Science & Technology Studies

3/2023

Science & Technology Studies

ISSN 2243-4690

Open access & copyright information

Science & Technology Studies

Volume 36, Issue 3, 2023

Articles

Book reviews

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How Matters of Concern Invade Technologies: The Case of the Menstrual Cup

Franck Cochoy

Toulouse Jean Jaurès University, LISST-CNRS and Institut Universitaire de France, France / cochoy@univ-tlse2.fr

Abstract

Markets have evolved from classic markets to concerned markets – that is, markets that focus not only on economic efficiency and the utilitarian matching between supply and demand but also on the negative externalities produced by market products and exchanges. The menstrual cup is used as a good example to address such matters. This device has supplemented disposable tampons and pads, and if the original focus on practical and material dimensions remains (absorbency, lightness, smallness, disposability, etc.), new concerns have invaded the scene. Significantly, in the advertisements for menstrual cups, reusability, recyclability, safety or hypoallergenic issues have replaced the past quest for efficiency and feeling carefree. How have matters of facts and of concern been involved and with what implications? I propose to address this question based on a computer-assisted analysis of 5,235 consumer reviews (posted on Amazon.com) about the Star Cup (pseudonym), a leading product on the market for menstrual cups. The analysis points out that health and sustainability are only two of the many reasons behind the current use of menstrual cups. Various and often conflicting concerns are intertwined in cup consumption. This helps us understand that the development of sustainable technologies requires taking many more elements and dimensions into consideration than mere environmental friendliness.

Keywords: menstrual cup, health, sustainability, concerned markets, consumer reviews, digital humanities

The evolution of contemporary consumer markets provides evidence of the shift from 'matters of facts' to 'matters of concern'. Bruno Latour (2004a) coined the latter distinction as a new way to look at "things", that is, entities that combine objective and moral dimensions. For Latour, both dimensions, far from being opposed, are instead closely related – the unquestioned 'facts' of science and the material power of technological artefacts can (and even should) be discussed, not because of their 'social' or 'constructed' character, but because of the concerns they embody and raise at the same time (Latour, 2004a, 2004b). For instance, the myopic preoccupation with the functional aspect of technologies gives way to an increasing care for their impacts on human health and wellbeing, as well as on the environment. This leads to the emergence of 'concerned markets' – those that focus not only on economic efficiency and the utilitarian matching between supply and

demand but also on the negative externalities produced by market products and exchanges (i.e., discrimination, inequalities, exclusion, pollution, hazards, etc.), as well as how better market designs or public policies may avoid or alleviate such problems (Cochoy, 2014; Dubuisson-Quellier, 2018; Geiger et al., 2014).

Menstrual products represent a well-suited case to illustrate the evolution from classic to concerned markets. Their development has proceeded from focusing on absorbency and efficiency to questioning about their toxicity and polluting aspect (Cochoy, 2021). Menstrual management techniques have never ceased to exist, but it seems that they and the accompanying discourse have evolved. The menstrual cup and period underwear[1] have supplemented tampons and sanitary pads, and if the original focus on practical and material dimensions remains (absorbency, lightness, smallness, disposability, etc.), new concerns have invaded the scene. Significantly, in the advertisements for menstrual cups, reusability, recyclability, safety or hypoallergenic issues have supplemented the past quest for efficiency and feeling carefree. Similarly, the growing sensitivity to the vocabulary that is appropriate for describing female-related issues illustrates well how various concerns have invaded menstrual management technologies – or have been 'refracted' into them (Johnson, 2020). For instance, the will to get rid of the prejudices attached to 'hygiene' has led to the use of the phrase 'feminine care' or 'menstrual products' (Bobel, 2010; Fahs, 2016). Similarly, the determination to detach virginity from anatomic misconceptions has led to the abandonment (at least in Sweden?) of the misleading term 'hymen' in favour of the more appropriate 'vaginal corona' – that is, not a membrane but "a loose ring of skin that circle[s] the vaginal wall" (Johnson, 2020: 110).

Thus, the following questions are raised: what has fuelled the evolution from pads and tampons to cups? More importantly, how have matters of facts and matters of concern been involved in these consumer goods? Do health issues and environmental consciousness drive the production and use of menstrual cups? How is it possible, technically speaking, to trace such evolutions?

I propose to address these questions with an original computer-assisted technique aimed at grasping the themes involved in a corpus consisting of 5,235 consumer reviews (posted on Amazon.com) about the Star Cup (pseudonym), a leading product on the market for menstrual cups. In this paper, I focus on consumers' views about this cup, whose manufacturers now praise its supposedly safe and environment-friendly character yet with little concern for the practicalities of using such products. Indeed, the analysis points out that health and sustainability often clash with other concerns, such as comfort and practicality, thus raising the problem of a 'disorder of concerns'. After a brief overview of the research topic – the menstrual cup – and the kind of data that I rely on – online consumer reviews – I present the method chosen to make sense of these data, that is, a computer-assisted thematic analysis based on the Iramuteq open-source software. Finally, I review the results obtained. Various and often conflicting concerns are intertwined in cup consumption. This helps us understand that the development of sustainable consumption paradoxically requires taking many more elements and dimensions into consideration (see comfort issues, use conditions, etc.) than the mere environmental friendliness of consumer goods.

A brief presentation of the menstrual cup: A cyclical Phoenix-like product

There may be no better case than menstrual products for those who wish to study the development of markets and their social and moral underpinnings. These products claim to address a universal female bodily function and propose various solutions to do so. For over a century, sanitary pads tampons, and menstrual cups have undoubtedly contributed to easing women's lives and promoting better gender equality, especially as ways to help women 'pass' in the work and the public spheres. In the United States, before the widespread diffusion of disposable pads and tampons, physicians often presented menstruation as a periodic illness and recommended that women should stay home during their periods. The new technologies have helped in fighting against such

prejudices; they have assisted women in better managing their menstrual flow, keeping it private and showing that they are fully able to participate in every event of social life, whatever their periodic state might be (Vostral, 2008).

The analysis of the available literature, on one hand, and the close examination of patents for menstrual products, on the other hand (Cochoy, 2021), show a series of interesting developments. At first glance, the history of the market for such products provides evidence of a clear succession of a series of more or less familiar technologies: napkins, tampons and cups (more recently joined by menstrual panties and reusable pads). However, the same history shows a strong asymmetry; whereas pads and subsequently tampons quickly became mass products in the first half of the 20th century, the cup – although present from the late 19th century, well before its successful competitors – remained far behind them for a long time. This asymmetry is reflected in the literature; there are countless publications on menstruation issues, specifically on pads, tampons and other menstrual management methods, in sharp contrast to the literature on cups. The device has been largely neglected in related studies, apart from Shure's (2016) press article, O'Donnell's (2017) pioneering paper on the history of the menstrual cup or brief mentions in Vostral's (2008) comprehensive history of menstrual technologies. Significantly, of the 71 chapters of the impressive *Palgrave Handbook on Critical Menstrual Studies* (Bobel et al., 2020), none focuses on the menstrual cup as its main topic. Similarly, recent papers that investigate cups more closely do so as part of studies focused on other devices (Gaybor, 2019; Dutrait, 2022). Additionally, the available literature often takes the cup as a generic good and focuses on its adoption dynamics in various contexts (Fahs and Bacalja Perianes, 2020; Hytte et al., 2017; Mason et al., 2015; Oster and Thornton, 2012; Phillips-Howard et al., 2016; van Eijk et al., 2019). This literature highlights both drawbacks and merits of cups in terms of price, hygiene, health or sustainability, without paying close attention to technological aspects and use details. Drawing on Dutrait's (2022) care for the latter dimensions, and following works focused on materiality and body experience in the case of female-oriented technologies (Della Bianca, 2022; Hamper, 2020; Johnson, 2020), I aim to review the reasons behind the modest adoption of the cup. I explore the relations between the cup and down-to-earth body issues, use matters, technological aspects and market practices, on one hand, and larger societal issues, on the other hand. Of course, a lot of work has been done on embodiment issues in the fields of feminism, STS and other social sciences (for a review of the literature, see Shilling, 2016). For instance, Haraway (1988) renewed our vision of the complex relations among sex, gender and technologies. In this paper, I adopt a slightly different focus. I approach issues related to the body from the perspective of consumerism by showing that practical issues (e.g., the ways to use menstrual devices, adjust them to the body and cope with the use environment) should be taken into account better when developing and promoting such products.

Despite the common yet mistaken understanding, which views the menstrual cup as one of the latest innovations in menstrual products, this device was developed even before the invention of sanitary pads and tampons. 'Menstrual receptacles' or 'catamenial[2] sacks' had been devised long ago by several single innovators, as evidenced by the series of 19th-century patents.[3]

However, the subsequent history of menstrual cups has proven to be as cyclical as the periods they are meant to address. Pioneers' proposals went nowhere, probably because of the awkwardness of some of the early designs and the inventors' failure to advance their prototypes to production and marketing. However, in the late 1930s, a woman, Leona Chalmers, eventually succeeded in turning a long-lasting patent idea into a real mass-marketed product, Tassette. This name is based on the French word *tasse* (cup) and the diminutive suffix *ette* (Tassette thus means small cup) (Waldron, 1982).

After an incredible cycle of market failures and 'remarketing efforts' and the parallel introduction of several technical improvements, including the design of "air vents" to avoid suction effects during removal (US Pat. No. US1996242A, 1935), or the adoption of latex rubber (in 1987) or medical-grade silicone more recently, as well as other innovations in terms of better design and various sizes,

the cup market seems to have eventually gained ground (O'Donnell, 2017). In 2018, the value of the global menstrual cup market accounted for around $1.2 billion (Kunsel and Sumant, 2019) compared with the $29.1-billion value of the total market for menstrual products (pads, tampons and cups) (MarketWatch.com, 2022), that is, a modest but growing 4.1% global value share.

