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Breaking the Chains of Open Innovation: Post-Blockchain and the Case of Sensorica

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Abstract: Open innovation is a concept in flux; from the practice of large-scale, internet-mediated collaboration, to a strategic option and business model for firms. However, the scope and breadth of its transformative dynamic is arguably restrained. Despite the theoretical and empirical benefits of openness, established firms face significant challenges deploying the coordination patterns of open innovation communities, further reducing the potential of spill-overs in the supply chain. Viewed differently, open innovation presents more user-centric and responsible innovation paths. These are manifested in the processes and outputs of open innovation by empowering participation and by successfully employing the capacities of user communities. To reap the benefits of open innovation, a rapid reconfiguration of the production and exchange structures is needed in intrafirm and interfirm relations. Sensorica is an open enterprise that achieves such forms of organization and a unique techno-social infrastructure supporting them. It illustrates a potential path that can realize the full potential of open innovation, for users, firms, and the economic system as a whole.

Keywords: open innovation; open value network; commons; peer production; post-blockchain; REA; Sensorica

1. Introduction

"It is mostly in periods of turmoil and strife and confusion that people care much about history;" ([1], p. 45). The same can be argued with the study of social sciences and, especially, economics. Even more, the growing interest, both in popular and scholarly discourse, of alternative economic and business forms indicates we are indeed in such a time.

Open innovation has sprung out of an expanding universe of practices and ideas around the sharing of knowledge and ideas largely effectuated by Information and Communication Technologies. The general logic is one of problem solving, exploiting a hitherto unseen capacity for large-scale engagement and coordination of diverse contributors. As a phenomenon, open innovation relates to a broad spectrum of practices, ranging from centrally planned and controlled processes like crowdsourcing [2] and online labor markets, to more open and bottom up ones, such as commons-based peer production (CBPP) [3]. Many different strategies can be identified for how the human resources, capital, and degree of uncertainty are defined [4]. Yet, the underlying dynamic remains the same: a generic capacity to employ knowledge in dynamic and uncertain processes. This capacity is gradually affecting the way firms approach innovative activities, reshape their business models and, potentially, their very nature.

In the innovation literature open innovation is mostly approached as a strategic option for firms to employ external inputs [5–7]. On the one hand, a wide array of options unfolds, for both firms and users, but on the other hand, the scope of this interaction remains limited. More radical models concentrate on the virtues of CBPP, and develop structures and organizational patterns that better

enable and support it. CBPP shifts the locus of innovation and production outside the boundaries of either firms or networks and postulates an alternative view of value creation altogether.

Blockchain technology, which arose itself as a CBPP project, has evolved to attract even wider attention. From the CBPP perspective, blockchains have been envisioned to support and stabilize its value model, rationalizing openness and sharing in economic affairs. However, many different groups with diverging political values are looking to deploy the functionalities of distributed ledger technologies (DLTs) and heavily influence the relevant iterations and technological outcomes. Simultaneously, the blockchains are yet to establish a viable dominant design. Still, DLTs have challenged the core assumptions of the financial and monetary system, opening up a discussion where these matters become relevant for an increasing fraction of society. Now, an ontological shift is necessary to break the chains of open innovation through CBPP. Post-blockchain encapsulates such a vision of a blockchain-informed transition that is not necessarily blockchain-driven.

The aim of this paper is to explore these emerging relationships between open innovation and CBPP through a case study. Using an alternative view of open innovation as a starting point, I will explore the inner dynamics of CBPP insofar as they enable and support sustainable and responsible innovative activities. To this end, I will examine the case of Sensorica, an open enterprise based in Montreal, Canada, producing open hardware sensor technologies. Sensorica is an emblematic case of open innovation through commons-based organization. Its diverse community has devised unique solutions to coordinate productive resources, employ the necessary knowledge and skills, and successfully interface with the market. In addition, Sensorica has developed a pioneer accounting system to track, assess, and distribute value that offers useful insights on how to capture value from open innovation.

The case study of Sensorica, being part of an emerging phenomenon such as CBPP, posits several challenges as a research project. First, the data gathered are very "thick" in the sense that they carry along many elements from the context and environment in which they are embedded. Therefore, it is often difficult to distinguish the research subject from the broader phenomenon, and vice versa. Second, as an organization it has undergone, and is still undergoing, several transformations. Since the beginning of this research, some of the observed elements and relationships, being themselves defined in a dynamic fashion, have also evolved, along with a rapidly changing environment. Likewise, the descriptions of the various components comprising its technological infrastructure are at different stages of functionality and use in different times. Hence, the analysis mostly reflects the technical feasibility and deployment of these features, even though their real-world use may differ. Therefore, it should be clarified that the case is not presented as a fully functional automated system or a crystalized organizational model, while its eventual form and very success need to be tested through time. Nevertheless, the story of Sensorica, as it is unveiled through its extensive documentation, online presence, and experiences of the different people involved, remains highly relevant and has important lessons for organizational design based on open and distributed technological infrastructures.

In the following sections, a brief background is provided on open innovation and blockchain technology, followed by a review of the resources–events–agents (REA) accounting model that underpins the Sensorica infrastructure. Afterwards, I present the methods of the case study and the case of Sensorica, which follows the formulation of a narrative based on interviews with key persons, along with data retrieved from their rich and freely accessible documentation. Finally, I will discuss the main outtakes and draw some conclusions.

2. Background

2.1. Open Innovation: From a Strategic Option to a New Innovation Paradigm

The concept of open innovation signifies a paradigmatic change in the way firms approach innovative activities [8]. Open innovation has been largely documented and popularized by Chesbrough [5,9,10] to contrast traditional, vertical Research and Development. In open innovation,

knowledge flows and market paths from internal and external origin are conflated in innovative firm activities, triggering larger implications in the respective business practices and structure. The firm boundaries become less definite and network-based forms of organization gain prominence in successful strategies.

