

The Roles of Agency and Artifacts in Assembling Open Data Complementarities

Completed Research Paper

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Abstract

Strong claims are made about the potential of opening government data to drive service innovation. Yet little is known about the detailed processes of how hackers create or reshape services out of new releases of public datasets, and the conditions for the move from data release to service innovation. We argue the utility of open data is accrued through the creation of new artifacts with enhanced performativity transformed by human and material agency. In a multimethod study of the open data hackers in the UK we identified a series of interlocking processes involved in the conversion of public data into services of public value. We found that few of the 'rapid prototypes' developed through hack day events are maintained or sustained as service innovations beyond those events. Five artifacts provided the value stack of complementarities: cleaned data available through APIs or bulk downloads, linkable data, shared source code and configuration, source code repositories, and web technologies. Our findings also suggest that only a few open datasets induce the process of change, and that initial contributions are driven by the use values but can only be sustained through an open innovative approach to induce further collaboration within a wider open data community.

Keywords: Open Data, Complementarities, Materiality, Artifacts, Performativity

Introduction

The release online of government datasets, under open licenses allowing for re-use, has received sustained policy attention under both previous and current UK government administrations. Since the data.gov.uk data store was publicly launched in January 2010 with nearly 3,000 datasets listed, the range of UK open government data available for re-use has grown significantly, with pressure on government departments, local government and trading funds to release raw data. Arguments given for the release of data include reference to increased transparency and accountability, and the potential for open government data to stimulate the development of the web of linked data and the semantic web. One of the most prominent arguments for the release of data, however, is that developers and hackers will be able to take raw datasets and create mash-ups and applications, combining public data with other datasets and services to provide useful information, tools and services to the public. This is seen as supporting both co-production of public services (e.g. Boland and Coleman 2008), and the development of service innovations, as entrepreneurial actors outside the state bypass complex procurement arrangements and institutional barriers to deliver prototypes and scalable services based on open data (Michel et al. 2008; Vargo and Lusch 2004).

High profile competitions such as Apps for Democracy in the US, and Show Us a Better Way in the UK have emphasized the potential benefits (both in terms of financial savings to the state, and potential for innovation) of releasing data to developers, and allowing actors outside of government to build products and services off the back of it. Both Data.gov.uk and the London Data Store feature 'Apps' or 'Inspirational Uses' of the data they provide - ranging from new websites that provide interactive access to performance data on schools, to visualizations of travel times in London, and a Live Tube Map, drawing on London Underground data to show the location of underground trains on the network. Whilst these anecdotal examples underline the intuitive plausibility of the claim that opening access to government data can bring significant benefits through third-party hackers working with it, established and systematic metrics for evaluating the impact of open data are lacking. In this paper we set out to identify in more detail the processes involved in the use of open data, and the enabling and limiting factors for the creation of sustainable service innovation based on open data. Furthermore, we ask specifically how the accumulation of artifacts, and the agency of developers, impact on sustainable open data re-use.

Before the data becomes open, it is collected for a specific administrative purpose and forms an integral part of the performativity of a larger IT artifact (e.g. as an input to a relational database for taxation). If the ex-ante value of open data is largely determined by its prior context of use, the release of data may result in the loss of its prior performativity. This makes tracking the impact of open data tenuously complicated, due to the difficulty of establishing the value-chain as data loses its formal supplier-user relationship (Dekker et al. 2006). We use performativity to underscore that open data on its own has little intrinsic value; and that its utility can be enhanced by combining with other elements in the creation of a new feature and/or function (Didier 2007). In economics, Mackenzie (2007) makes a finer distinction between effective and Barnesian performativity, in that the former describes how the practical use of an aspect of economics affects the process it seeks to describe whereas the latter makes the economic process to follow the depiction of an economic model. Mackenzie's work shows the significance of performativity by design in inducing change, in that some models and theories are effectively in altering behaviours amongst their users. The behavioral changes make the models and theories more accurate as they continuously change the material contexts and conditions which give them the needed authority and legitimacy. The release of open data can induce several iterations. Which model and/or theory leads to a greater performativity requires a closer examination of how complementarities can be developed and accumulated despite the constraints that often come with open data.

In design science research, the utility of an IT artifact is measured by its levels of goal attainment previously conceived by its designers, such as, "Does the IT solution perform a task at hand?", "Does it induce certain behavioral change as predicted by the underlying design principles and/or theories?" (Hevner et al. 2004; Kuecher and Vaishnavi 2008). With data openly available to the public, designers (including developers and hackers) can apply different models and/or theories to the data, and create new artifacts. Yet data (even timely and comprehensive data) is, on its own, insufficient to drive innovation in the design and development of better services. In assessing the impact of open data, rather than focusing upon establishing outcome measures (e.g. counting the number of new start-ups building around data-driven businesses), this paper seeks to examine how the performativity of open data can be enhanced and

the underlying processes of change manifested in multiple contexts of use by its designers (Robey and Boudreau 1999).

By tracing the different processes and sequences involved in the use of open data for provision of information and services of public value, we identify elements of those processes that facilitate and impede the realization of that value. These processes involve human and material agency in creating and enhancing the performativity of existing and/or new artifacts, which constitute a value stack of complementarities. To develop our theory, we used a combination of methods comprising ethnographic research, archival analyses of blogs and activities of hackers, and interviews with key informants. While we collated and analyzed our data, we identified theoretical categories that led us back to the literature. This approach provided a practical middle ground to iterate between empirical data and theory, avoiding the pitfalls of ignoring the literature (Suddaby 2006). During our analysis, we found that by treating open data as a non-material artifact we were able to shed new light on the integral relationship between agency and performativity through the creation of new artifacts and a value stack of complementarities. By focusing upon artifacts, we examined the extant literature on artifacts from both within and outside IS discipline including the role of artifacts in the performativity literature.

For clarity of presentation, we review the literature prior to the discussion of the research setting and our findings although we examined it throughout this research as data collection and analysis indicated its theoretical relevance. Following our discussion of the literature, we provide more detail on the methods, and then present our findings.