How could we explain the recent breakthrough of menstrual cups, which for the first time seems to have brought them to the scale of a globally marketed and now irreversible product, despite their modest market share? How has eco-friendliness been embedded into menstrual cups and to what extent/against what obstacles? More generally, how do technological features (matters of fact) and moral and political issues (matters of concern) interact, as well as articulate and contribute to this shift?

I draw on the latter distinction between matters of fact and matters of concern to address the above research questions. The two notions are borrowed from Latour. According to him,

> Reality is not defined by matters of fact. Matters of fact are not all that is given in experience. Matters of fact are only very partial and, I would argue, very polemical, very political renderings of matters of concern and only a subset of what could also be called *states of affairs* (Latour, 2004a: 232, emphasis in original).

By matters of concern, Latour means what people care about and also what social scientists should care about for them. Examples of such concerns are "family, love, religion, health, sex, security, education, justice, money, food, violence, sports, the environment, and so on" (Stephan, 2015: 214). In other words, matters of concern amount to the realm of emotions and meanings, values and valuation processes. As such, matters of concern echo David Stark's (2009) framework of the orders of worth (based on Boltanski and Thévenot's *Economies of Worth*, 2006). In the same way that, according to Stark, people and objects are valued along multiple orders of worth – such as the classic price dimension and other valuation criteria, including performance, creativity, fame and so on – I suggest that actors care about human and non-human entities along varied *orders of concern*, for instance, their comfort, economic, environmental or health dimensions. Similar to Stark's (2009) orders of worth, orders of concern may be presented as part of a 'heterarchy', that is: an organised set of valuation principles. However and as explained in this paper, they may also appear as elements of a messier and even self-contradicting whole, for example, when environmental issues clash with health ones.

Matters of concern have been attached to cups in the course of various events and societal evolutions. It was only in 1976 that menstrual products were classified as medical devices by the US Food and Drug Administration and thus submitted to test procedures and subjected to the related concern about toxicity – even if this regulation came too late to be applicable to the Rely tampon responsible for the Toxic Shock Syndrom (TSS) (Vostral, 2008, 2011, 2018). The latter scandal strongly contributed to spreading the concern about toxicity among the general public. More generally, it also favoured the broader distrust in menstrual products and their subsequent association with environmental concerns, eco-feminism and menstrual activism (Bobel, 2008), the rejection of single-use disposable products (Hawkins, 2018, 2020), the criticism of the business of menstruation (Arveda Kissling, 2006; Mørk Røstvik, 2022) and the quest for safer and more sustainable alternatives (Armstrong and Scott, 1992; Bobel, 2006; Costello et al., 1989).

As shown in this paper, networks do not only bind tangible entities but also connect artefacts and persons with abstract feelings, responsibilities and values. More recently, the Internet has made an important difference by embedding matters of facts and matters of concern even further. The Internet is a material infrastructure (Bowker et al., 2010) with the power to convert private and isolated experiences into public and shared expressions, that is, turn intimacy into 'extimacy'. Of course, consumers have not waited for the Internet to sometimes express their views publicly, from the level of their local neighbourhoods and communities to formal consumer associations or through readers' letters to various newspapers (Cohen, 2003). Nonetheless, the Internet and related channels have contributed to changing such expressions' form, scale and visibility. Until

recently, product qualification was overwhelmingly controlled by the top-down discourse of marketing and advertising. However, with the new interactive media, corporate discourse can be challenged by bottom-up and shared expressions of the public, whether on websites and webzines (Bobel, 2006), blogs, forums, social media or in consumer reviews. It is precisely this ability of digital media to express and share consumer concerns on a global scale that I explore further, through a detailed analysis of a collection of consumer reviews posted on Amazon.com.

Consumer reviews: Potentials and caveats

How can consumers' concerns about the products they use be accounted for? Are sustainability and health issues the key drivers behind the recent spread of the menstrual cup? Considering the global market for menstrual products, it makes sense to approach it based on global data. To trace and analyse these views at the worldwide level, I have chosen to rely on digital methods, which are among the best means to address social practices on a global scale (Lupton, 2012; Marres, 2017; Rogers, 2013). I focus on consumer reviews, given this type of expression's growing importance for contemporary markets (Beuscart et al., 2016) and society (Blank, 2006). I retrieved the complete collection of consumer reviews posted on Amazon.com about the leading product on the market for menstrual cups worldwide, that is, 5,235 reviews posted between 2005 (two years after the product development) and 2019. In some respect, the choice of the database is somewhat contingent; I favoured a source for which a simple scraping procedure existed.[4] Hopefully, working on Amazon data makes sense; as the largest online marketplace, it covers the global market and thus offers the largest and most diversified number of reviews. For a point of reference, I also scraped the reviews about leading disposable sanitary pads and tampons (288 and 318 reviews, respectively).[5] I shall not mention product names because my purpose is obviously not to present a kind of comparative advertising. In the following developments and for the sake of simplicity, I refer to the three products as disposable sanitary pads, tampons and cups, but it is important to keep in mind that I refer to particular brands and models, not generic products. First, I shall extract some basic facts and insights from this comparison.

Consumer reviews constitute a novel and rich source of information about consumer behaviour. With some exceptions, they amount to a kind of voluntary, global and massive expression, in contrast to solicited, situated and more or less directed interviews and questionnaires. Additionally, since most consumer reviews are about products purchased and often used for the first time, they help us gather information about consumer experience in terms of both practice and feelings. Several studies have explored the role of online consumer reviews in purchase decisions (e.g., Hu et al., 2014; Karimi and Wang, 2017; Maslowska et al., 2017; von Helversen et al., 2018). Of course, relying on online reviews as historical data also provides evidence of serious drawbacks. One is anonymity, which prevents analysts from knowing the characteristics and the structure of the underlying population. Another caveat is the now classic suspicion about fake reviews. It is difficult to directly overcome the first problem, but at least two observations can be made. First, even if anonymous, countless reviews reveal details about their writers, such as gender, occupation and so on. Second, the importance of social characteristics depends on the research objectives. Because my aim is not to assess the cup usage of the overall population but to analyse the way that consumers evaluate the products they have bought, the lack of systematic information about these consumers' backgrounds is acceptable, if not optimal. The third drawback of consumer reviews is their individualised and market-oriented character; each review comes as a specific testimonial, with little or no consideration for the neighbouring ones, and focuses on a particular brand from a consumer point of view. This contrasts with online forums or Facebook groups where participants share their views, debate and interact with one another, adopt many more perspectives than just a commercial one and thus have the potential to bring additional insights. For instance, Gaybor's (2019) study, partly based on such data, covers better political views fuelled by menstrual activism; her inform-

ants seem to envision the cup as an empowering tool, far beyond the view of a mere hygiene device that most Amazon reviewers tend to convey.

As far as fake reviews are concerned, several resources help address the issue. First, now there is extant literature about this problem. Based on various detection algorithms (Mukherjee et al., 2012, 2013), IT specialists have shown that the phenomenon is far more modest than what mass media claim; fake reviews generally represent 3–6% of the total (Anderson and Magruder, 2012; Ott et al., 2012). If Amazon claims that 99% of its reviews are legitimate because more than 99 percent of them are written by real shoppers who aren't paid for them[6], unscrupulous merchants use social media to flood the platform with fake reviews (Dwoskin and Timberg, 2018). Hopefully, special third-party detection tools, such as Fakespot and ReviewMeta, help provide a clearer view. In their reports, these service providers show that the proportion of fake reviews varies considerably according to the industry sector and may even exceed 50% for some products, including Bluetooth headphones or speakers, diet pills or testosterone boosters, which are often made in China.[7] However, for the menstrual cup that I focus on, the ReviewMeta search engine returns a score of 0% potentially unnatural reviews and shows less than 10% of the reviews using repetitive phrases. None of the reviewers admits receiving a free or discounted product in exchange for one's review.[8] Based on these clues, cup reviews seem overwhelmingly authentic, an impression congruent with the longer than average length of these reviews – a clear sign of real consumers' willingness to share their experiences.

The comparison among pad, tampon and cup reviews conveys significant results. The particular single-use pads and tampons that I focus on, that is, items belonging to the category of absorbency-based products that dominate over 95% of the contemporary market for menstrual products, received far fewer reviews (72 and 35 on average a year for disposable pads and tampons, respectively) than their modest cup challenger (349 on average a year). The disposability and thus the endless repurchase of these products generate huge profits, all the more so that the industry builds on the feelings of embarrassment and stigma attached to menstrual management as ways to increase brand loyalty and rent effects (Patterson, 2014). The numbers of disposable pad and tampon reviews remained modest over time, with a maximum of 125 a year for pads and 82 for tampons. In contrast, the number of cup reviews experienced continuous and considerable growth; less than 100 reviews were posted from 2005 to 2010, but the figures subsequently increased, reaching a maximum of 1,021 reviews in 2015 and a relative decline afterwards (530 in 2018, the last full year of observation). The more pervasive the product, the less reviewed it is and vice versa.

Of course, the market for disposable pads and tampons is fragmented into multiple and frequently updated products, which could be thought of as the reason for the scarce number of ratings about the models I selected. However, comparing the lengths of reviews leads to another explanation. Whereas the average lengths of pad and tampon reviews are 120 and 150 characters, respectively, the average length of cup reviews reaches as high as 590 characters, that is, up to almost five times the length of pad reviews. Moreover, this figure hides a huge standard deviation of 735 characters (versus 169 for pads and 207 for tampons). In fact, less than one-fourth (23%) of cup reviews are shorter than the highest average length of pad and tampon reviews (150 characters). An impressive 17% of these cup reviews are 1,000 characters long or more, and the longest cup review consists of 14,250 characters. In contrast, only 2 tampon reviews and 2 pad reviews are 1,000 characters long or more, and these reviews are not longer than 1,633 and 1,353 characters, respectively.