However, there are still a few problems with the adoption of open innovation. First, the current discourse is mainly restrained in a rather instrumental level. That is, in the way firms coordinate inflows and outflows of knowledge and ideas to advance their technological capacities and introduce successful market strategies. From a more critical reading [11], open innovation offers not much more than a puffery term to discuss well-established concepts in innovation literature, such as absorptive capacity [12], external linkages [13], complementary assets [14], or exploration and exploitation [15]. From this perspective, the view of open innovation as old wine in new bottles [16] is not completely unjustified.

Moreover, open innovation has been increasingly treated and presented as a strategy rather than a radically new paradigm [17]. Although the strategy part is increasingly supported by empirical evidence in larger or smaller firms [18–20], many of the challenges of its paradigmatic significance still remain unsolved. Most importantly, the "paradox of openness" [21] quite concisely describes the tension between the otherwise self-evident virtue of knowledge sharing and collaboration with diverse actors, and the ability to capture the returns in the market. Despite the increasingly accepted virtue of openness exemplified in successful digital innovations, a set of "anomalies" still remain for established firms, which pertain to ownership over resources, exclusive rights, and barriers of entry [17]. This way, open innovation is often reduced to what is referred to as "strategic openness"—which might as well be "strategic closedness" (The point on strategic openness/closedness was made by free software pioneer Benjamin "Mako" Hill in his keynote at LibrePlanet 2018 conference. For details see: https://boingboing.net/2018/06/21/digital-enclosure.html)—with open innovation sleepwalking between an oversold hype and a necessary transition.

Conversely, open innovation is arguably linked to more radical transformations in the way productive processes incorporate knowledge to create more socially meaningful outcomes. Theoretical approaches under "user-driven innovation" or "free innovation" [22–24] and "commons-based innovation" [25] have come to validate and reinforce the understanding of innovative activities as fundamentally collective and synergetic. Simultaneously, they provide a more political connotation that also considers the accountability of innovations towards their users and the systems upon which they rely. It is then the task of innovative firms to translate this relational dynamic into valuable products and services.

Arvidsson et al. [26] spoke of a "crisis of value" showcasing a turning point in the way our value regime recognizes new value and how this is created. Novel forms of social production, like commons-based peer production (CBPP) [27], have illustrated new pathways of value creation and distribution. A growing ecosystem of free and open-source software projects and the free encyclopedia Wikipedia have showcased how loosely-affiliated individuals can communicate and self-organize over peer-to-peer infrastructures and co-create use-value that is freely accessible as commons [27].

In CBPP, value is collectively contributed and distributed through participatory practices, and the shared outputs are used in new iterations [27]. There are several strategic advantages and efficiency gains stemming from CBPP [28]. The modular design of CBPP projects allows more, diverse, and independent agents to join the production process, while keeping the transaction costs significantly low. Moreover, the different modules are also often granular, which mobilizes agents' high varying levels and qualities of motivations. Yet, integration at low-cost is a core characteristic of CBPP projects, due to the transparency and interoperability of the different modules. CBPP features a broader spectrum of options for the functionality and association of different modules, along with shared protocols for their fixation, thus solving many of the integration and optimization problems often imputed to modularity [29].

This cycle of open input, participation, and commons-oriented output signifies different nuances of openness. It provides an enabling environment for human creativity to flourish and often leads

to sophisticated, improved, and adaptable innovations. A broad spectrum of products speaks for this potential, from the GNU/Linux operating system, the Apache HTTP Server, Mozilla Firefox web browser, and Wordpress content management system, to the RepRap open hardware 3D printer, and open design technologies like Wikihouse or Farm Hack. CBPP projects extend and reformulate the meaning of open innovation, from a mere strategic option to integrate external knowledge resources, to a relocation of a firm's productive capacities. The commons, then, provide a new locus of freely circulating knowledge and learning beyond the confines of the firm.

However, the value of this form of innovation largely remains unaccounted for. Innovation, as conceived and appreciated in our times, has been interwoven with the capitalist enterprise. Yet, Schumpeter himself would most probably argue for the function of innovation permeating the confines of the capitalist political economy [30]. It embodies a quality that would be manifested in any different setting associated with dynamic change and novelty. From this perspective, if open innovation constitutes a more radical transformation of innovation capacities, this would simultaneously require both functional and institutional changes.

2.2. Blockchain Technology: Reworking Value

Blockchain technology has been said to envelop the potential to "rework fundamental systems and institutions that define modern society, including payment systems, financial markets, commercial agreements, and many of the organizational structures that populate our society" [31] (p. 10). The power of distributed ledgers and smart contracts promises to eliminate friction and radically reduce the costs of transactions, while increasing security, verifiability, and transparency [32]. These features are particularly relevant to business and industrial organizations, allowing the optimization and automation of manufacturing and transactions [33]. Likewise, in supply chain management and logistics, providing a single, verified state of affairs almost simultaneously across the involved agents can be crucial [34]. Being itself an open technology, blockchain allows for a greater degree of agility and a distribution of power that can create favorable conditions for open innovation.

Yet, many of these claims are still premised on assumptions and practices that are prone to the same pitfalls of today's economy. The logic of transactions unveils an adherence to private or exclusive ownership and control of resources and the power dynamics that come along. Then, verifiability and transparency may simply serve the most powerful nodes of the system to control and coerce production and impede destabilizing factors.

Elsewhere [35], we have explored and analyzed these elements of blockchain technology, but premised on a tentative transition of a value regime led by CBPP. The latter provides a new basis for meaningful contributions to societal needs, by replacing private ownership and control with collective self-management; hierarchical command of labor with peer-to-peer coordination; and the production of surplus value with social value. Seed forms of commons-oriented enterprises develop their systems of value representation to encapsulate the polycentricity, fluid coordination, and multiplicity of contributions found in CBPP. They rationalize new types of meaningful social relations, along with the institutions that make the accompanying value forms perceptible.

So, blockchains can make new value forms perceptible, but blockchains alone cannot guide a tentative transition towards them. Blockchains can support the functionality of several components of large-scale mutual coordination, but are not flexible enough to support the multifaceted requirements it entails. The architecture of many DLTs, despite being distributed, still very much functions as a platform, in the sense that all nodes run the same code and logical sequence. CBPP is a complex, asynchronous process, involving diverse agents, both individuals and organizations, that engage in various contributions and need to act independently, while remaining interoperable [36].