Complementarities

The theory of complementarities has been used to explain how coordinated, rather than uncoordinated activities yield not only higher returns, but also lower cost. Releasing open data to drive service innovation, rather than government transacting to allow third parties access to its data, enables new forms of 'coordinated' activity, and different mechanisms of coordination. Whilst the notion of complementarities has been variously defined and used in different contexts, a dominant theme in the literature is the economic theory of complementarities. This theory is often understood in terms of super- and sub-modularity (Tanriverdi and Venkatraman 2005). It suggests that certain activities when brought together are more than the sum of their parts, in that, coordinated activities are mutually enabling and reinforcing each other's performance. The theory is implicitly limited to being a contingency account, as if coordinated activities provide the only optimal condition for realizing complementarities (Cooper and Haltiwanger 1996). Furthermore, the implicit assumption that both coordinated activities can exist independent of each other has precluded a closer examination of the emergence of complementarities.

Analysis of our data suggested there are other conditions (including contextual factors; e.g. Why coordination happens around certain tasks (or datasets) but not others?; intervening factors: e.g. Who and/or what instigates the coordination?; and causal factors: e.g. Can one activity lead to the emergence of the other to form one complementary set?) that explain why a contingency approach towards open-data use and service innovation can fail without accounting for the temporal emergence and the sustainability of complementarities.

Andrew Pickering (1995) used the concept of 'the mangle' to underscore the significance of temporal emergence in scientific practice, suggesting that the way human and technology are co-configured through social actions can either dissipate or generate resources in an on-going manner, and that the resulting intermediaries (including new roles, routines, and material solutions) temporarily emerge to overcome current material constraints. This concept has been sanctioned by other IS scholars (Jones 1998; Orlikowski 2006) to account for how materiality of technology emerges, is sustained and is configured. This practice-based perspective provides a useful lens to study the conditions (contextual, intervening, and causal) that can induce the assemblage of complementarities. Where many accounts of open-data use treat data as a simple raw material, and developers or hack-days as agents and processes to be applied to any suitably accessible raw data to turn it into useful artifacts, a practice-based perspective draws attention to the specificity of different instances of open-data use, including their temporal context, and their embeddedness in ongoing processes generating and regenerating human and technological resources that support data use.

Any analysis of technology risks falling either into over-prioritizing the role of technologies (material agency), or over-prioritizing the role of human agents and agency in realizing a particular set of outcomes. A sociomaterial lens draws attention to the mutually constituted nature of both human and material agency (Orlikowski and Scott 2008), and the roles that social and material artifact play. Volkoff and her associates (2007) use a longitudinal case study to show how roles and routines were inscribed in technology through instantiating the material aspects of technology, which in turn circumscribe other actors' future activities. Mutch (2010) argues that, "we need to consider not only the ways in which structures can be embedded in technology and at which levels, but also how such embedding is perceived by and responded to by a range of users" (p. 511). He also argues that "in many circumstances, structures, language being a key one, are bequeathed to us by actors no longer present, but they form the involuntary context, a context that can both constrain and enable, for our action now" (p. 510). In relation to open data, the ways that data has been collected and the formats it is encoded in may impose a set of constraints for further use, as they are collected for different administrative purposes (such as census, accounting, etc); and that, for example, they may appeal more to the press and rights activists than to hackers focused on public service innovation. Some constraints are irresistible; others simply create resistance and barriers that may be overcome by suitably motivated data re-users.

In the case of open source, social norms and culture provide key context, but material infrastructures and artifacts support its instantiation in action. Many hackers are incentivized by (in addition to private and social reasons such as fun, peer recognition, and showcase of abilities; see von Krogh and von Hippel 2006) ideological commitment to the idea of freedom to reuse and modify codes. The extent to which codes are malleable for individual and collective use provides a unique set of opportunities for individual learning and collective creativity. Lanzara and Morner argue that "the source code and its multiple beta versions anchor and circulate software-related knowledge while at the same time inscribing component components of human agency and social interaction that facilitate the coordination of a high number of human agents" (Lanzara and Morner 2003, p.3).

The source codes serve to provide a structure to cement and/or facilitate actions, and interactions of hackers. Hackers can reuse each other's codes in the public repository by combining with new ones in developing further modules and files of the same and/or a different applications. The applications (apps) represents the material agency and the actions of modifying codes and developing new apps represent the human agency. In contrast to human agency, Leonardi (2011) defines material agency "as the capacity for nonhuman entities to act on their own, apart from human intervention. As nonhuman entities, technologies exercise agency through their performativity", through which the utility of material agency is realized. He illustrates when human and material agencies are interlocked in a particular sequence, the interaction can be mutually enabling and initiate a set of conditions that are conducive to change. The nonmaterial aspect of open data makes it less subject to the physical attributes and constraints associated with form. Faulkner and Runde (2009) argue that physical form can functionally circumscribe firms' innovation activities. Because to radically change the form of the technology, firms have to not only change the manufacturing process but also risk losing the technology identity. Hence firms have to engage in robust design whereas lead users (in our case, developers and hackers) are more liberal in either radically changing the design or creating new design.

In this study, we collected qualitative data to examine how open data were being assembled and reassembled by hackers. We identified several interlocking sequences of this process centering around the creation, or use, of five distinct artifacts: cleaned data, linkable data, software source code, shared source code (in a revision control system such as github), and service technologies. We found that the 'hacky' nature of much current open government data (including missing data, poorly curated data, tricky to use formats) spurred concerted effort to clean data by hackers. This cleaning increases the reuse value of open data by providing a linkage point to mash up with other types of data. This not only reinforces the value chain of data to information but also induces the creation of new software and/or the use of analytics and visualization tools. By making source code accessible through a source code repository this induces further code modification in the support of developing new service technologies, which ultimately supports the development of new services, and/or the integration of data into existing services.