Before thoroughly scrutinising the content of cup reviews, I focus on one last external aspect of the three collections of reviews – consumer ratings. Consumers can rank Amazon products on a scale ranging from 1 to 5 stars. The average marks are very close: 4.2 for pads, 4.4 for tampons and 4.4 for cups. Further examination is thus needed to find whether differences exist in rating patterns. If the ratings are simplified into the mere opposite ratings of "bad" or "good", where "bad" corresponds to 1–3 stars, and "good" corresponds to 4–5 stars,[9] a slight difference is observed:

80–87% of the three products receive positive ratings (green zone), with the least favourable ratings for disposable pads and the most favourable ones for cups, although just two points above tampons. However, a closer examination shows an interesting difference: the share of intermediary ratings (2, 3 and more importantly, 4 stars) is significantly higher (28%) for cups than for the other two products (15% for pads and 21% for tampons). Stated the other way around, extreme ratings are fewer for cups; 1 and 5 stars account for 73% of all given marks compared with 85% for pads and 80% for tampons (Fig. 1).

Overall, cups clearly attract far more reviews, much longer reviews and (slightly) more positive (although more balanced) ratings than pads and tampons. The reason behind such discrepancies is obvious. Disposable pads and tampons are what economists call 'experience goods', whose purchase mostly entails repeating the previous consumption to refill consumers' stocks and rarely triggers comments, except mostly as short and binary judgements expressing satisfaction or dissatisfaction. In contrast, reusable cups are 'search goods', that is, things experienced as novel

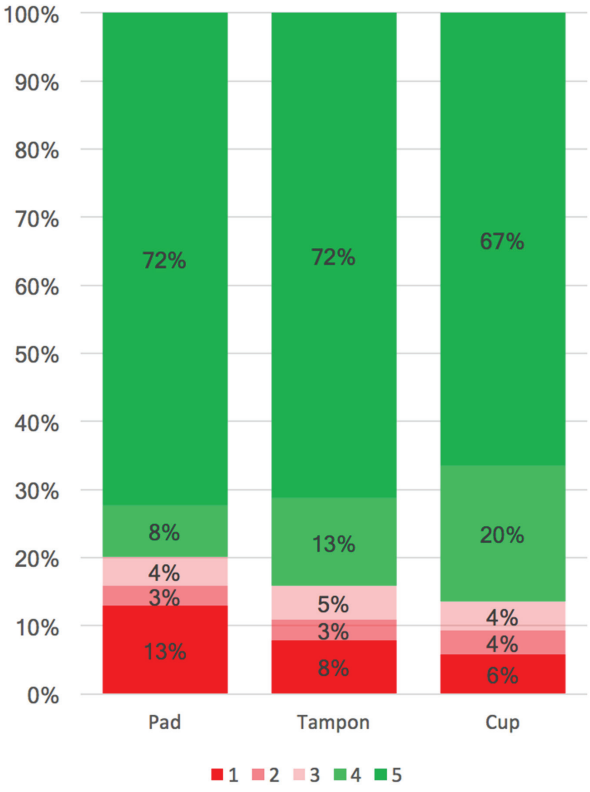

Figure 1. Consumer ratings of pads, tampons and cups

products, involving real adventures and highly disrupting changes in use, intimacy, physical experience and so on, with tremendous promises yet high uncertainties (Nelson, 1970). Cups thus entice a higher involvement from consumers and tend to lead them to post more reviews (note the spectacular asymmetry: 5,235 reviews for cups versus 288 and 318 for pads and tampons, respectively) and develop more precise, careful and nuanced valuations. Moreover, cup users, who are often beginners, feel the need to share at length not only their overall judgement but also their varied experiences, emotions, worries, feelings, tips and so on.

For instance, the following review reports the experience of a new user:

> I was so excited to try this! I hate how much waste is created by tampons, plus the bleach and synthetic materials are scary… The first day of my period I was too nervous to use it since I would be working all day and the only restroom at work is a 6 stall bathroom and someone always seems to be in it. I read through the instructions and reviews when I got home and almost chickened out again after reading a couple reviews where some women couldn't get it out, but I womaned up and tried it! I got it in surprisingly easily and I didn't get the "weird feeling" some women mentioned; I couldn't feel it at all! I didn't need to trim the stem either. I left it in for a few hours then decided to take it out before I went to bed. I started getting nervous again and read the directions again and read through some more reviews for tips. It came right out, no problem at all! Just a little strange to see a cup of your own menstrual blood, but definitely preferable to tampons – the gross string, bleach, waste, and cost! (Review no. 3715, 2017, 5 stars)

As the review shows, this user is eager to share her first time with her new device and to express a wide array of concerns, from environmental issues (see the second sentence: "I hate how much waste is created by tampons […]") to economic matters (see the last word: "cost"), and more private concerns in terms of anxiety, privacy, technical problems, disgust and so on.

Textometric analysis of cup reviews: A 'thlemmatisation' method

If reusable cups are search goods, they also belong to a class of merchandise that marketing specialists call high-involvement products (Petty et al., 1983), that is, items whose purchase and consumption elicit high reflexivity, information-search efforts, various trials and experiments, calculation and valuation procedures,[10] value investment and sometimes even moral and political commitment. Nonetheless, systematically conducting such an analysis is a task beyond a single researcher's capacity, given the size of the corpus. The full collection of reviews amounts to 3.9 million characters or 673,633 words, that is, 1,444 single-spaced A4 pages using 12-point Courier font. To overcome the problem, I propose to complement the classic reading of reviews with the assistance of Iramuteq, a well-known software program for automatic text analysis.

To better trace what and how concerns are expressed in these reviews and with what implications, I have developed and implemented a procedure that I label 'thlemmatisation'. This neologism is a contraction of 'thematisation' and 'lemmatisation'. The idea is to code active forms of a given corpus based on a list of thematic categories where they belong and to replace lemmas with their corresponding themes. For instance, words such as "durable", "earth friendly", "eco-friendly", "ecological", "green", "natural", "organic", "recycle" and so on, are replaced by the theme, "environment friendly" (see the Appendix for a full presentation). This strategy helps in combining the focus on particular research themes (in my case, the issues of health, the economy and environmental protection) and the work of automatic text analysis. As will be shown, 'thlemmatising' a corpus is a good way to simplify it according to *a priori* research interests and to increase the readability and the significance of the graphs obtained through classic textometric procedures. It would be wrong to perceive this method as tautological; by definition, if thlemmatising a corpus emphasises the notions that are focused on, these notions function as starting points, not as expected results (the contrary would be absurd). The aim is to start from the elements involved in the research effort in order to better identify and trace the other (often unknown) elements to

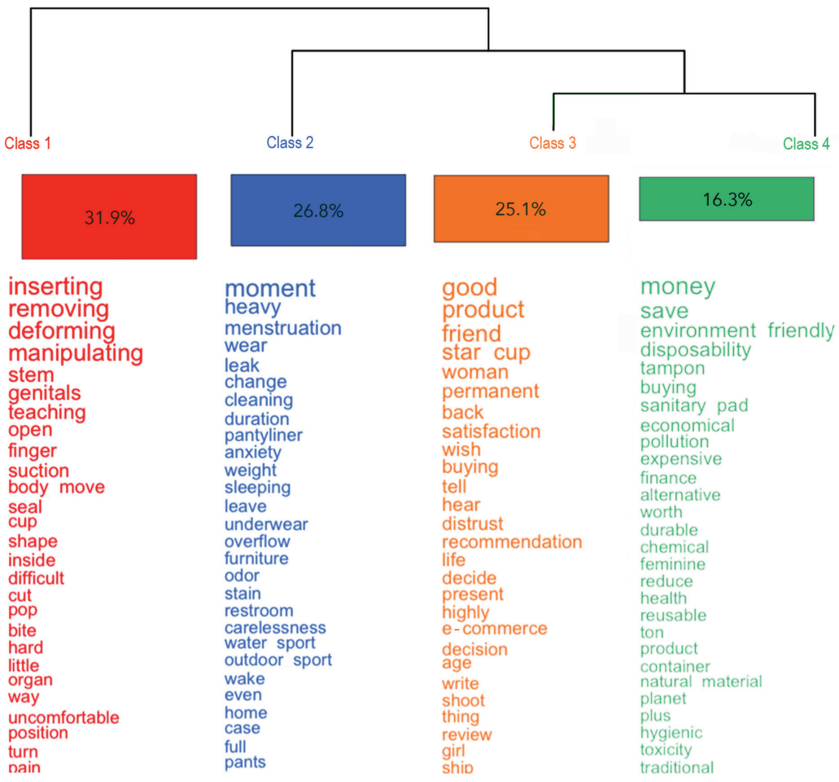

Figure 2. Reinert classification of the corpus

which they are connected. This kind of approach is not novel[11] but rarely used, probably because too many digital analysts tend to favour a 'one-click' analysis and avoid tedious handmade recoding practices. The following developments present the results of my analysis of the thlemmatised corpus.

Because the thlemmatised corpus is more readable and better suited to the research objectives than the standard version, I exclusively rely on it in the following developments. First, I have performed a Reinert classification of the thlemmatised corpus to identify the main types of concerns expressed in the consumer reviews. In the Reinert classification, the forms that are most frequently associated together in the corpus are grouped into classes (see the Appendix for more details).