A new generation of DLTs has been striving to develop tools that cover the aforementioned requirements [37]. For instance, the Economic Space Agency (https://economicspace.agency) introduces a stack of tools to support the operation, finance, and cooperation of "open-source economic spaces", i.e., autonomous, commons-based ventures engaging in any sort of economic activity. These entities

can deploy smart contracts, optimize and issue crypto-tokens embodying their internal productive relationships and ethics, and use them to attract investments that are not only looking to profit, but also support and expand these relationships. Likewise, DAOstack (DAO stands for "Decentralized Autonomous Organization". For details see: https://daostack.io) features a technological infrastructure to support resilient collaboration at scale between decentralized organizations. The project largely builds on the idea of Backfeed [35], with the difference being that instead of a shared protocol between different projects, DAOstack envisions diverse teams developing different protocols, embedding their values and principles. The distribution of crypto-tokens serves to coordinate these teams and their interaction with the rest of the system to incentivize investments.

Finally, Holochain (https://holochain.org) has developed an alternative proposition to distributed ledgers, introducing instead a generic framework for distributed applications [37]. Holochain takes an agent-centric approach, where diverse agents, individuals, organizations, or even bots share distributed data. Access is granted only to the data that are useful or relevant for every agent, while validation is based on a shared set of rules across the nodes. Most DLTs typically require all nodes to synchronize with a common state. Instead, Holochain establishes a shared set of rules and requires nodes to cryptographically verify it for every action against their own record. This architecture solves many of the scalability issues of blockchain technology, allowing more agency for applications to develop and enforce their own rules, while maintaining the system's interoperability.

The experimentation of alternative architectures is not only motivated to address the scalability and energy-use issues of blockchain technology. Rather, they are purposely developed to better adopt new forms of value creation that are based on shared resources and peer-to-peer collaboration. Open and collaborative economic forms increasingly influence the common sense of the future business models and are called upon to mitigate some of the most pressing societal and ecological problems of our time. A significant part of the world's engineering talent is dedicated to building tools to further strengthen and stabilize these forms.

2.3. Resources–Events–Agents: A Post-Blockchain Accounting Model

The new forms of productive coordination and value creation surfacing in the digital economy have exacerbated some of the limitations that double-entry bookkeeping had already been facing in covering the needs for accounting information. McCarthy [38] identified four main categories of such deficiencies:

1. Limited dimensions: Double-entry elements almost exclusively express monetary representations. This does not allow for representations of other valuable, multidimensional data, such as productivity, performance, and reliability;
2. Not (always) appropriate classification schemes: The categories used to represent the information related to the economic affairs of an enterprise are limited to accounting objects. This often omits data that do not fit these categories, while it organizes data in ways that are of little use to non-accountants;
3. High-level aggregation for stored information: The aggregation of accounting data takes place on a level that only informs executive decision-making and the relevant information concerning economic activities is not available in a primary form to be aggregated on a different level, where different forms, quantities, and foci are needed to serve other functions;
4. Restricted degree of integration with other functional areas of the enterprise: Accounting data concern representations of various phenomena, which are often separately documented by non-accountants in different forms. This leads to inconsistencies, overlaps, and information gaps.

In the face of these limitations, resources–events–agents (REA) has been presented as a model for accounting systems re-engineered for the information age. It was originally presented by McCarthy [39] as a generalized framework designed to cover accounting needs for enterprise environments, utilizing shared data amongst their functional constituents. The main motivation behind the development

of REA was the limited capacity of double-entry bookkeeping to facilitate information flows in post-industrial business entities.

These limitations are addressed by the REA framework through a semantic approach that aims to reflect real-world business activities rather than double-entry accounting objects [40]. As the name implies, the model creates computer objects that represent: (a) resources (e.g., goods, services, cash, assets); (b) events (e.g., processes, transactions, agreements, contracts); and (c) agents (e.g., individuals, groups of individuals, entities, machines). REA preserves the duality of economic events that is typical of double-entry, retaining the causal relationship between inflows and outflows. For instance, in a productive process, several resources (e.g., components, labor time, machine time) are employed as input, and in turn produce other resources (e.g., products, parts). Simultaneously, REA identifies the agents involved in these events and connects the activities with stock flows, which represent resources moving from one activity to another [41]. This way, it integrates all the planning, monitoring, and communication functions, providing greater granularity of data to effectively track the economic activities and inform decision-making [40].

The technological roots of the REA model reach back to the development of relational databases in the 1970s [39]. The double-entry-based accounting entries then impeded their transformation to database form, as they created data redundancies and decreased data integrity, which violated the rules of normalization. McCarthy's [39] solution simplified this process, while providing the same options for financial reporting.

Even though the model in its initial form did not provide significant benefits for business operations, it has opened up the development of accounting solutions apt for databases. In this direction, Enterprise Resource Planning (ERP) systems emerged, which follow normalized databases, offer significant advantages in terms of cost reduction and user experience [40]. Recently developed enterprise systems, such as Workday and REA Technology, have applied the core of the model in their architecture, while many ERP systems that do not fully embrace the REA accounting model are still largely consistent with the design theory [40,42,43].

Nevertheless, REA has not yet been widely adopted in business due to path dependencies with the traditional accounting practices. Most ERP systems are consistent with double-entry bookkeeping artefacts in the way they provide information for their applications and thus include add-on general ledger modules for the relevant accounting tasks [44]. As this type of information is mainly handled by accountants and financial managers, they, in turn, prefer ERP systems to be designed in a way they are more familiar with.

The rapid changes in the structures and business logic of enterprises in the information economy necessitate greater agility from information systems. The demanding business climate rationalizes collaboration and integration across the value chain, in the form of clusters (Porter, 1990; 2000) or strategic alliances [45], challenging the definition of corporate boundaries. The semantic representation of the enterprise reality offers such agility in a greater degree than on artificial constructs [46].