This research provides two distinct theoretical contributions. First, we show how artifacts provide a linchpin for human and material agencies to work in tandem, noting that these artifacts instantiate certain assumptions about the data and how it should or could be used. This dovetails with prior research,

in that, by separating artifacts from material agency, the role of artifacts serves to complete human agency, and at the same time, either permits or precludes material agency. Although both artifacts and material agency collectively define the materiality of technology, the decoupling explains why complementarities temporarily emerge or fail to emerge (e.g. complementarity is restricted when source code, or cleaned data, is not released to the public and instead remains proprietary: the agency of the artifact is limited). Second, we clarify that the temporal emergence of complementarities is a sequentially interdependent process, with which human and material agency recursively constitute each other and enhance the performativity of open data mediated through the creation of artifacts. The five artifacts we identify create a stack of complements similar to that of software stack (Gao and Iyer 2006), each stack layer can both enable and constrain further development. This observation suggests that ways in which complementarities of open data are assembled and/or reassembled are more recursively interdependent than linearly independent.

Data, Hackers and Apps

According to the Open Knowledge Foundation's Open Knowledge Definition (2006), open data is made openly accessible (usually via the Internet), published in open formats (so it can be read without proprietary software), and under open licenses (removing restrictions on re-use of the data). The UK government is seeking to take a leading role in the development of open data, consulting actively on a Right to Data and exploring ways to structure government 'trading funds' to promote access to data that is currently only available on commercial terms (HM Government 2011). A key focus of open data advocacy is for 'raw data': data shared prior to processing or analysis that might reduce its level of granularity (Mayo and Steinburg 2007). A significant emphasis has been placed on 'hackers' as intermediaries between raw data and its use to impact democratic engagement and public service delivery (Hogge 2010), often focusing on making raw data accessible and/or creating applications (apps) to visualize the data.

In the open source software (OSS) community hackers¹ may be defined as individuals who "enjoy exploring the details of programmable systems and how to stretch their capabilities" and as "experts" capable of advanced and innovative programming. Hackers are frequently motivated by the intellectual stimulation of problem solving, rather than by commercial gain from creating software and services (Lakhani and Wolf 2003). von Krogh and von Hippel (2006) outlines how hackers operate within a "hacker culture" that encourages norms of sharing the source code and innovations that result from their work, rather than enclosing them for private gain. Whilst in the OSS field many hackers now contribute to open source software as part of paid employment, in the emerging open data context a significant emphasis has been placed on voluntaristic hacking, with efforts to catalyze 'civic hacking' taking through weekend hack-days and competitions. This may reflect the relative immaturity of the open data field, and whilst our research draws heavily on examples of voluntary engagement with open data by hackers, we do not exclude from the analysis those who are engaged with open data as part of paid work.

Strong analogies can be drawn between open source and open data; but attention must also be paid to the differences between them. Both software code and datasets can be identified as 'material' artifacts, adopting Leonardi's (2010) definition of materiality as the instantiation of a concept. Software instantiates concepts about methods to achieve a certain task. Datasets instantiate certain conceptual understandings of the entities the data is about: making choices of modeling and representation in the process (Bowker 2000). Many uses of open source code, and of open data, will combine multiple material artifacts to generate new artifacts. In general, open government datasets refer to regularly changing entities, from annual accounts, to performance statistics, and geographical data on transport networks or land ownership. This influences the ways in which resources for working with open data may be modularized².

¹ Although common media use frequently adopts the term hacker to refer to individuals using computer skills maliciously and breaking into systems, hacker communities reject this definition, describing those with malicious intent as 'crackers' and as nothing to do with hacking per-se.

² In a number of the cases we explored we noted open data being exchanged between distinct modular projects, often running across the Internet, as opposed to different components being downloaded and integrated into a single software project as may happen with open source code.

There are also distinctions in the licensing regimes and conventions around open source and open data. The output of OSS hacking is generally openly licensed and shared source code (Alspaugh et al 2010). Whilst an OSS project may draw on other OSS code as an input, the focus is on shared openly licensed output. In open data hacking, the emphasis has been on the openness of the input. Many established open source licenses include ‘share-alike’ terms that require any software building on their shared source to share its modifications, however, the majority of open data licensing frameworks, including the UK Government’s Open Government License, eschew such terms – allowing that applications, services and source code created to work with, or to provide functions based on, open data, do not necessarily need to themselves be openly shared. Although the licensing regime around open data is not a primary focus of our data collection and analysis, some of the determinants of sustainable re-use of open data for service innovation that we note below may be affected by licensing choices. Understanding how the relationship of open data, hackers, and, to some extent, a wider collection of open source artifacts and services, impacts on the realization of value from open data is the core focus of this paper. The elucidation we put forward draws upon notions of complementarities and the interaction of both human and material agency.

Method

In attempting to tackle an emerging phenomenon, we used multiple methods as a way “to attack a research problem with an arsenal of methods that have non-overlapping weakness in addition to their complementary strength” (Brewer and Hunter 2006, p.4). One of us took the role of a participant observer in the open data field, seeking practical insights into how open data use can be supported; the other approached open data as an outsider to this field of study. By combining our insights, and cross-checking our findings with multiple methods, we sought to develop practical knowledge and to contribute to the development of theory.

To provide an overview of the rapidly developing open data field and to anchor our research, from January 2010 to June 2010 we used a custom-built computer assisted qualitative data analysis system to record and analyze public Twitter messages that included the ‘#opendata’ hashtag (Huang et al. 2010), presenting data in tag-clouds for exploration (Rivadeneira et al. 2007) and to highlight issues worthy of exploration. Tweets were regularly reviewed and emerging themes recorded through a private wiki-based research journal (Borg 2001, Janesick 1999, Huberman and Miles 2002).

Between March and October 2010, we participated in 7 open-data events which involved discussions of policy and the challenges in using open data. These events also included hands-on hack-days, working with public data to generate innovative prototypes and services. Table 1 summarizes the events and their respective aims. Participants involved policy makers, data managers, commercial organizations, and hackers/developers. The events provided us with a fresh empirical perspective not bound to the existing theories, deepening our understanding of issues related to open data use and facilitating the identification of key questions and themes for later analysis. We participated in these events both as external observers, and in two cases, one of us engaged as a participant-observer, joining specific groups ‘hacking’ with open data to understand the process of generating an app from an open data hack day. We took extensive field notes from these days, journaling on paper and digitally, and complementing our own notes with an exploration of social media generated by other event participants.