Four clear categories emerge from the classification (see Fig. 2). Class 1 comprises almost one-third of the forms (31.9%). This class is clearly about handling the cup and the related problems (inserting, folding and removing it, knowing how to use one's fingers, avoiding suction effects, etc.). The three other classes account for more distant concerns. Class 2 (26.8% of the forms) is about the context of use in terms of both time (at what moment, for how long, etc.) and space (in restrooms, in sports practice, at home, etc.), with expressions of the associated risks ("leak", etc.) and complex feelings (from carelessness to anxiety). Class 3 (25.1% of the forms) is consumerist, dealing with gaining knowledge about the cup, judging it and sharing one's view with other menstruators through varied forms of media. Class 4 (16.9%) combines health, economic and environmental concerns, that is, the dimensions on which the product can be judged. It is mostly interesting to find that practical concerns largely outweigh the others: practice-oriented concerns belong to the first two more important classes and account for the majority of the forms (the total share of classes 1 and 2 is 58.7%), while issues such as economic concerns occupy a smaller position.

To better identify the reasons and the logic behind this broad picture, I propose (according to the theoretical framework presented in the previous section) to concentrate on the core subject of consumer concerns. To achieve such an objective, I have neutralised two dimensions. First, I have excluded tampons and sanitary napkins by unselecting the corresponding themes. Indeed, if cup users frequently compare their use with the available classic alternatives, removing the latter from the analysis helps me focus better on what is stated specifically about cups. Second, I have renounced sentiment analysis and thus excluded positive and negative views by unselecting the "good" and the "bad" themes, even if they account for an impressive number of positive and negative forms. Indeed, the generally rich, lengthy and wordy collection of reviews shows that what matters for menstruators is less the overall judgement (still available through the ratings; see above) and more the varied experiences to which it is connected. Similarly, what is important for them is less the general criteria on which valuation procedures can be based and more the incredible array of topics and worries emerging from the intimate experience of cup use. Consequently, I suggest temporarily disregarding the notion of the 'orders of worth' addressed in valuation studies (Stark, 2009) and focusing on what I label 'orders of concern'.

I have conducted a similarity analysis accordingly, that is, a procedure based on graph theory that maps the network of associations between the words of a given corpus. On the network map, a word appears as a node, and an edge reflects the co-occurrence between the two related words. To ensure maximum readability, I have thlemmatised the corpus for the forms (lemmas and themes) that appear at a frequency of 100 times or more (sanitary pad, tampon, bad and good themes excepted, along with menstruation, i.e., one of the most frequent themes but to the point of being meaningless). I have performed the similarity analysis for the 299 remaining forms. I have exported the underlying data from Iramuteq to Gephi, a large graph network analysis software program particularly suited to handling such data and increasing their readability. I have made the size of the labels and the thickness of the edges proportional to the underlying frequencies. I have highlighted the communities based on the modularity class (0.74) and adjusted the colours accordingly (with mixed colours for the edges bridging different communities). The overall result is displayed in Fig. 3.

Results: From orders of worth to (dis)orders of concern

The graph conveys at least five major, clear and meaningful results.

Trademark cup versus generic cup

The first and most striking result is the bimodal way that menstruators account for the menstrual cup. Indeed, as Fig. 3 shows, the evocation of the device is split into two disconnected communities. On the graph's right periphery, the cup appears as "Star Cup", that is, the brand of the particular device that consumers discuss in their Amazon.com reviews. In contrast, on the centre left, the "cup" appears as a generic device with no specific name. When evoked as the trademark "Star Cup", the device is compared with competing products (all the other brands are combined under the "competing cup" theme). It is something that consumers do not take as a matter of fact only (see above) but also address with broad concerns in mind (e.g., "economical", "health", "environment friendly"). It is a product about which consumers search for information ("reading"), and it works as a topic about which users are eager to share their personal views (e.g., "write", "review"). In contrast, when sharing their experiences, menstruators forget the brand, report about the device in more generic terms and shift to more intimate concerns, such as bodily sensations, anatomical issues and so on. This second approach to the device significantly occupies a central position in the network and leads to a much richer array of satellite concerns.

A networked cup

The second result is that this central version of the cup is immediately connected to an incredible array of items. It would be too long to comment about all of them, but readers might notice the strong presence of the body (e.g., "body state", "bottom", "genitals", "finger", "leg", "head"), as if the cup functioned as an artificial organ. This hybrid cup–body entity calls for the intervention of technical elements (e.g., "stem", "component", "tool") and human expertise (e.g., "medical", "health professionals"). These observations confirm Dutrait's (2022) and Gaybor's (2019) findings

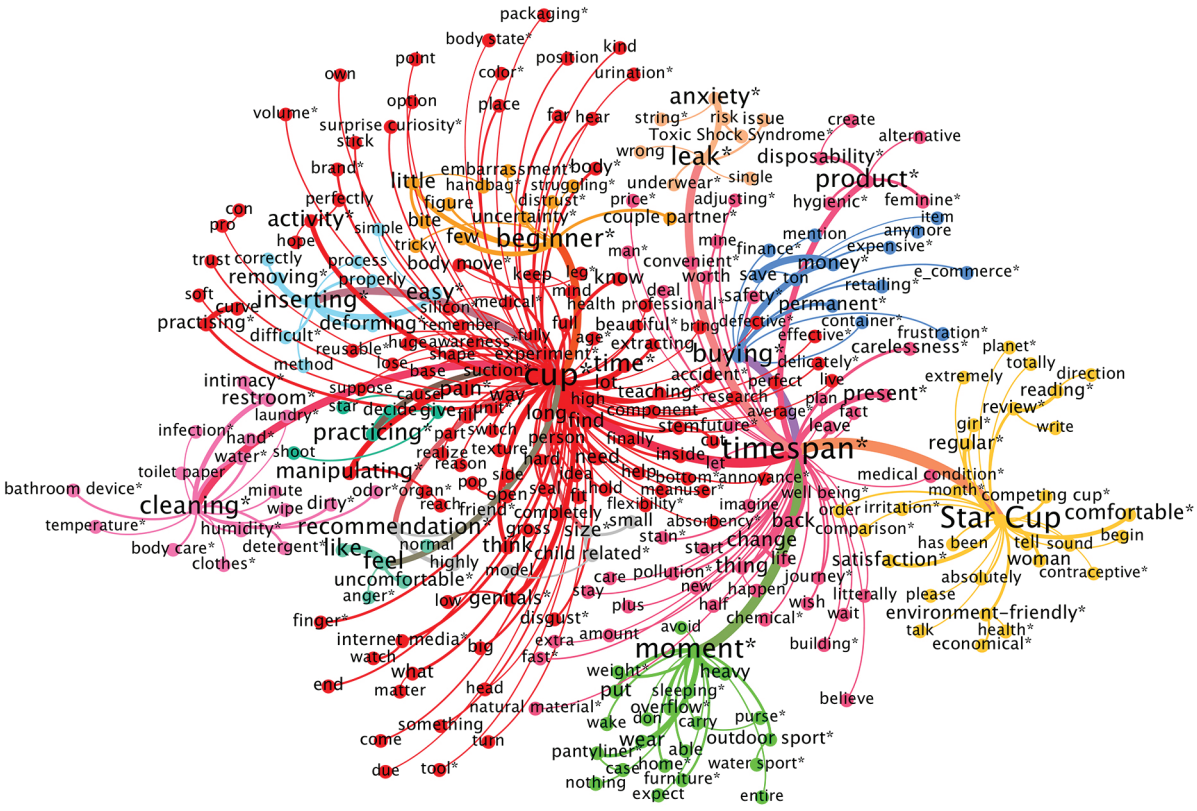

Figure 3. Similarity analysis of the thlemmatised corpus (*thlemmas)

that present the cup as a way to learn about one's body. The cup is also closely related to varied sensations. These feelings are both physical and psychological, ranging from "pain" and "suction" to "disgust" and "surprise curiosity". Last but not least, it is highly significant that the "reusable" aspect of the cup is highlighted, in strong contrast to the remote evocation of other "products" and their disposable aspect ("disposability"). These elements show that the socio-technical networks dear to the actor-network theory cannot be restricted to the classic associations between humans and non-humans for two reasons. First, prosthetic objects (Callon, 2008) become parts of the human being herself, thus merging subjects and objects into cyborg-like entities (Haraway, 1985) – such entities could be named 'actorants', that is, combinations of actors and actants. Second, the shift from matters of facts to matters of concern helps us understand that networks do not bind tangible entities only but also connect artefacts and persons with abstract feelings, responsibilities and values (Geiger et al., 2014; Hawkins, 2020).

A matter of trajectory, practice, sharing, cleaning

The third result is that the cup is connected to a series of major, hub-like themes, each leading to similar dimensions. First, consumers relate cup use to their consumer trajectory. In so doing, they highlight the particular position of the "beginner" that they often occupy, as well as the relative burdens ("distrust", "embarrassment", "struggling", "tricky", etc.) and "uncertainty", to the point that beginners soon feel the need to share their intimate problems with their "couple partner". Second, such problems are gathered around the "inserting" theme. Complementary handling operations, such as appropriately "deforming" and "removing" the device, are obviously prominent in this respect, with a distinct care for the relevant knowhow (e.g., "method", "process", "correctly", "properly"), and varied feedback about its implementation (e.g., "easy" versus "difficult"). Consequently, consumers stress that cup use needs a lot of "practice". Third, the knowledge acquired through practice may eventually lead to experience-sharing attitudes ("recommendation"). Fourth, practical problems do not stop after use. An important concern involves "cleaning" the device, with the related problems of preserving "intimacy" in public "restrooms", the necessary resources (e.g., "toilet paper", "detergent", "water", "bathroom device"), sensory burdens (e.g., "humidity", "odor") and hygiene risks ("infection").