New enabling technologies and business models transcend the limits of the value chain towards an approach comprising "value systems" [47], including all the interconnected economic agents and resource inputs involved in productive processes. The REA as a design theory can provide a common vocabulary to enable the coordination of all involved parties in integrated enterprise and inter-enterprise systems [40,41]. Individual entities and their respective records matter less in this view, while the focus is on resource flows. It poses as a discontinuity in the design paradigm of electronic accounting systems, where instead of focusing on the automation of traditional accounting artefacts, it conceptualizes a new way of representing the complex economic reality.

Research on REA has also progressed in recent years and the model has gradually evolved from a generalized framework to a design theory for enterprise systems with a semantic orientation. REA already forms the basis for the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) standard 15944 for Information Technology—Business Operational View, Part 4 "Business transaction scenarios—Accounting and economic ontology"

(ISO/IEC 19544-4:2007), specifying the concepts and relationships for business transactions in open-electronic data interchange. Moreover, with distributed ledger technologies gaining additional attention in supply chain management systems and business networks, the ISO standards committee is further looking into the creation of a blockchain standard, which also involves the participation of REA experts [36].

With this, I return to the main motivation behind this paper: to examine the REA model as an enabling medium for representing the economic reality of CBPP. So, without getting into more detail of the technical aspects of the REA model itself, I attempt instead to provide an overview of one of its arguably paradigmatic implementations. To this end, I present the case of Sensorica.

3. Materials and Methods

This paper was based on a case study, to gather and analyze diverse empirical data provided by the examination of an individual case and thus reflect on a broader phenomenon [48]. The value of the case is intrinsic, in that it is, "in all its particularity and ordinariness" of great interest in the way it reveals its story [49] (p. 237). Nevertheless, the case selection was purposive [50], as it illustrated an organization specifically designed for CBPP, which has successfully introduced innovations in the market.

Acknowledging the importance of diverse research techniques in case study research [48], a combination of multiple sources of data gathering was used, including interviews, as well as internal sources of documentation and a variety of online tools typically utilized by the Sensorica community, which provided further data for triangulation [51].

As, by definition, Sensorica avoids rigid hierarchical structures, the individuals targeted for the interviews should be considered key informants rather than gatekeepers. Sensorica has been highly influenced by the principles of peer governance [52] and have adopted a bottom-up decision-making system based on consensus, mutual validation, and meritocracy.

The interviews were semi-structured and emphasis was placed on providing flexibility for the interviewees to discuss what they deemed most important. The goal was to establish a dialog with the interviewees, in the form of a "guided conversation" [48] (p. 236) to reach a common understanding of the issues explored. The interviews were structured around certain base questions and probes that attempted to elicit data regarding their goals, desires, and ideologies, as well as their coordination and development methods. In total, three interviews were conducted using a video call tool due to large geographic dispersion of the interviewees and time limitations. The interviewees were anonymized to avoid potential impacts from the exposure of their views.

Lastly, data were gathered from Sensorica internal documentation (reports, agreements, working documents, etc.), as well as from an overview of the accounting system for specific projects, which is openly accessible in most parts. Data from online platforms, fora, discussion sections, and documentation (audio-visual material, reports, articles, blog posts) available were also studied, as well as email communications with individuals. Given the fact that openness is a principle permeating such initiatives, there are rich and diverse sources available for the mining of research data. Like the interviews, key documents and discussions were selected that provided the most insight in each sub-case, shedding light on the intricacies of the technology development, as well as the participants' incentives.

4. The Case of Sensorica

4.1. General Overview

Sensorica is a collaborative network, established in 2011 in Montreal, Canada, dedicated to the design and deployment of sensors and sense-making systems. Inspired by free and open-source projects, the vision of Sensorica has been to devise an appropriate business model and support infrastructure to make such forms of production economically sustainable.

Sensorica is arguably more complex than a traditional enterprise. It is a productive network that is simultaneously a commons-based community, as well as a market-oriented entity. On one hand, individuals and organizations pool resources to initiate projects, driven primarily by intrinsic motivations, rather than financial rewards. On the other hand, the innovative solutions developed in Sensorica are introduced to the market to generate income by "exchange firms". The latter refers to independent internal or external entities which undertake marketing and logistics operations while being liable for maintaining ethical and quality standards of the solutions [53].

Sensorica identifies itself as a new type of organization, which is referred as an Open Value Network (OVN, see Figure 1) [54]. An OVN is a generic organizational and business model, which could possibly enhance and support commons-based peer production. As an organization it is highly adaptive, fully decentralized, and governed through distributed decision-making processes and resource allocation [55]. As the name implies, it supports open participation, has very low barriers of entry, and is designed to empower permissionless individual action through open knowledge and transparent processes.

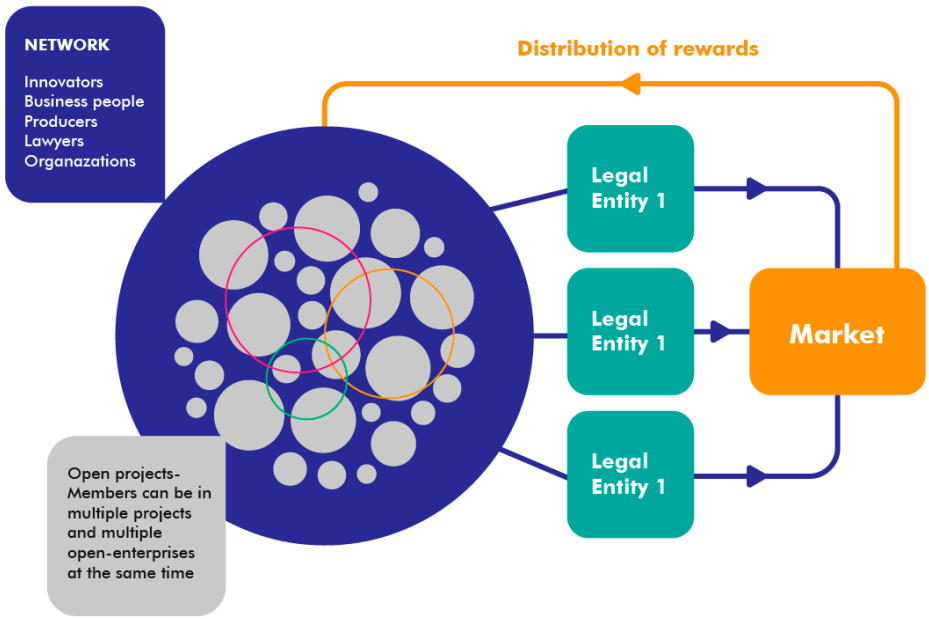

Figure 1. Open Value Network (Adaptation by the author and Nikos Exarchopoulos from Siddiqui, Y. and Brastaviceanu, T. Open Value Network: A framework for many-to-many innovation. Available online: https://docs.google.com/document/d/1iwQz5SSw2Bsi_T41018E3TkPD-guRCAhAeP9xMdS2fI/pub#h.pkzfosme7qaf. (Licence: CC-BY 3.0).

