solutions they are developing, and discussions of the potential of biomarkers. Future research will seek to use our findings to build on research on visibility and sustainability in other areas of Supply Chain Management, study the barriers to adoption of biomarkers, extend our understanding of institutional theory by examining the industry's reaction to the tool, and examine how distributed ledger technology may help create trusted biomarker libraries.

8.2 Practical implications

Lack of SCV in cocoa supply chains is severely hampering chocolate brands' efforts to become more sustainable, maintain quality and reduce supply risks while protecting vulnerable communities. We propose that end-to-end SCV may be enhanced using biomarkers, helping to address many of the issues in current chocolate supply chains. By generating control databases of farms and cooperatives which are already certified or following sustainable principles, the method detailed here provides organizations with SCV to demonstrate to B2B and B2C that their product can be traced to farms known to be free of labour and environmental abuses. Cocoa industry leaders could mandate visibility, using biomarkers across supply chains, providing a lead for other industries with similar issues e.g. cotton, timber, fish (Scarano and Rao, 2014). There is precedent for chocolate taking a lead in reducing child labour from the case of Cadbury, originally a Quaker company (Nevinson, 1906), which might act as an example to the industry now. While little progress has been made on labour abuses in decades, there was once a time when chocolate executives were sufficiently moved by suffering to spend what was necessary to investigate the issue and publicize findings in order to bring about an end to that misery.

This paper was written as Black Lives Matter protests spread globally. As corporations and citizens speak out against abuses perpetrated against black people in developed countries, some of those firms, and many of those citizens, continue to produce and consume cocoa-derived products which devastate black lives across West Africa. This poses the question of whether confectionary or black lives are more important to the public and the businesses supporting the movement.

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