A time-related device

The fourth result indicates the prominent importance of time; the main "hub-like" theme connected to the cup is "duration", a notion that gathers several time units, including "minute", "hour", "day", "week" and so on. Of course, this makes sense in the use of a device related to menstruation. However, it is more interesting that more specific concerns are connected to various durations. Some of these concerns are linked to unexpected events, such as "stain(s)" and other types of "accident(s)". Significantly, a major satellite concern involves the risk of "leak(s)" and the related "anxiety". More importantly, "duration" is heavily connected to various "moments", a theme that qualifies the particular points in time when events are likely to occur ("morning", "mid-day", "afternoon", "evening", "night", etc.). As shown, time is connected to space. The concern for moments varies according to the place and the related activity (when "sleeping" or at "home", when practising "outdoor sports" or "water sports"). This unveils the web-like character of cup use, which is part of a much wider agencement than the components of the product itself. Eventually, duration also leads to the time it takes not only to use the device but also to buy it, with the relative care for the "money" spent by a consumer, the retail outlets used ("retailing" versus "e-commerce") and so on.

The disorder of concerns

Last but not least, the fifth result is that health and environmental issues, even if 'boosted' by thlemmatisation, appear as somewhat lost concerns among the many other more down-to-earth and practical worries that I have just reviewed. This helps in balancing the importance of the eco-friendliness of the cup highlighted in previous research based on qualitative investigations (Gaybor, 2019) and the value of more practical

concerns. Once again, it seems as if environmental issues are disconnected from the underlying practicalities. To summarise, the analysis of the thlemmatised corpus makes it clear that cup use is primarily a highly practical and material matter, a 'use story', and this pragmatic dimension is obviously connected to an incredible web of interrelated concerns. In other words, if consumers often buy their goods by relying on various external "orders of worth" (e.g., price, fair trade, sustainability, corporate social responsibility, etc.), they use these goods by depending on an infinite array of 'orders of concern'. The latter includes all previous ones, as well as more practical and intimate matters, such as comfort, embarrassment, privacy, anxiety and so on. In this respect, it should be even more appropriate to discuss 'disorders of concern', to the extent that the web of concerns is largely unstable, messy and entangled, far more than the 'heterarchic' world governed by orders of worth.[12] Several of these preoccupations contradict one another or even clash; for instance, menstruators often find it difficult to reconcile their eco-friendly values with the burden of the periodic use of the cup, as if a sort of material dissonance is supplementing the classic cognitive one (Festinger, 1957).

Discussion

Latour notes that no 'inflatable parliament' exists; building a satisfactory political organisation cannot be limited to the hard sell of generic democratic ideas but also needs a long and tortuous effort aimed at complying with local situations (Latour, 2005: 24). Similarly, there is no easy road from problematic to healthy or responsible menstruation control. Finding the proper way is surely possible but only by taking into account all the little down-to-earth, personal, pragmatic and over-practical stories that the reviews convey. Marketing an alternative, eco-friendly product such as the menstrual cup is a solution, but to make it workable, one should also pay attention to bodily issues, use operations, surrounding infrastructures and so on. This final example mirrors the first quote cited in this paper but with a more negative tone:

> I was so, so, so excited to get a Star cup. […]. I have been using it for two cycles now, and I have to say, I am totally disappointed. […] Maybe it's my frame or my vaginal canal, but ladies, I cannot get this thing to work for me. I have read so many forums and watched so many videos and looked at so many diagrams, and no matter how much I fiddle and do ridiculous acrobatic moves in my shower or on the toilet, this thing always leaks. Always. I've gotten to a point where I can put it in […], and put on a pantyliner, and it will just leak a small amount, but come on! That is not why I bought the Star cup. I wanted something with no waste, that felt really secure, and something that I could take backpacking and swimming without worrying about anything. Thus far, it is not serving that purpose at all, and I have to say, I am so sad! I was really looking forward to my brand new Star cup lifestyle! I was going to be a changed woman! I was going to wear white pants year round, and dance in them with hopeful music playing and not worry about a damn thing! But alas. I suppose the tampon wearing version of me will have to do. […] (Review no. 1093, 2014, 2 stars)

This consumer expresses the great hope she placed in the Star Cup and her environment-friendly values, all the efforts she made to adopt the device, then her extreme frustration when facing failure but softens with benevolence when generously citing her specific anatomy as a probable cause. Nonetheless, independently from success or failure, this example seems to show that too much pressure is placed on consumers, when it should be, if not placed elsewhere, at least better distributed.

Since the beginning of the 21st century, the social sciences have tended to present lay people's practices as the best ways to address major political issues. This approach is promoted in the abundant literature on "political consumerism", which presents every consumer purchase as a way to vote in favour of higher stakes (Bostrom et al., 2018; Micheletti, 2003; Micheletti et al., 2003). The same approach is developed in political science, focusing on the participative forms of democracy as viable alternatives to classic representative institutions and procedures (Callon et al., 2009). There are several reasons behind this shift from top-down to bottom-up politics. The most ancient influence is that of pervasive yet important theo-

retical evolutions. Garfinkel's (1967: 68) famous claim that people are not "cultural dopes" framed by remote structures but are fully reflexive "members" capable of structuring the world they live in started the process. The movement has ceaselessly been enriched since then, notably with the practice and the pragmatist turns. Practice theoreticians insist on actors' capacity to pursue varied goals through a complex articulation of materials, competencies and meanings (Shove et al., 2012). Such views have attracted considerable attention for their novelty, seductive rhetoric and ability to present classic regulations as outmoded and irrelevant, due to their supposed lack of subsidiarity, blind top-down rationale and actor unfriendliness. Meanwhile, the rise of Web 2.0, social media and the related boom of innumerable forms of participation and activism have strongly supported the idea of actor-based production (for the popular idea of 'prosumption', see Ritzer and Jurgenson, 2010) and politics (for the literature on 'ethical consumption', see Dubuisson-Quellier, 2013). Last but not least, the study on such actor-based politics is also favoured because of its easier accessibility in fieldwork. Indeed, ordinary consumers and citizens are far easier to approach than larger companies and institutions.

However, if ordinary actors are obviously not cultural dopes, critique and action are nevertheless not accessible to everyone at the same level. In this respect, it is politically dangerous to propose politics that are supposed to rest on street-level initiatives only. Surely, serious health and environmental issues need to be addressed. Menstrual products certainly contribute to the alleviation of both problems. Nonetheless, does it mean that solving the latter should be the responsibility of consumers only, by urging them to adopt the safest and most sustainable products and shaming them if they refuse or fail to do so? This would be acceptable if the problems were limited to menstrual products and if these products themselves were fully equivalent, independently from their contribution to the problems at stake. My research results show that these two conditions are far from being fulfilled. The differences between disposable tampons and pads, on one hand, and reusable cups, on the other hand, are not restricted to their more or less innocuous or sustainable character. Furthermore, these differences matter. Indeed, they raise a series of concerns regarding embarrassment, privacy, practicality, reliability, comfort, wellbeing and so on, and these concerns often conflict with political ones. Of course, companies care about their consumers and try to improve their products according to consumer needs and wishes (Hartman, 2020; Fahs and Bacalja Perianes, 2020), all the more since doing so meets the manufacturers' best interests. However, the latter may be slow in addressing concerns that were previously ignored. They often cannot stretch the inherent limits of the technologies they promote, especially when their devices are mass produced and cannot be individually adjusted, apart from a limited set of forms and sizes. Moreover and as found in this study, user problems are not confined to the products themselves but involve the larger web-like agencement to which they belong. It would indeed be a mistake to regard customers as the sole acting entities. As Strengers and colleagues (2016) convincingly show, consumption is not just the effect of consumer action but also the outcome of the articulation of complex human and non-human agencies. Thus, an honest call for shifting practices would require a complete transformation of practice environments.

Conclusion

This study makes both methodological and substantial contributions. Regarding the method, an *ad hoc* digital procedure has been used and adapted to show how various concerns are embedded in the use of technologies. It is important to stress that such a method cannot suffice in itself. It is also essential to emphasise that consumer reviews are written by consumers who do not mind in sharing their intimate experiences. This material does not account for the full female population and probably underrepresents the feelings of embarrassment and stigma that dominate the history of menstruation and remain largely pervasive (Johnston-Robledo and Chrisler, 2013). A researcher understands and analyses the results better when reading at least part of the underlying corpus and when complementing it with additional data and literature.

Understanding the meaning of contemporary consumer reviews about menstrual cups requires knowledge of past history, contemporary practices, as well as greater knowledge of the market and the society where they fit in. Nonetheless, if additional research would be needed to provide a more complete account and full answers to the research questions, the reviews provide at least part of the answers by focusing on the consumers' points of view, while most available data focus on the industry. With this paper, I join the plea for using digital humanities beyond specialised scholars, disciplines and journals (Gold and Klein, 2016; Jockers, 2013). The method used in this paper is not restricted to the digital age but can be applied to older data, for instance, to the patents themselves, thanks to the growing optical character recognition of historical archives (Cochoy, 2021). Accordingly, the method is just a means, and what matters most constitutes the substantial results that it conveys.