4.2. Organization: The Open Value Network

The OVN is characterized by three fundamental principles: open membership, transparency, and variety of contributions [55]. Open membership means that members can freely join or leave the network and form, join, or acquire enterprise entities. Also, members can be individuals of diverse backgrounds or organizations, including non-profits, government entities, enterprises, or even other OVNs. Transparency enables the open-source communities to gain access to information, knowledge, and processes, with certain restrictions regarding specific types of resources that may need to be handled exclusively by special expertise (e.g., dangerous chemicals may be restricted to chemists). Finally, a broad spectrum of contributions can take place, including material (e.g., resources, tools, consumables) and immaterial inputs (e.g., time, effort, information) or capital (e.g., financial investments, space, equipment, infrastructure).

The aspiration of the OVN model is to create a viable structure that harnesses the advantages of open collaboration and sharing, while it addresses the challenges of open-source projects related to

governance and sustainability. Its economic dynamics are based on large scale collaboration and on customized production to create economies of scope. The OVN takes advantage of the diversity of inputs and shared resources to create innovative solutions and effectively reduce time-to-market for innovations. Through diversity and variety, a unique potential is created and exploited by the linked business entities in an attempt to become competitive in the market. At the same time, the OVN model provides solutions for open-source projects, so that they can effectively capture, manage, and distribute financial rewards to the contributors; deals with issues related to trust; retains and protects a formal legal structure and brand; and formulates and executes a business strategy.

To achieve this, the Sensorica OVN rests on a techno-social infrastructure that reinforces decentralized organization and renders the network efficient and sustainable. It utilizes the REA model to coordinate diverse agents, either individuals or business entities, in a flexible manner, considering their legal and ownership arrangements. It also performs all the traditional business functions, including Research and Development, coordination, production, distribution, marketing, sales, distribution of revenue, and legal liability. Simultaneously, it keeps track of the different contributions in a transparent network-based system, which allows the created value to be fairly distributed within and beyond the network.

The Canadian Academy for the Knowledge Economy (CAKE) is a nonprofit organization that all the agents of the network are affiliated with. As a caretaker of the network's assets, it manages the shared pool of the network's resources in such a way that large-scale collaboration is fostered without compromising the fair distribution of value [55,56]. Towards this goal, a "non-dominium" agreement is used that excludes the domination of an agent over the shared system.

4.3. Technological Infrastructure: Contributory Accounting and Network Resource Planning

The OVN infrastructure comprises three main interlocking systems [57]: (a) a Contribution Accounting System (CAS) (in previous versions, Sensorica's accounting system was referred to as Value Accounting System (VAS)), which records and evaluates every member's input and calculates revenue in proportion to each contribution; (b) a reputation system, which determines the behavior within the community and attributes merit in accordance with the collective interest; and (c) a role system, which allocates the arrangement and interrelation of the different activities among the agents, based on their skills and interests. The reputation system fulfils an important function to regulate value creation and the flow in the network by filtering participants for the tasks to be undertaken.

Specifically, reputation is linked with the voluntary commitments that people make for the work that needs to be done in the network. These commitments may be connected to one or more deliverables, which in turn are required by other processes. Reputation is gained when someone fulfills their commitment, and is reflected in the subsequent processes and the people involved. At the time of writing, the system keeps track of the different types of work conducted (e.g., electronics, 3D design, prototyping) and generates an accumulated score based on the hours worked by each person [58]. Likewise, an additional function is sought to be integrated to also include the quality of the work completed.

Respectively, roles weigh the significance of a certain task with regards to the distribution of value in a certain project. For every project a value equation is created that is decided among the participants. The various tasks to be performed are weighed according to their contribution to the project. For instance, in a certain project, one hour of engineering work can be equated to two hours of manufacturing. Similarly, the participants in one project may prefer an egalitarian value arrangement or a more meritocratic one [59].

The aforementioned systems enable the OVN to track and evaluate the contributions, as well as redistribute revenue produced in the market. The Sensorica CAS is a contribution-based reward system, which proportionally redistributes revenues to the related projects based on each contribution. The logged contributions are evaluated through a metrics system, while participatory evaluations by the members can also be an option [60]. The aggregated data generated by the CAS are fed into

the other two systems, which in turn support the CAS. This way, the system generates a permanent quantitative and qualitative record of all contributions, in terms of who is doing what (role), how well (reputation), and how much (value) in a particular project.

The different dimensions of value are made commensurable using a value equation system, which attributes a percentage of the total revenue to every participant, in the form of "fluid equity" [61]. The fluid equity of every contributor in a certain project is visually represented in the form of a pie-chart, illustrating its share of the potential revenue related to the project. That is, if exchange value is created in the market, the CAS guides the redistribution of the revenue to the contributors.

Given that the OVN is a dynamic structure, certain types of contributions are simultaneously associated with the creation of new resources [62]. For example, a design or a prototype which has been contributed to one project represents a resource that can be used in a different context. To facilitate the interoperability of the resources in different projects, the CAS is complemented by a Network Resource Planning (NRP) (in other sources, NRP is also referred to as "Network Requirements Planning") system that matches resources with certain value streams.

The NRP is an Enterprise Resource Planning (ERP) type of software based on the REA model to support the complexity of operations in an OVN. It collects, stores, and interprets data from all the different types of activities in the network and connects them to specific resources, events, and agents to keep track of the contributed value on resource level.