The ethnographic observation and interaction with users led us to focus upon the documentary evidence and participants from the first 10 hack-days (between March 2009 and December 2010) organized by Rewired State (<http://rewiredstate.org/>), allowing us to gain a deeper understanding of the practical processes by which open data was used. Rewired state described these events as “where developers show government what is possible, and government shows developers what is needed”. The Rewired State website recorded details of ‘hacks’ created at the one or two-day events it organized, and allowed us to identify which datasets attracted most attention and the identities of the lead hackers. In the 10 hack-days, 130 open-data projects were initiated but only 43 produced clear prototypes. Of these, 10 remained active at the start of 2011 (based on an identification of those remaining updated and maintained). An

online survey (Gray 2009; Fink 2006) conducted in May and June 2011 was circulated to key UK open government data mailing lists, yielding 72 full responses, and 42 brief descriptions of instances of data use from data.gov.uk. These instances were coded and used to identify different patterns of use.

Table 1. Open Data Events

Date	Event/Aim
March 2010	A sponsored whole day event, focusing upon the challenges of using location data including Ordnance Survey open data, and user-contributed data. Two hack-days attended by over sixty people, exploring the creation of data and information-driven services to support the core UK government sites.
April 2010	A whole day event, focusing on international development and aid data.
June 2010	The second annual Open Source GIS UK conference (a two-day event), focusing upon practitioners' perspectives on the use and development of geospatial open source tools and geospatial open data; participating in a workshop of the use of Ordnance Survey open data and the Open Space tool for mashup
June 2010	Annual meeting of OSGeo Foundation
June 2010	A sponsored whole day event, focusing upon the UK government open data policy of using public open data to build location-based services
October 2010	The first Open Street Map (GB) meeting (a whole day event), focusing upon the development of a work plan to create a re-engineered version of the Open Street Map database for the GB

To supplement the field, survey, and archival data, eight semi-structured interviews were conducted, based on purposive sampling from respondents to the online survey (Bryman 2008), and designed to gather insights into a range of different approaches to using open data: each data-use process detailed in Table 2 was represented by at least one interview. Interviews invited open data hackers to give detailed account of a particular instance of open data use, their reasons for working with open data, and challenges they encountered. All but one interview took place by phone, recorded, transcribed and coded for key themes. By triangulating among multiple sources of evidence, the multimethod provided greater depth and accuracy. With the profiles, blogs and tweets of project leaders and contributors of hackdays, and a range of uses of data, our analysis proceeded through four rounds of coding. In the first round, we coded data use instances into five types as summarized and illustrated in Table 2. In the second round of coding, each author independently identified the reasoning and rationales for the particular uses of open data, and expressed challenges and issues relating to the use of open data. We then replicated the coding with transcripts of the interviews. In the third round of coding, we wanted to determine how open data were assembled and reassembled to increase use and reuse. Thus, we studied the ways hackers appropriated and used open data, and the types of artifacts and technical solutions that they produced. In the fourth round of coding, we sought to discover relationships in the data, by coding for conditions (intervening, causal, and contextual), and actions and interactions, and consequences. We replicated the coding with two further sets of embedded cases of open data use from the Data.gov.uk Data Store. The replication of the coding on embedded cases was to subject our analysis to further testing, ensuring that emerging themes and findings were not specific to a specific dataset, event or medium of interaction (Yin 2003). The first set focused on education data (the EduBase dataset); the second set on public spending data (the COINS).

Table 2. Processes of open data use with illustrative examples

Process (n = instances)	Summary (and example)
Data to Fact - through extract including search and browse (8)	A dataset is used directly to identify a specific fact of interest (e.g. finding out the voting history of a local constituency)
Data to Information - through report including manipulate, statistically	Content from a dataset is given a single representation or interpretation that is reported in text or graphics (e.g. composing a report that profiles communities of interest as part of the Council's equality and diversity

analyze, visualize, contextualize (19)	agenda)
Data to Interface - through interface including configure interface tools, write custom code (26)	An interface is provided allowing interactive representation of a dataset - providing information customized to the user's input (e.g. creating a searchable interactive online map of rail stations)
Data to Data - through an API for data download (17)	A derivative dataset is provided for download, or access via an API (e.g. I "took Westminster Constituency data, combined it with scraped [General Election] 2005 data and exposed it as RDF")
Data to Service - through service integration and creation (4)	A service is provided that relies on open data, whilst not necessarily exposing it to the end user (e.g. using boundary data from the Census to run an application that forwards reports of Potholes to the correct Highways authority)

Results

The presentation of our results in this section is organized around three core elements: the imperfect 'hacky' nature of much current open government data; the motivations of hackers and other open data users; and the assemblage of open data complementarities through complex process of open data use. We argue that the emergence of complementarities is principally rooted in the motivations and culture of hackers as users of open data, responding to the constraints on the data available to them. Open data is seldom sufficient on its own to induce hackers' involvement, and the ways hackers modified and reassembled open data introduce a material aspect to the resulting technology which either constrains or enables further development.

Open Data. Although considerable quantities of data have been released through portals such as data.gov.uk, the quality of that data varies widely. Hackers we spoke with unanimously noted the poor quality of much open government data, ranging from bad data formats (e.g. "issues with quotation marks in the CSV data which can be confused with field delimiters, caused errors in mapping the data to XML") and infrequent releases, to a lack of granularity or inconsistency in naming or choice of identifiers. Hackers contested some open datasets are "no more than a bunch of statistics not useful whatsoever to derive any utility" and some datasets, often Excel datasets which rely heavily on visual presentation, are "very pretty looking things" but that have little re-use value. Another hacker also commented that:

Applications based on old data which is out of date are worthless, they don't provide utility at all, and they only build customer dissatisfaction.

Yet the imperfect nature of open data did not deter many hackers from working with it. A lead hacker disclosed that:

The secret to our success was not staring at the endless list of incomplete/hacky data but actually asking ourselves what the government was doing wrong.

The incomplete/hacky nature of open data provided a degree of malleability for hackers to clean the data, by "chucking out all the dodgy stuff because there is some dodgy stuff in there", in order to provide useful and usable data.