From this substantial perspective, it is tempting to perceive the recent rebirth of the menstrual cup, with its supposed reusability and safer materials, as an obvious answer to both environmental and health threats and a way to introduce "sustainability" and "non-toxicity" into the products themselves. However, my analysis of the large corpus of consumer reviews posted on Amazon.com about the "Star Cup" shows a more complex picture. As discussed in this paper, cup users do not take the device as a generic good but pay attention to the details of the particular cup they experience; they do not perceive it as just an object (a matter of fact) but connect it to broad issues such as economic, health and environmental aspects (matters of concern). They do not report an abstract experience but relate the cup use to their menstrual trajectory and context- and time-dependent practices. Overall, it clearly appears that if health and environmental concerns surely exist and motivate some of the consumers, these issues belong to a much wider array of varied, intertwined and sometimes conflicting concerns. Women do not restrict the menstrual cup to abstract health or environmental stakes but account for all its dimensions, with even a major focus on practical issues, such as proper use, handling problems, psychological and physical effects, and so on. Consequently, it seems important to acknowledge this experience, unveil the responsibility of all involved stakeholders and thus relieve menstruators of a possible sense of guilt, whatever the solutions they favour.

Acknowledgements

I warmly thank Antti Silvast, two anonymous reviewers, a proofreader, Jean-Samuel Beuscart, Cédric Calvignac and Claire Dutrait for their helpful comments, suggestions and guidance on previous versions of this article.

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Notes

1 Cups and period underwear are both reusable alternatives to tampons and pads (respectively). In this paper, I focus on cups only.

2 Catamenial is a synonym for menstrual (from the Greek *katamenios*, i.e., menses), widely used in early company records.

3 Hockert (US Pat. 70843, 1867); Johnston (US Pat. 182024, 1876); Farr (US Pat. 300770, 1884); Vernier (US Pat. 467963, 1892); Dautrich (US Pat. 535980, 1895); Beach (US Pat. 599955, 1898). Source: United States Patent and Trademark Office.

4 I used Google's web scraper, a Google plugin aimed at scraping web information from a given site. To scrape Amazon reviews, Google web scraper requires two elements: the URL of the product and the JSON of Amazon reviews (i.e., a file describing the structure of Amazon reviews). This latter file is available at https://gist.github.com/scrapehero/cefaf014076b953f865a63ad453d507b#file-amazon-reviews-json

5 It is important to note that fabric reusable pads and period underwear are currently a growing market. Conversely, disposable cups also exist.

6 The remaining 1% amounts to the Amazon Vine program, which offers free products to selected customers in exchange for their impartial reviews, each shown with a note that states, "Vine customer review of free product".

7 https://marketingland.com/study-finds-61-percent-of-electronics-reviews-on-amazon-are-fake-254055

8 https://reviewmeta.com/

9 In this case, 3 out of 5 stars are considered poor judgements in order to balance them with e-consumers' acknowledged propensity to provide quite generous ratings (Beuscart et al., 2016).

10 Calculation and valuation are two sides of the same cognitive process that I call "qualculation" (Cochoy, 2008).

11 See the "EQUIV" function available in Spad-T during the 1980s and other tools aimed at performing similar recoding procedures based on lists offered by more recent software packages (e.g., Taltac). Thlemmatising a corpus is also close to topic modelling, that is, tagging the key notions that the researcher focuses on, although with thlemmatisation, the aim is not to train machine-learning software to categorise texts that convey these notions (e.g., consumer reviews) but to better trace how the tagged notions are related to others in the entire corpus.

12 "As the term suggests, heterarchies are characterised by minimal hierarchy (lateral accountability) and by organizational heterogeneity (diversity of evaluative principles)" (Stark, 2007: 5).

Appendix

Additional information about the thlemmatisation method

Iramuteq is a powerful tool, which helps in conducting various investigations aimed at unveiling conceptual classes or network patterns hidden in huge textual databases.

The first treatment is the Reinert classification. This method divides the corpus into text segments (identified by punctuation). It then builds a presence/absence table that crosses the text segments with the full forms of the corpus. The objective of this table is to bring together text segments that tend to contain the same forms in sets called "classes". A form's membership to a given class is established according to its independence, as measured by a chi-square test. With this procedure, the software is able to identify the different themes addressed in the corpus and the words that are most associated with each theme.

Another treatment is similarity analysis. This type of processing, based on graph theory, entails tracing co-occurrence patterns among the words in a given corpus. Once the co-occurrences among the words have been identified, the software draws the corresponding graph. This figure displays the overall network of forms, with both their spelling and the ties among them, and it clearly highlights the subcommunities of frequently associated notions, indicated by appropriate colours or "halo" zones (Marchand and Ratinaud, 2012).

However, when performing a similarity analysis on a large corpus with a rich vocabulary, the researcher quickly understands that the resulting graph will be truly readable only if the number of forms considered is reduced. Indeed, without prior selection, too many forms overlap on the resulting graphs. Iramuteq designers are of course well aware of the problem and have provided a means to overcome it. To help the researcher reduce the vocabulary before performing the analysis, the software proposes a list of selectable forms, sorted according to their frequency. Of course, it is perfectly possible not to focus on the upper part of the list. The researcher can click on the available forms as he or she wishes, keep some and ignore others, but with thousands of forms, such manual selection quickly proves impossible to implement. The researcher cannot make any rigorous selection without using a set of well-defined criteria, which requires acquiring knowledge of the entire list before performing the selection. Even when such preparatory work has been undertaken, selecting the words manually from the whole list proposed by Iramuteq proves far too tedious. It is important to note that the software is in no way responsible for the problem. Indeed, deprived of any way of knowing the meanings of the words, Iramuteq can only propose word frequency as the lesser evil to assist in word selection, despite the claim about the relative irrelevance of this criterion.

Another existing approach can be used to overcome the difficulty. Instead of ordering words according to frequency, why not group them based on their meanings? The idea is to focus on lexical fields and find a way to lead Iramuteq to account for the latter. This approach is better than frequency filters because it is purely focused on meaning. To cite a basic example from my case study, when evaluating a product on a commercial website, people use innumerable qualifiers, either positive ("amazing", "fantastic", "great", "terrific", "wonderful", etc.) or negative ("awful", "deceptive", "dreadful", "horrible", "terrible", etc.). Textometric software can know neither what these words have in common (i.e., being valuation adjectives) nor what makes them different (i.e., being either positive or negative). For the software, these words are just words, similar to all of the others. Of course, given their close meanings, it is highly probable that positive and negative adjectives will be associated with similar words in the corpus and be part of homologous syntaxic structures, thus appearing in the same area of the graph. However, graphically superimposing close notions faces the risk of unnecessarily blurring the reading. Similar adjectives will overlap at best and be scattered at worst, with the risk of becoming invisible, while expressing the same frequent and strong idea.

To counter such effects and help Iramuteq take into account the meanings of words, I propose "thlemmatising" the corpus where these words belong. This neologism combines two notions: themes and lemmas. As generally known, a lemma is the common linguistic root shared by a set of parent forms (e.g., "find" is the lemma for "find", "finds", "found" and "finding"). Iramuteq is able to

connect the forms to their corresponding lemmas, due to an underlying table (a dictionary). Similarly, given his or her topic and research questions, a researcher knows which words denote the same meaning. According to Iramuteq's specialists, "a theme can be defined as a set of plain and co-textual forms tied together by their object and context" (Ratinaud and Marchand, 2015: 57–58). Thus, the idea is that if themes matter, instead of just waiting for the results to identify just a few of very broad ones, why not cheat the software to lead it to learn from scratch how to grasp a much wider diversity of particular meanings? This can be done due to a reconfiguration of the dictionary. The operation consists of replacing lemmas with themes to force the software to consider different forms as resorting to the same lexical field (theme) instead of the same root (lemma). In the same way that lemmatising a corpus involves bridging the varied forms of a given word under their linguistic root, thlemmatising a corpus entails bridging the varied words that are used to express the same idea under a general equivalent. In the above-cited example, a researcher interested in 'sentiment analysis' – accounting for the varied feelings expressed in a given corpus (Liu, 2012) – will declare the theme "good" as the lemma for "amazing", "fantastic", "great", "terrific", "wonderful" and so on (and of course, the theme "bad" as the lemma for "awful", "deceptive", "dreadful", "horrible", "terrible", etc.). The researcher will thus replace the existing lemmas of the dictionary accordingly.

At the heart of the thematisation strategy lies this intriguing paradox: obtaining a sharper view of a given corpus (highlighting concerns that matter) rests on a blurring procedure (merging quasi-synonymous notions into a single equivalent). Another paradox is that the procedure is workable and useful only if applied partially. In fact, lemmatisation and thlemmatisation work hand in hand. On one hand, given his or her research objectives, literature reviews, previous investigations, exploratory studies (see, e.g., my account of the history of menstrual products – Cochoy, 2021) and inductive reading of the entire lexicon or the corpus, the researcher identifies and constructs the lexical fields that deserve to function as key themes under which part of the lexicon can be thlemmatised. On the other hand, the researcher leaves all of the other words unchanged, with their lemmas as they exist in the standard dictionary.

There are several reasons for conducting a partial thlemmatisation instead of a full one. Some of these reasons are trivial. Because a corpus counts thousands of words, designing lexical fields is highly time consuming and possibly very tricky (it is often difficult and even impossible to figure out which theme could encompass some rare, isolated or special notions). However, these are not the main reasons. No theme exists in itself – in contrast to lemmas, themes are not generic and universal; their number and definitions depend on the research at stake and are thus necessarily limited. Moreover, partial thlemmatisation helps highlight the chosen themes among the corpus. Because a given theme gathers and replaces several underlying notions, its frequency amounts to the sum of the thlemmatised forms, thus making their hidden importance visible by increasing the overall frequency. In other words and paradoxically, distorting reality appears as a good means to show it in the right way. Conversely, thlemmatisation may also be used to quickly exclude some themes from the analysis. Because some forms have been replaced by the corresponding overarching theme in the dictionary, ignoring whole sets of notions just requires "deselecting" the name of their theme on the list of available forms provided by Iramuteq. Last but not least, because thlemmatisation significantly reduces the number of forms in the entire corpus, selecting part of these forms based on the frequency list becomes faster, clearer and easier.