In NRP, everything is connected together. Economic agents are associated with other agents and participate in events of various types, such as processes, exchanges, or transfers. Events change the state of resources by using, citing, consuming, creating, or transferring them. A certain resource may be an output from one event and then an input to another one. Those events are then again connected with a resource flow.

More specifically, the REA model operates in three levels in the NRP (see Figure 2) [63,64]. The first level concerns the definition of "types" (or recipes). These define resources, processes, agents, or events associated with productive activities in the network. The second level refers to "plans", which entail different forms of commitments for scheduled activities, including productive processes, orders, transactions, or purchases. Finally, the level of "events" (or actuals) contains all the different economic occurrences that effectuate changes in the quantity or ownership of resources, performed by the participating agents. Each event has a respective definition on the type level and entails different commitments on the plan level. Different processes connect the events level with the plan level, as they contain inputs and outputs related to either commitments or economic events. Projects define the context where different things or processes are involved in one of the three levels.

The NRP integrates the function of the CAS in Sensorica, by allowing the re-use of resources in different contexts. This is especially relevant in the case of CBPP, which relies on the circulation of digital commons, which are abundant and can thus be utilized simultaneously in many different contexts. In turn, further utilization of the associated resources results in further increase in the aggregated use value for the network. The NRP-CAS thus enables the advantages of network effects, while effectively supporting the complex underlying relations.

At the same time, the NRP-CAS supports the expansion of the OVN, as it may attribute equity to resources generated by external sources and integrate them into the network [52]. For example, a piece of open-source software code, which has been developed by non-members of Sensorica, can be used within a Sensorica project to compile a final product that is then exchanged in the market. The external developer is given a percentage of fluid equity in the project and a proportional distribution of any revenue. This way, the OVN can connect creative communities in mutually beneficial terms with the NRP-CAS providing the common language.

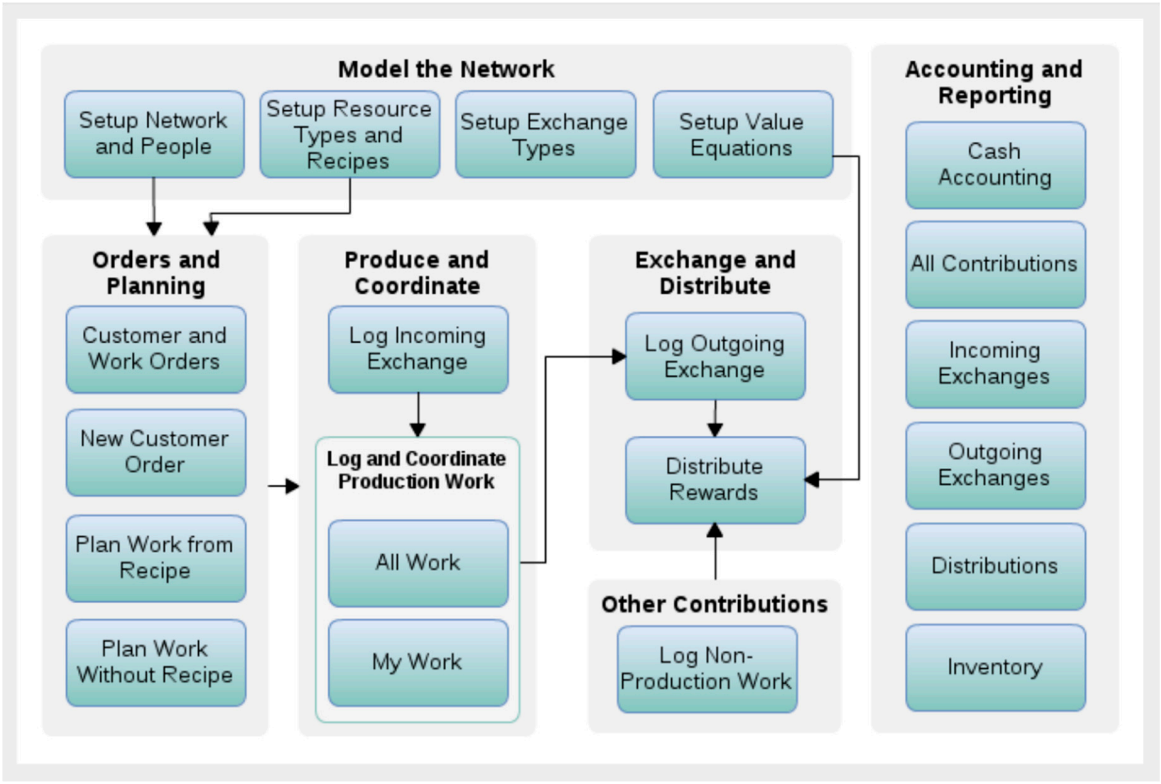

Figure 2. The Sensorica NRP-CAS structure (Available online: http://nrp.sensorica.co).

4.4. Projects and Operation

In Sensorica, government grants or market operations generate income. The NRP-CAS enables revenue to flow back to its contributors based on the quality of each contribution. The latter is evaluated via peer review techniques and self-logging, eliminating rent-seeking behaviors and reciprocating benefits to network through common value creation. Thus, a sense of fairness permeates Sencorica's techno-social infrastructure, which, in turn, supports its network's contributions and operations.

Regarding the initiation of Sensorica's projects, the related processes can take place either internally or externally. Ad hoc projects can emerge through discussions set off by the network participants. By engaging more people in the network, the planning and research process takes place, followed by the arrangement of the NRP-CAS. The development of the project is thus fostered, including contribution records of the participants, marketing, and accounting processes.