Hackers. We explored uses of open data in a range of contexts, from hack-day events, where hackers come together in one location and set themselves the challenge of initiating a new open data-related project in one or two days of intense activity, to uses of open data by individuals working in their own time to explore and engage with data. Because our period of study has been one in which a lot of new datasets were released as open data, even without hack-days being organized, the periods shortly following to release of key datasets such as the COINS public spending dataset, and the Ordnance Survey postcode databases, often took the form of 'virtual hack-days', with hackers across the country working on the same datasets in loosely co-ordinated networks.

There are many different reasons for engaging with open data. Analyzing a wide range of instances of open data use, and drawing on conversations with and documentary evidence from open data users, we identify a range of factors that incentivize engagement with open data. For some, desire for access to specific facts motivates engagement with data. One open data user noted that as he had lost one appeal regarding a school place for his daughter, so he decided to look up for the appeal data:

I was just interested in trying to find out how many appeals succeeded and really what the status was around the different councils and whether we actually had a chance...when you are in that sort of situation you want to know about what happens to other people and how likely it's, and the type of arguments that do win.

In this instance, once the user had located the facts he was looking for, he had no incentive to develop tools or applications to help others access this data, nor to conduct any further analysis of it. By contrast, a school governor challenged by the education authority over his school's revenue balance (retained funds), sought out multiple sources of public data (including data obtained through a Freedom of Information request as it was not proactively published) and combined them in an analysis published on his blog. The details of how the analysis was carried out were not published (though they are detailed in E5 in figure N based on an interview with the individual), but rather the information generated was offered as an advocacy tool for debate over revenue balance policy. The governor noted that:

These numbers tell a story, and if you go out and say I want to reduce all the other balances you may end up finding that you're actually dis-improving the schools that are out there because generally it's a characteristic of good schools to have a high balance.

Some hacker users of open data were driven by a specific desire to show how government services could be run better or more efficiently with digital technologies. The tag-line of Rewired State ("Coding a better country") captures this idea. A number of instances of open data use were specifically oriented at demonstrating what could happen if more data was opened up – highlighting the potential of data, and the current limitations on its realization given the limited support of data. An elder hacker noted that "younger hackers were more interested in solving problems"; and that once they identified the problems that needed solving, the next logical step for them is to consider where to "source the right data". This may contrast with those with greater awareness of current data availability, and so who focus their energy on problems tractable with currently available data, including recently released data. As with the fact- and information-focused uses of data above, it was common for hackers to draw on personal frustrations as a motivation for development. Often this might include trying to identify a shared problem and then to focus on sourcing data or cleaning hacky data in order to deal with it. One younger hacker noted that:

Everyone, at some point in time, has been irritated with the excessive demand on select tube stations – anyone that's been past Oxford Circus in rush hour will understand where I am coming from. In addition, time is at a premium in London more than anywhere else – every minute lost waiting around for a train (or worse, waiting to get off of one) is a minute's money. Our solution is to show people hotspots, and how to avoid them.

In other data-use instances, we observed the utility value had direct relevance and appeal to hackers' current situation and beliefs, e.g. "moving to London [hence contributing to this particular project]", "[this app] helps you to get fit", "I am a bike user...[this app] can get people to move bikes to emptier docks". In some situations, hackers developed solutions to directly benefit their collaboration with other hackers:

We stumbled upon the fact that we'd been using the same set of tools for the past few hack days, and then the idea hit us that we could build a tool which just helped to coordinate rapid development...after all, regardless of whether the project won or not, we would still end up with a great tool we could use in the future.

We observed that open data users were motivated for not only by altruistic, private and social reasons but also by the prospects of monetary reward, and engaging with the economic potential of open data. One hacker noted that:

My two hats are very different. Certainly, as a private citizen I see the way people have adapted and started using the data...on a professional level, we will see our data actually being published in things like RDF in the not too distant future to allow it to be found and used more easily, and then we have to figure out how we make money out of it in time, and keep me in employment.

Many of the hackers involved in hack-days developed software as a profession rather than a hobby, though not necessarily working with public sector data on a day-to-day basis. For some hackers, their contribution to open hack-day events aimed to showcase their abilities to prospective employers. A hacker

unreservedly stated “*offer me a job*” on his website. And among all the lead project developers of the Rewired State projects we explored, 78% provided their affiliated work contacts (including names of the companies and/or email addresses), with others consisting of young hackers still in education, academics and researchers.

The data-use instances demonstrated the innovation possibilities, but rarely were they sustained or developed into sustainable services. Of the 43 initiated projects in the ten Rewired State events, only ten remained actively updated and maintained. The active projects exhibited several unique characteristics which were similar to a typical open source project (e.g. Kuk 2006). They comprised: not a loner project; having immediate relevance and appeal to the hackers; devising a technical solution to a well-defined problem; aiming to form an open source community; seeking to improve the reuse value of data and other associated artifacts; and seeking to exploit the resulting technologies for service innovation and/or profit. Whereas other non-active projects were characterized by short-term goals, i.e. using open data to solve a problem of personal needs and use benefit (use value).

Although over 3000 datasets had been released from data.gov.uk, and more from local data stores such as the London Data Store, we observed hackers clustered around specific datasets and APIs, partly due to the completeness of the available data, and partly due to the thematic focus of that data. This pattern was also particularly pronounced exploring hack-days related to the London Data Store. Although the London data store included over 425 datasets at the time of study, we found just 47 uses of that data publically noted. Amongst the datasets, 8 in particular attracted the majority of attention – all of which were transport-related datasets. We noted 22 instances of this data being put to use, generating 8 smart phone apps (4 paid, 4 free), 2 APIs (application programming interfaces) and 12 websites (including interactive maps, graphs and visualisations). Whilst some were ‘experimental’ uses of the data, a number of these would constitute clear service innovations – creating tools that the state had failed to provide with prior proprietary access to the data. The disproportionate focus on particular datasets can be attributed to the fact that hackers developed solutions in response to the popular demands from the public. On the website of London Data Store, the public was invited to make suggestions and vote for their popularities. The top ten mostly voted suggestions were all transport related. Hence, it was not surprising that the eight transport datasets attracted most developers’ attention, and that 78% of the solutions were contributed by hackers (either working for themselves or commercial organizations) and the rest were contributed by researchers affiliated to academic/research institutes. The utility accounts for hackers’ preferential attachment, in that, hackers were most likely to provide solutions that yielded the most utility to themselves and/or the public. This has interesting implications for identifying the datasets around which complementarities may autonomously emerge, and those datasets (more niches with respect to hacker interests, but potentially of significant social value) around which active effort may be required to assemble complementarities that support their re-use in service innovation.