Conducting the whole operation, from the thlemmatisation of the corpus to the theme selection and analysis, is a long trial-and-error process. A good approach consists of three steps. First, the researcher identifies large themes (in my case study, a list of concerns, including "psychological state", "body sensation", "economy", "environment", etc.). Second, the researcher attributes these themes to the vocabulary on a spreadsheet and sorts the results according to the themes. Third, the researcher splits these themes into subfields under the third column on the spreadsheet and recodes the vocabulary accordingly (e.g., "psychological state" is shifted

to anger, annoyance, anxiety, awareness, carelessness, confidence, disgust, distress, distrust, embarrassment, frustration, intimacy, safety, satisfaction, surprise curiosity, trust, uncertainty and wellbeing). Each subtheme encompasses a large number of original forms (e.g., "anxiety" is the subtheme I have chosen for afraid, alarming, anxiety, anxious, anxiously, apprehensive, concern, concerned, danger, dangerous, fear, frightening, hazardous, insecure, insecurity, intimidate, intimidating, nervous, panic, panicky, paranoia, paranoid, risky, scared, scary, stress, stressful, terrify, terrifying, terror, threat, unsafe, warn, warning, worried, worries, worrisome, worry and worrying). I have applied such a procedure to the entire corpus (10,756 forms), hapaxes excepted (4,451 forms). Out of the 6,305 reviewed forms (10756 - 4451), 2,643 have been thlemmatised (41%) according to 60 broad themes and 290 subthemes. Only subthemes have been used for thlemmatising the corpus. The choice to operate at the subtheme level has been considered a good compromise between the search for increased readability and respect for lexical diversity. The underlying idea is to respect the classic lexical analysis procedure while slightly simplifying the vocabulary somewhat according to a basic logic of synonymy.

Pigs and Chips: the Making of a Biotechnology Innovation Ecosystem

Ann Bruce

The University of Edinburgh, United Kingdom/ ann.bruce@ed.ac.uk

James Lowe

The University of Edinburgh, United Kingdom

Abstract

This paper presents a longitudinal case study in UK biotechnology covering some 30 years during which genomic technologies were introduced into pig breeding. This case study demonstrates how co-innovation involving existing small and medium sized enterprises, together with contributions from academics, has enabled companies to obtain the resources needed for value creation. Important contributions at critical junctures from public funding, pivotal contributions of individuals, and entry of new enterprises supplying essential resources, have enabled the fruitful realisation of new value creation. This paper contributes to the literature by taking a historical perspective, demonstrating how enabling long-term networking relationships including relevant academics, research institutions, funders and knowledge brokers has the potential to generate an innovation ecosystem that can respond effectively to a range of external challenges and take advantage of new techno-scientific opportunities.

Keywords: innovation ecosystem, animal breeding, biotechnology, Sus scrofa, SME

Introduction

Biotechnological research generates a host of novel tools and knowledge, which, if exploited, could contribute to the bioeconomy. However, a critical step is the translation of these resources into commercialisable products and processes. This paper aims to contribute to an understanding of translation processes through a longitudinal case study illustrating how genomic and biotechnological knowledge was transformed into innovative products in the agricultural sector. Our research therefore aims to answer the question of how biotechnological innovations have been developed and implemented in practice by the UK pig breeding sector. This paper takes an interdisciplinary approach, combining the strengths of history of science in understanding longer-term developments, with the appreciation of innovation processes provided by science, technology and innovation studies. It also aims to provide new insights into emerging value creation

by the processes of co-operation and competition among companies in one industry sector.

The case is that of the adoption of genomics in the United Kingdom (UK) pig breeding industry from the 1980s to 2019. Close examination of this sector reveals it to be far from mundane and traditional. It readily adopts biotechnological and genetic knowledge and methods, and demonstrates the contributions of biotechnology in a wide-range of contexts. In particular, the case study highlights the capturing of value from the 'genomics revolution' that promised so much in the 1990s (Hilgartner, 2017; Watson, 1990), and continues to attract policy and funder interest (Green and Guyer, 2011; Bell and Life Science Strategy Board, 2017). Much of the research undertaken in this area has considered the impact of human genomics (e.g., Glasner and Rothman, 2004; Hilgartner, 2017); less attention has been paid to its impact on livestock agriculture.

The case study is approached from an innovation ecosystems perspective. The innovation ecosystems concept has been adopted both in the business literature and in innovation studies (Gomes et al., 2018). An innovation ecosystem can be considered as "the collaborative arrangements through which firms combine their individual efforts into a coherent, customer-facing solution" (Adner 2006: 2). These collaborative arrangements allow firms to create value in ways that no single firm could undertake alone (Durst and Poutanen, 201: 3). The external environment provides a milieu in which selection pressures act on the ecosystem actors, resulting in new opportunities and threats.

Innovation ecosystems can be contrasted with a linear model of innovation in which development follows research, and commercialisation follows development. We seek to demonstrate that innovation in this case study is more complex and draws on scientific developments, their interactions with market processes, and on research funding policy. External pressures may further arise from biological constraints in our case of pig breeding and production, as well as regulatory environments, although the latter plays only a small role in this case study.

The innovation ecosystems approach allows us to foreground the interactions between different kinds of public and private sector actors, with distinct and shifting institutional drivers and histories. This paper therefore allows us to contribute towards the growing appreciation of the ways in which public and private sector actors are intertwined in research and innovation processes (Didier, 2018; Edgerton, 2012; García-Sancho et al., 2022a; García-Sancho et al., 2022b; Godin and Schauz, 2016; Sunder Rajan, 2006, especially chapter 1; Yi, 2015).

Innovation Ecosystems

A plethora of terminology has been formulated using the concept of the ecosystem to explain aspects of techno-scientific research, development and commercialisation. Examples include: innovation ecosystems, knowledge ecosystems, entrepreneurial ecosystems and business ecosystems (Scaringella and Radziwan, 2018; Xu et al., 2018). Key to innovation ecosystems are networks and social relationships, both formal and informal, embodying trust and tacit knowledge (Scaringella and Raziwan, 2018).

Papaioannou et al. (2009: 319) refer to innovation ecosystems as "a complex network of interdependent relationships". Granstrand and Holgerson (2020:102101) suggest a more focused definition which involves an "evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or population of actors".

The innovation ecosystem concept takes ideas from biology and applies these to business, a transference that has been critiqued. Oh et al. (2016), for example, argue that innovation ecosystems could equally well be described as innovation systems, and that ecosystems, unlike innovation systems, do not have a clear purpose. In contrast, Shaw and Allen (2018) argue that both natural ecosystems and innovation ecosystems are complex systems producing valuable outputs. Walgrave et al. (2018) identify innovation ecosystems with specific goals, or what they term "ecosystem value propositions". Ritala and Almpanopoulou (2017) distinguish between systems that have been engineered (often by public funding policies) and those that co-evolve

(as a result of market drivers). They pinpoint the emphasis on co-evolution as a key aspect of an ecosystem approach. Pushpananthan and Elmquist (2022) emphasise that a combination of competition and co-operation distinguish innovation ecosystems from innovation systems.

For Shaw and Allen (2018), a key motivation for articulating an approach using the ecosystem analogy, is how it enables the comprehension of flows of resources, in particular the re-circulation of resources typical of an ecosystem. Walgrave et al's (2018) "ecosystem model" foregrounds the examination of the structure of the innovation ecosystems and how, as a network, this system creates and delivers value. Furthermore, compared with innovation systems perspectives, the innovation ecosystems approach emphasises collaborative and complementary interactions between distinct actors, and exchanges between sectors rather than focusing primarily on competitive dynamics within a sector (Granstrand and Holgersson, 2020).

We therefore suggest the innovation ecosystem concept provides an appropriate analytical basis for our case study, because our focus is on interrelationships among academics and industry actors (Dedehayir et al., 2018) and the co-evolutionary processes involved in creating value. Our emphasis is on the mechanisms associated with value creation: how enterprises obtain resources to create value for customers, and how technology and ideas interact with each other. Our longitudinal approach focuses on what actors actually did, and on who had power to influence the course of events (Sotarauta and Mustikkamäki, 2015).

By contrast to innovation systems approaches that are often anchored in specific geographical domains, the innovation ecosystem concept is often applied to individual firms and their supply chains. This enables researchers to range more freely across sectoral and geographical boundaries. Here, we consider an industry sector, namely companies supplying breeding pigs to farmers, in its interactions with a different sector, academia.

Method

This research is a longitudinal qualitative case study (Yin, 2003). This historical dimension has enabled us to discern long-term trends and changes across the industry and academic sectors concerned, and the interactions between them.

We interviewed personnel from across the companies and academic institutions involved in pig breeding, as well as knowledge brokers and policy-makers. We collected data during 2018-2019 by 37 semi-structured interviews, and two focus groups consisting of thirteen and four participants respectively. Interviewees and focus group participants were chosen on the basis of their previous or current involvement in some aspect of the pig breeding innovation ecosystem. They were identified in part through one of the author's investigations into the history of pig genetics and genomics, which included network analysis of publications derived from submissions to data repositories, and from the other author's experience of the animal breeding sector and research on agricultural innovation. Additional interviewees were identified through snowballing from suggestions and mentions in interviews themselves. We also undertook extensive searches of scholarly, grey and commercial literature as well as inspecting historical archives (including of the Roslin Institute and personal archives of two respondents). This enabled the information provided in the interviews to be further assessed. Interviews were conducted by the two authors. A sample of interviews were undertaken by both interviewers ensuring consistency of approach. Ethical approval was given by the University of Edinburgh.