There are typically nine steps to initiate an endogenous project in Sensorica [65]:

1. Project idea: People begin broadcasting an informal proposal in the Sensorica forum or through other media. The rationale and main idea are discussed and explored;
2. Creating an official project: After a round of informal discussion, a formal procedure to create a project is followed, based as set of shared instructions [66], methods, and templates provided [67];
3. Building capacity and communication strategy: The project participants agree on the procedures for project execution and the appropriate communication channels and coordination tools;
4. Establishing project structure: A minimum working structure is developed, comprising, at least, the description of the project's (a) governance, including the rules of conduct, conflict management, and distribution of rewards; (b) roadmap, including important milestones and plans; and (c) custodian agreement, signed by the custodian to administer the relevant funds;
5. Creation of a core team: After the conditions for communication and structure have been agreed upon, a core team of instigators is formed and they reach out to the network to map interest, gather feedback, and create incentives for participation;

6. Establishing incentive structure: A structure is developed to motivate potential contributors, including a market plan and a plan of the necessary resources, including skills, equipment, materials, and financial resources;
7. Expanding the team: Once the incentive structure is set, a process of outreach, onboarding and engagement, and information mining begins to attract the necessary talent and resources;
8. Planning activities: The activities needed for the project implementation are systematized and formalized in the NRP-CAS using "workflow recipes" [68], i.e., a set of pre-defined descriptions for a series of processes and distributions of tasks;
9. Documentation: All activities in Sensorica are followed by extensive documentation in the project website, as well as in a main shared document, which functions as an index for various working documents concerning major components.

For example, the "Mosquito" technology, a force-displacement sensor, exemplifies how a project can start internally in Sensorica. It was launched in 2012 under the coordination of 15 network participants, who undertook several roles, ranging from design and development to marketing and documentation. In 2013 the company Tactus Scientific Inc. introduced the Mosquito Scientific Instrument System into the market. Being initially tested in cardiovascular diseases, it has now expanded its use in robotics and wearables.

Similarly, Sensorica's network can undertake innovation processes of projects that have been outsourced by external parties. For instance, the development of an Internet-of-Things solution was outsourced to Sensorica by a Montreal-based company in 2015. Following the Sensorica's modus operandi and openness values, the company agreed to release the product under open-hardware license. In addition, it financed CAKE—the network's custodian—to distribute revenue to the participants in the product's development process. Based on the data available in the Sensorica NRP-CAS [69], 686 contributions were made in various tasks, ranging from software design, electronics, and optics development to admin and documentation work, generating over 60,000.00 CAD in income for the eleven affiliates participating in the project [70,71].

In general, Sensorica has been able to sustain its operation for almost a decade. Based on the latest available data [72], a rough estimate of 330,000.00 CAD has been raised since 2011 in grants and loans, while revenue from commercial activities has been ranging around an average of 50,000.00 CAD annually, from 2015 to 2018. At the time of the writing, about 30 affiliates were active in Sensorica, who, between 2016 and 2017, had invested an aggregate of almost 6000 h of work and more than 16,500 CAD in the infrastructure, maintenance, and development of the network [73].

Conversely, as the distribution of rewards is based on past economic activity, the accumulated data comprise a public socio-economic profile related to a particular person or organization. There is a significant amount of power that this type of information can potentially provide if it is appropriated or centrally controlled. For this reason, as of 2015, Sensorica has been exploring the deployment of the NRP-CAS infrastructure on the blockchain, to maximize integrity and security [74].

5. Discussion

Sensorica features some unique and admittedly impressive features to speak for a full-fledged open innovation through CBPP. Its infrastructure and organizational model is, of course, not completely conflict free, from a technical, conceptual, and a human-centric point of view. However, these do not reduce the main lessons to be learned from the case.

5.1. On the Viability of the OVN Model

To begin with, the OVN model, as demonstrated by Sensorica, carries some decisive solutions for commons-oriented projects. The unique modality of production effectuated by CBPP communities can connect with the market and the public sector by translating, rather than transforming, the value of the commons in iterative transactions. Financial or other types of rewards can be captured,

managed, and distributed to contributors, in a way that is decided among them. Simultaneously, trust-related issues are dealt with functionally and systematically, while the network is able to retain community-based values, along a formal legal structure, a marketable brand, and coherent business strategy.

Sensorica is, quoting one of the interviewees, "a peer-to-peer network for innovation and production, the same as Bitcoin is a peer-to-peer network for providing a service of exchange". The OVN model fundamentally provides a protocol that allows the functional reality of a firm to be transposed to a peer-to-peer network. People contribute to the economic activity because they trust the protocol and that they will be rewarded in the end. This opens up a field of experimentation for different ways that people evaluate contributions and distribute benefits. They can try different incentive and evaluation systems to coordinate a variety of contributions and distribute different types of benefits, be it financial rewards, visibility, reputation, learning, or access to governance.

Market signals still serve to attract participation. People engage in a project because they intuitively believe there is a market for it, but that is less imperative compared to conventional firms. They may also participate for the social or ecological concerns of a project or the opportunity to learn new skills. More importantly, they have agency with where the project goes, as people appoint themselves to one or more roles. "[. . .] if anyone comes and solves a problem, delivers a task you cannot refuse it. And that person can be anyone in the world", mentioned one of the interviewees. Hence, there are two dimensions of openness that Sensorica demonstrates: one is access to information, knowledge, and processes, and the other is access to participation. As another interviewee put it, it "is just the basic transparency. [. . .] People can see everything, so I think that's what's helpful with coordination."

However, this openness and transparency often also comes at a cost. Open systems can sometimes create disaccord and can obfuscate relationships with third parties, especially when it comes to external clients. This, of course, goes both ways. The community might be intrinsically motivated to further explore and experiment, but when market-driven clients are involved this is not always the way they want to go. Additionally, this can also affect investment, as, besides all the challenges common to open-source business models, Sensorica also needs to effectively communicate its modus operandi. As one interviewee eloquently presented it, "you can put it under one roof, but the job security is not there. [. . .] It's hard to fuse money and protect the community at the same time." Sensorica tries to operate within an existing system that is largely not compatible. The structure may be in place but there is still a big gap to be bridged.

5.2. Breaking the Chains: From Chains to Ecosystems

Overall, Sensorica contributes to a more inclusive discussion on open innovation. Capturing value from innovations has long been a central topic for the relevant disciplines, to which the concept of open innovation has hitherto contributed insignificantly. Cases like Sensorica demonstrate how openness may be an intrinsic and functional, rather than strategic, option. The focus is placed on agency and stake, instead of structure and control. There is of course structure; someone still needs to make sure all the necessary roles in a project are fulfilled and that the project delivers. Products need to be introduced in the market and there is ongoing debate of what is valuable and how funds are distributed. However, there is at least the discussion taking place and openness allows people to contribute to it. "There are templates that emerge but we don't claim to have the recipe and I don't think there is one recipe," mentioned one of the interviewees.