Assemblage of Complementarities

Direct use of open data seldom occurred in most of the data-use instances that we analyzed. We found open data had to be first cleaned or curated by hackers, and then made available as a cleaned data dump on a website or through the use of API. The cleaning process changed the material aspect of the original dataset, and created a new artifact that permitted the use of a technical platform for its distribution. The technical platform effectively performed the role of material agency by distributing the cleaner version of open data. The cleaned data which was structured and discoverable permitted various linking possibilities with other datasets (e.g. linking against schools/departments, programme codes, places, and people). The resulting linkable datasets offered other open data users the opportunities for exploiting some of the known analytics and visualization techniques. Others involved hackers writing code and/or configuring existing tools to work with the linkable datasets, for example, configuring Yahoo Pipes by drag and drop. By separating artifacts from material agency, this allowed us to identify the key intermediaries in the assemblage of open data complementarities for service innovation. The artifacts formed the components of a value stack: from messy raw data to linkable data; from linkable data to software; from software to shared code repository; and from repository to new web services. At each layer of the stack, the material aspects of the artifact served to linchpin human and material agencies in an interlocking sequence. We identified five interlocking sequences to illustrate the emergence of complementarities (as shown in Figure 1).

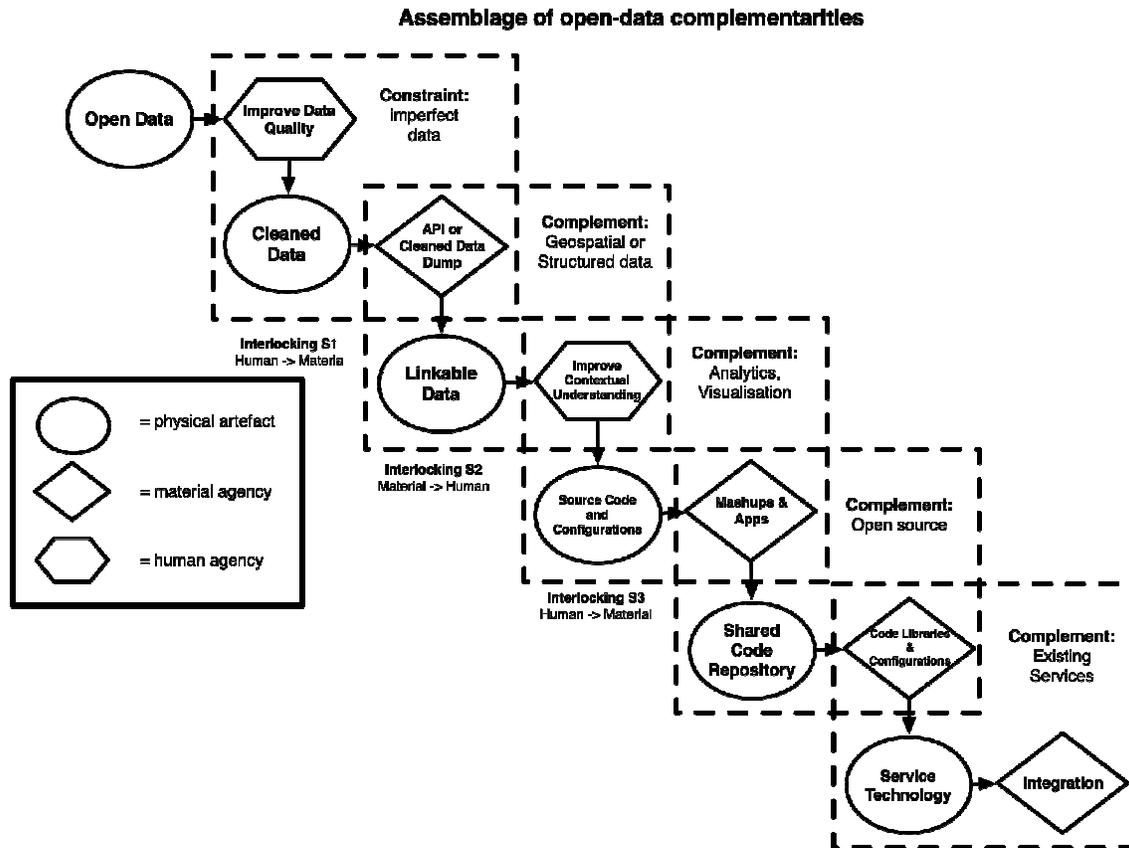


Figure 1. Assemblage of open-data complementarities

In the first interlocking sequence, human agency changed the material aspect of open data (by cleaning the data) and created a cleaner dataset (artifact), and the material agency enhanced the performativity for easy access and distribution of the data through the use of API (or data dump of the cleaned data). In the second interlocking sequence, the material aspect of the cleaned dataset (artifact) intended to improve the understanding of the data, in that, not only what users could do with the data but also how they could draw in extra data, without need for prior knowledge of all other APIs or data sources. With various possibilities of how cleaned data could be linked with other usable and useful datasets induced further exploration activities (human agency) to improve the contextual understanding of the data. This was similar to the two aforementioned data-use instances regarding the rate of successful appeals, and the relationship between school performance and annual reserve. In the third interlocking sequence, despite its intended goals (material agency), linkable data could still impose certain constraints and challenge on users to look for social and technical support. The following two quotes illustrated the limits of linkable data, and how human agency sought to circumvent the material constraints:

I put a plea out of Twitter saying anyone knows where I can get political controls of councils and someone pointed me to a page somewhere. It's some with a geeky interest in it who has actually gone out and got the data.

We reviewed as many of the provided datasets as possible, looking for common data points such as people, events or places on which we could do a linking exercise. We drew a blank on this, and instead did a mapping exercise based on NGR co-ordinates.

Table 3. Embedded cases of education data-use

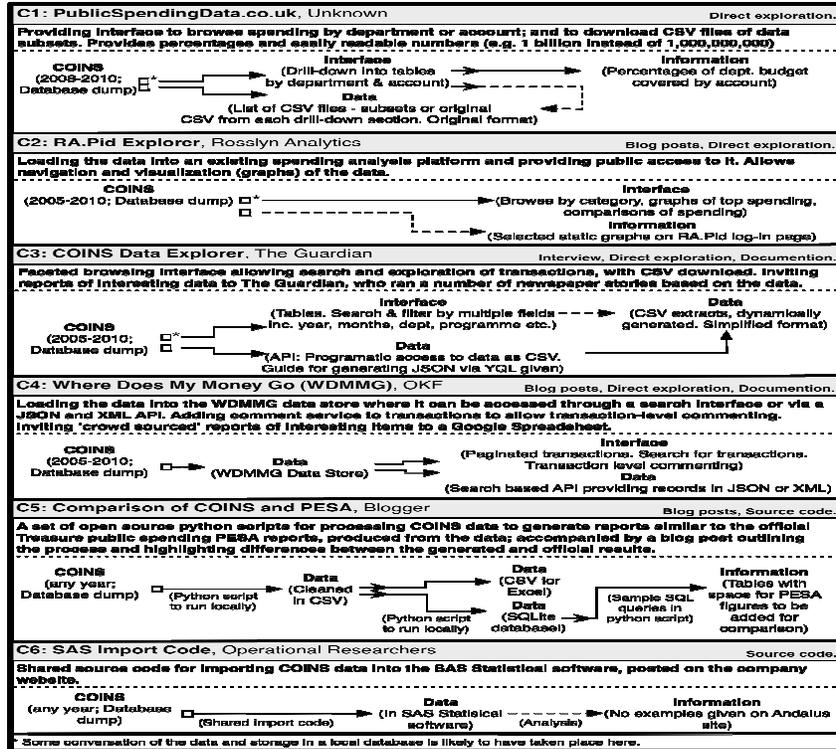
Case ID: Title, Creator	Sources for embedded case
E1: UK Schools Map, Independent developer Searchable list of school locations and performance, presented on a map. Created before widespread availability of OGD in 2006.	Blog posts, Source code, Direct exploration.
E2: EduBase as RDF, Data.gov.uk team and partners Converting the EduBase data to RDF and exposing it via a SPARQL endpoint and API	Blog posts, Direct exploration.
E3: Lichfield My Area Map, Local authority web manager Plotting school locations on a District Council website online map. Sharing code and tools to help others to do the same.	Interview, Blog posts, Direct exploration.
E4: Schoolscope.com, Commercial developers. Funded by 4IP Providing a visually rich interface onto school performance - translating statistics into graphics and plain English statements	Blog posts, Direct exploration.
<p><i>*Full technical processes unknown. Certain details are not publicly documented</i></p>	
E5: School Revenue Balance FAQ, School Governor Analysing school performance against school 'Revenue Balances' and blogging the results.	Interview, Blog posts, Survey.
<p><i>*The project explored multiple relationships and correlations but only reported on one control of local councils...*</i></p>	
E6: Refugee Charity Research, MSc Student Exploring spreadsheet of local demographics on young people to inform planning and funding bids for a local charity.	Interview, Survey.
E7: School Admissions Appeals, Project manager Exploring a spreadsheet to identify the success rate of school admission appeals in a specific area and comparing with other appeal success rates.	Interview, Survey.
E8: Guardian Data Blog - Admission Appeals, Data Journalist Datablog entry on school admissions appeals data. Published as Google Spreadsheet; sortable list and heat-map. Written up as news story on the website and in newspaper.	Interview, Direct exploration.

In addition to seeking support, other open-data users would reconfigure existing tools, and write codes for data mashups and new applications. This marked the beginning of the fourth locking sequence which involved the hackers. Hackers who embraced open source would chose to deposit the source code of their apps in a shared source code repository. The donation underlined the ethos of open approach that “it won’t be a sole developer who ultimately brings it to fruition”. The private donation by hackers led to the last interlocking sequence whereby other hackers could reuse and modify the codes, in a limited number of cases we observed, integrating shared code and/or open data into new service technologies, or using it to complement and innovate within an existing service. Because the data use instances were drawn from multiple datasets, we applied the framework of interlocking sequences in two sets of embedded cases to show the sequential interdependency of the value stack. Tables 3 and 4 illustrate how same dataset can lead to different assemblage of complementarities, and how, in a number of cases, the absence of certain sequences and complementarities has led to duplication of efforts. For the embedded cases of education data-use, the cases E1, E3, E4, and E8 exhibited the characteristics of interlocking sequences 1, 2, and 3; E2 exhibited 1 and 2; and E5, E6 and E7 exhibited the first interlocking sequence. And for the embedded cases of COINS data-used, only C4 exhibited all five interlocking sequences; C2, C5 and C6 exhibited 1, 2 and 3, and C3 exhibited 1 and 2.

The case C4 describes the Open Knowledge Foundation (OKF) use of COINS public spending data, and exhibits all five interlocking sequences. It is worth noting that there was close collaboration between the hackers involved in C3 and C4, although not represented in the diagram. On the day of COINS launch, OKF collaborated with others to clean the data, using an etherpad and IRC channel to discuss strategies for cleaning the data. The data was imported into their own database, and they provided an API onto it, allowing others to draw upon the clean data in raw or filtered form. As the COINS data made use of a lot of programme codes and categories for which no public code-list was available, they worked together with The Guardian Newspaper to crowd-source definitions of codes, improving the ‘linkability’ of the data. The processed and linkable spending data has subsequently been used to generate a range of visualizations and analysis, and to power WhereDoesMyMoneyGo.com, and existing open source project for visualizing

spending data that has been adopted as a framework by a number of other national projects working to visualize public spending. Source code for working with COINS, and for the WhereDoesMyMoneyGo site has been shared through the OKFs own source code repository.