Furthermore, the NRP project has itself evolved through and with Sensorica. Some of the main instigators of the Sensorica infrastructure admit they are happy to see their work being taken over by other groups of people, which are now also coming together: "It's all coming out of the NRP project but it's not really the NRP project anymore." At the time of the interviews, new iterations of the NRP project were initiated in collaboration with the Freedom Coop (https://ocp.freedomcoop.eu/freedom-coop) in Europe and The Mutual Aid Network (https://www.mutualaidnetwork.org) in Madison, Wisconsin, among other communities around the world. The next challenge is to make all of the different systems

interoperable. As it was righteously put by one interviewee, "because when the software can talk to each other, then the groups will be able to interoperate with each other. They will be able to exchange with each other, but more importantly they will be able to create supply chains and, better yet, networks of ecosystems."

This vision is particularly relevant to the blockchain domain. The code may be open but communities gathered around a certain cryptocurrency or protocol can easily get locked in. So, from an infrastructure viewpoint, a common vocabulary among different systems is crucial. Organizations, firms, or communities can be free to use their preferred software and infrastructure, but systems need to be interoperable. Much like double-entry bookkeeping provided a common vocabulary for market exchanges, new forms of accounting can help diverse agents interface with each other. However, this time there would also be diverse motives driving interaction, other than prices and account bottom-lines, allowing more pluralistic relationships to emerge.

For instance, the NRP iteration of Freedom Coop, called the Open Collaborative Platform (OCP), is an organizational tool for network-based organizations. It started as a platform that helped the Freedom Coop members coordinate and describe, organize, and evaluate the network's projects and the collaborative work conducted. The OCP has built on several features of the NRP to expand and incorporate other projects and functions of the network, including the Bank of the Commons, serving as an alternative banking tool supported by the network's cryptocurrency, FairCoin [36,75].

The next steps would be for these emerging forms of organization to build common vocabularies and protocols to convert and distribute data across different networks, tools, and applications. In the case of the Freedom Coop, the creation of an Open Cooperative Ecosystem [76] is aimed at fulfilling this vision. Moreover, the ValueFlows project is dedicated to the development of a common vocabulary emerging from the various mutual-coordination networks based on the REA ontology [77]. ValueFlows begins with the definition of the required components that would work across different apps and agents and can be run on different decentralized protocols and frameworks, including Holochain, ActivityPub (https://www.w3.org/TR/activitypub), and Secure Scuttlebutt (https://scuttlebutt.nz).

5.3. Beyond Innovation, towards a Better Life: A Human-Centric Technological Trajectory

Finally, it should be obvious that the whole point of introducing the commons to peer production is to emphasize that a human economy is still more than interoperating software and integrated supply chains. As one of the interviewees explained, "[. . .] you have to think about the whole lives of the people involved in it. [. . .] They have to be able to eat, they have to be able to have families, they have to live somewhere, there's healthcare, there's the production, there's also the reproduction, we have to educate children, there's this whole set of things that have to happen and it's not just this supply chain." When it comes to being a Sensorica contributor, there is no clear consensus on how the rest of the factors can fall into place.

The OVN structure makes a lot of sense to someone who lives as a digital nomad, but for someone who needs to support a family there can be several risks involved. However, as one of the interviewees put it, "Personally, I think [. . .] it's the only structure that can capture my talents as an individual and really be able to learn, share and create at the same time, while making an income off of it. It's probably the only structure that I've ever encountered where I could really thrive as an individual." So, despite the various controversies and contradictions, it is still a discussion that needs to be put forward on institutional level. If anything, open innovation marks a shift in our understanding of the role of innovation from the view of innovation as a technical and economic process, to the acknowledgement of the meaningful improvements in people's lives that can be attained through the deployment of new technological capabilities.

6. Conclusions

Open innovation signifies a paradigmatic shift in the way innovative activities and the relevant socio-economic relationships are perceived and carried through. Emerging forms of production,

such as commons-based peer production (CBPP), and the accompanying organizational and business models, unveil different ways that diverse agents can establish coherent relationships and collaboration, based on shared knowledge and resources in open, transparent systems. The main purpose of this article was to explore such organization forms, along with the technological infrastructures that can effectuate and stabilize their underlying value models.

The development of blockchain technology has sparked increasing interest from diverse social groups. Among them, CBPP projects have been looking for ways to deploy blockchains to build distributed infrastructures able to sustain large-scale open collaboration. Blockchains have opened up a broad discussion challenging some fundamental assumptions about the function of money and finance and the way they coordinate value creation. However, blockchain technology alone has been shown to be inadequate to sustain the multifaceted dynamics of CBPP.

The case of Sensorica was presented as a post-blockchain model that is informed by this discussion but introduces an alternative techno-social configuration. Predating the surfacing of blockchain technology by more than two decades, resources–events–agents (REA) is an accounting model developed to adapt business information systems to the digital age. The unique value accounting system featured in Sensorica is based on the REA model, allowing loosely-affiliated individuals and groups to engage in open projects, introduce innovative products in the market, and fairly distribute rewards, according to collectively-agreed rules.

The case of Sensorica demonstrates a tentatively viable economic model consciously developed to support CBPP. It illustrates a path to harness the innovative dynamics of openness and sharing, but also the systemic contradictions and structural limitations that come along with them. Its economic model is still under reconfiguration and the potential evolution is yet to be seen, while broader institutional arrangements are necessary for it to be fully deployed and replicated.

Nevertheless, a growing community of projects is building further iterations of techno-social systems inspired by the same principles. A common vision is gradually formed, integrating the various components and making them interoperable to intensify the exploration of more human-centric forms of automation. Despite the internal contradictions and structural limitations, reinstating human wellbeing, societal justice, and visions of the good life in technological projects can be a first step towards more accountable and meaningful technologies.

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