Table 4.
Embedded case of COINS data-use



Discussion

To understand what complements open data, we examine the underlying processes that constitute the conditions for physical and social complementarities to emerge and accumulate. Our findings suggest the initial efforts by hackers (driven by the desire to create utility to themselves and/or the public) set the momentum for change. The cleaned data provides the first key intermediary for material agency to follow through the use of an open API or data dump. This induces further actions to enhance the utility of open data through the creation of an additional set of complementarities. Embracing open approach, hackers share the codes of their apps to induce further chain of actions and interactions. The interlocking sequences between human and material agencies, and their interactions with artifacts create the conditions for change; and notably accelerate the development of innovative solutions.

Our theory suggests complementarities of open data are sociomaterial assemblages (Latour 2005; Markus and Siliver 2008), constituted and re-constituted through an on-going interchange between human and material agencies, and during which new artifacts are created and new technical solutions developed. Each iteration incrementally enhances the performativity of previous artifact. The open approach instigates the conditions for further instantiation. Our theory can be used to derive evaluative frameworks to better assess the impact of open data at different stages of its use – both in terms of measures of tangible (such as new datasets) and intangible assets (reputation effect of hacking) along the path from the releases of open data to the creation of innovative services.

This study develops new theoretical explanations and presents new empirical evidence to advance our understanding about the conditions for the emergence and sustainability of complementarities of open-data use in the UK. Theoretical explanations and empirical findings of the study make important

contributions to a practice-based perspective of open data research and practice. We discuss some of the limitations of the study before discussing the contributions.

The context of inquiry is the open-data use in the UK. The limitation of a single-country study is that its empirical findings may not be generalized to other countries. Yet, in-depth study of open data is necessary for informing future more broad-based studies including cross-national comparison. Also our empirical work has been focused on just one context in which open data can drive service innovation: the use of data by hackers through more-or-less informal hack-day networks and individual engagement with data. Our ethnographic research and interviews were designed to identify other forms of engagement with open data, such as by established public service providers or larger enterprises – but at the time of study, no evidence of significant engagement in these contexts was found. It is reasonable to assume, however, that other settings may follow hacker communities in exploring the innovation potential of open data, and such contexts would warrant focus in further research. Nevertheless, the distributed nature of open-data uses makes it difficult to establish the boundary condition of the studied phenomenon. Though not part of our research question, we found a number of active hackers crisscross and participate in multiple open-data projects. How this boundary spanning activities affect the emergencies and sustainability of complementarities warrants future research.

With these constraints noted, the present study makes several contributions. Our first contribution is to the theoretical base of complementarities. We explicate additional conditions (contextual, intervening, and causal) of complementarities in addition to a contingency account which is implicit in the economic version of the theory. We explain why hackers' motivations and hacker culture provides an initial context in which complementarities emerge with the releases of open datasets. This initial motivational context not only drives hackers to expend various efforts (clean, curate, and scrape) but also creates a series of artifact that alters the materiality of technology to enhance performativity of open data for reuse and service innovation.

Our study also contributes to the sociomateriality literature. We show the way artifacts interlock human and material agency provides a basic structure for the stack of complementarities (including combination of external complements) to accumulate. The interlocking sequences explain how complementarities temporarily emerge and are sustained, underlying the significance of motivational drivers and the roles of artifacts to facilitate constant revision and co-configuration between technology and human. This dovetails from prior research on sociomateriality by shifting the emphasis away from resistance and accommodation (as in Pickering's concept of mangle) to a model that takes motivational drivers and artifacts into accounting for the temporal emergence in practice. The motivational drivers explain why hackers instead of resisting or circumscribing their activities to the limits of open data actively seek to circumvent material constraints by creating new artifacts and inscribing their goals (e.g. wider dissemination) in material agency. The new artifact and material agency serve to scaffold actions and interactions of other hackers (Orlikowski 2006). The sharing of artifacts is pivotal to address how complementarities can be sustained and configured. For example, the sharing of artifacts in form of software codes can induce code reuse which indirectly encourages open-data use. This openness instigates further iteration of performativity activities which lead to the creation of further artifacts. This leads to our third contribution to the design science research. The ways in which artifacts are shaped both in terms of form and function through different acts of instantiation addresses some of the problem of specifying design theory. By mapping out the evolutionary trajectory of artifacts, our theory provides a nuanced account and specification of the degree of mutability in artifacts put forth by Gregor and Jones (2007). They assert "the lack of theories about IT artifacts, the ways in which they emerge and evolve over time...are key unresolved issues for our field and ones that will become more problematic in these dynamic and innovative times" (p. 326). By taking the motivational and contextual factors underpinning the emergence of open-data complementarities, our theory foregrounds artifacts at the centre of change, supporting continuous redesign and enhancing performativity.

This study also makes a number of contributions to practice. Our framework of interlocking sequences of open data use highlights the various steps involved in moving from the release of data to the development of innovative services. This provides practical guidance for policy programmes seeking to promote uptake of data, and provides an evaluative framework for studying the value added to data through different initiatives. For example, it would facilitate a comparison of hack-day driven approaches to promoting data-driven innovation, in which a culture of sharing artifacts can support the emergence of

complementarities, with competition based approaches to promote data-driven innovation (e.g. Apps for Democracy in the US), in which social and material artifacts may be less readily shared. It also suggests the forms of infrastructure (e.g. source code sharing systems) that open data providers can explore to support more effective use of their data.

Conclusion

Our empirical work shows that there is no straight line from release of open data to service innovation, and that the action of lone hackers is insufficient to realize a revolution in the delivery of services through data. Grand claims for the service revolutions that open data may bring about are overstated; though more modest claims can be grounded in evidence. Our theory of complementarities suggests key conditions involved in the effective use of open data. We find few instances where such complementarities are fully assembled round any specific dataset or thematic area. Drawing evidence from a process methodology, our study explicates the distinction between the conditions for initial participation, and the conditions for sustained participation in service innovation with open data, noting the intricate interplay between human and material agency, mediated through a series of artifacts.

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