Due to the flow of personnel between industry and academia, as well as within industry and academia, it is only possible to broadly indicate a respondent's affiliations. The following interviews were undertaken: ten people from the UK pig breeding industry, four people from UK academia and four policy-makers. Additionally, three people from European pig breeding organisations and sixteen non-UK based academics were interviewed. Data were analysed inductively, paying particular attention to key themes arising from descriptions of interactions among industry and academia. The focus of this case study is the UK, but given the international nature of both the science and the pig breeding industry, reference will be made to developments in other jurisdictions where appropriate.

The longitudinal study starts by considering UK pig breeding in the 1980s, prior to the advent of genomic sequencing and the Human Genome Project. Instead, it was an era dominated by quantitative genetics approaches to breeding. Quantitative genetics is based on physical measurements and statistical inferences as to the underlying genetics, relying heavily on computational methods. We trace the impact of the opportunity that progress in mapping the human genome provided to pig breeders – could they take the steps necessary to create value from these new and potentially disruptive technologies? Next, we examine the evolution of the ecosystem to take advantage of genome mapping and sequencing methodologies and technologies. This required collaboration among the pig breeding companies as well as co-innovation with academics. The entry of new companies that specialised in producing Single Nucleotide Polymorphism (SNP) chips proved a critical milestone. New theoretical developments identified ways of using genomic data and tools in improved ways, making what became known as 'genomic selection' possible, but also challenging existing breeding practices. We then consider perspectives on commercialisation, to complement the focus on technological development. Finally, we review the current state of the innovation ecosystem. The focus throughout this paper lies on the relationship between industry and academia, and the way in which economic value has been created from advances in genomic science.

Findings and discussion

State of the UK pig industry in the 1980s

We begin our examination in the 1980s, prior to the commencement of whole-genome sequencing projects such as the Human Genome Project.

An innovation ecosystem can be considered as consisting of specialist organisations (actors and actants – including non-human ones) interacting with each other and in the context of a common environment (Pigford, 2018). After Walgrave et al. (2018), we consider the system goal as forming the boundary of the ecosystem, so defining the actors, actants, institutions and actions needed to produce this goal. A summary of these is provided in Table 1. The ecosystem that we are examining consists of academic research institutions and pig breeding companies with pig farmers as intended customers. A number of ancillary and brokering organisations exist in the ecosystem, notably the Meat and Livestock Commission (a levy body now part of the Agriculture and Horticulture Development Board) and government research funders. The goal of the system is to apply genomic information to producing breeding pigs for farmers.

Pig breeding companies are key actors in this system. In the 1980s, UK pig breeding was dominated by around ten companies, although individual smaller pedigree pig breeders also existed. Breeding companies maintained strong links with the Edinburgh-based Animal Breeding Research Organisation (ABRO) as well as animal breeding and genetics expertise at the University of Edinburgh. An Edinburgh-based research institute of the Agricultural and Food Research Council (AFRC; Agricultural Research Council up to 1983), ABRO later became part of the Roslin Institute, a key actor in academia-industry relations (García-Sancho, 2015; Myelnikov, 2017). Although a number of universities also had genetic expertise (e.g., Wye College University of London and Leeds University) their role in the ecosystem of pig breeding is less clear. Roslin Institute and its predecessors were set up to provide strategic research to industry (Button, 2018; García-Sancho, 2015), so unlike universities, they have a history of strong interaction with industry, which in the pig context dated back to the 1960s. For example, the lead product of the company PIC was named 'Camborough' to acknowledge the veterinary expertise from Cambridge University and genetics expertise from Edinburgh University involved in the development of the company.

The links between the research and commercial sector were close. In the words of John Webb, who worked at ABRO and later with a pig breeding company (interview data), "everything was aimed at making the industry successful". Multiple interviewees indicated that links were developed through companies actively going to the institution for advice, through consultancies and through an active recruitment of staff from the animal breeding MSc run by the University of Edinburgh. After the 1980s, the pig breeding

Table 1. Summary of actors, activities and artifacts in the innovation ecosystem

Actors	Activities	Artifacts/products
Pig breeding companies (e.g. PIC)	Using genetic and genomic technologies	Breeding pigs supplied to farmers
Publicly-funded research institutes (e.g. Roslin Institute)	Basic and strategic research	Statistical procedures, software programmes, genetic and genomic data and knowledge (including theory)
Universities (e.g. The University of Edinburgh)	Basic academic research	Statistical procedures, genetic and genomic data and knowledge (including theory)
DNA sequencing centres (e.g. Sanger Institute)	Large-scale, high-throughput DNA sequencing	DNA sequence data
Meat and Livestock Commission (a levy board)	Comparative data on different pig breeds; expertise on artificial insemination	Pre-competitive innovation for the breeding sector; information on value of products of breeding sector for producers
Pig Breeders' Roundtable/UK Pig Breeders' Consortium/Pig QTL consortium	Collaboration among pig breeding companies	Cross-sectoral understanding to smooth translation
Farm Animal Industrial Platform; European Forum of Farm Animal Breeders	Advocates for pig breeding at European level	Conduit to European-level policy-makers
European Commission	Research funders	PiGMaP, successive research projects and enduring collaborative relationships
Agricultural and Food Research Council; Biotechnology and Biological Sciences Research Council; Ministry of Agriculture, Fisheries and Food; Department for Environment, Food and Rural Affairs	UK research funders	Genome mapping, support for publicly-funded research institutions
Meishan pigs	Crossing with European breeds	Reference families containing many differences at the genomic level (polymorphisms) to enable genome mapping
Canadian research group	Research group identifying causal mutation for porcine stress syndrome	Enabled development of genetic test to detect the mutant gene
Genesis Faraday Partnership/Biosciences Knowledge Transfer Network	Knowledge brokers	Relationships between sectors, new translational research programmes
Illumina	Developed standard platform for genomic analysis	Pig SNP chip, DNA sequencing services

companies were also able to collaborate on training PhD students and hosting post-doctoral students. Consultancies were in place from the 1960s. One interviewee explained how consultancies produced questions which the academics then sought to answer (e.g. appropriate replacement rates for breeding stock), as well as translating information from academia to industry. The pig breeding sector was typified by strong links between academics and a highly-trained industry sector. Several of our interviewees emphasised the informal nature of contacts between industry and academia and the ease of communication between the two. Staff from the pig breeding companies attended academic conferences such as World Congress on Genetics Applied to

Livestock Production, the International Society for Animal Genetics and to a lesser extent the European Federation of Animal Science (formerly European Association for Animal Production). From these conferences, staff in pig breeding companies were able to follow-up lines of work that they assessed as promising for potential translation to the breeding sector, on an informal basis with the individual researchers. Through these interactions, scientific interests were able to overlap with industry interests. Furthermore, as John Webb (interview data) argued, the "small size of pig breeding industry in 1970s and 80s ensured totally fluid dialogue between industry and people doing the research", as did the dominance of Edinburgh University allied with ABRO and later the Roslin Institute as the main source of information on genetics research. According to animal scientist and innovation broker Chris Warkup (interview data),

> It wasn't just push from Roslin, it was also because of the history that was clear … industry knew where the expertise was and you didn't have to go shopping for it, it was all in one place.

This advice was particularly important for smaller breeding companies that did not possess the ability to undertake research themselves.

The pig breeding companies in the UK competed against each other for market share. The then Meat and Livestock Commission ran trials from 1984 to 2007 at a central facility, the UK pig industries Development Unit at Stotfold in Bedfordshire, to compare pigs from different breeding companies in a common environment and make these data publicly available to pig farmers. It was suggested to us by an interviewee who had worked in this arena that these external comparative data provided an incentive for the breeding companies to invest in genetic gains, as the availability of such performance data would mean that marketing could only sell genuine improvements rather than mask underperformance.

Although competing to sell to pig farmers, the companies had a common purpose in using genetics to improve the economic value of their breeding animals. Many of the companies supplied breeding pigs to global markets with an emphasis on lean meat production. To this end, the companies were able to collaborate at a pre-competitive level. Examples of this include the Pig Breeders' Roundtable and the UK Pig Breeders' Consortium.

The Pig Breeders' Roundtable was initiated by John King from ABRO. It was modelled on a similar, successful initiative in the poultry industry that brought together industry and researchers in a closed event, without papers being published. Multiple interviewees told us that this was a very successful model of interaction, with corporate staff willing to speak about their breeding programmes. Pig breeding companies were scattered around the UK. At the outset of the 1990s they were, nevertheless, organised into a British Pig Breeding Companies Committee, chaired by Rex Walters of the breeding company Masterbreeders. This and its later instantiation as the UK Pig Breeders Consortium provided support to academic research on pig genome mapping, as we discuss below.[1]

Regulation of breeding practice has played a relatively modest role in this breeding ecosystem.[2] The purpose of regulation has been primarily to ensure the quality of breeding pigs being sold, the main example being EC Directive 88/661/EEC on the zootechnical standards applicable to breeding animals of the porcine species. This Directive specifies the need for recording pedigrees in order to harmonise herd-books and registers for intra-community trade in breeding pigs. Animal welfare and environmental regulation has additionally been important, particularly for production aspects.

Other jurisdictions apart from the UK have similar strong links between academia and industry, notably Wageningen University and pig breeding organisations in the Netherlands. Land grant universities such as Iowa State University in the United States receive funds from the United States Department of Agriculture's Agricultural Research Service as well as the National Institute of Food and Agriculture (NIFA; the Cooperative State Research, Education, and Extension Service up to 2009). This funding, like the USDAs intramural funding of its own research institutes, is predicated on conducting research oriented towards, and often in collaboration with, breeding and

producer industries. Part of NIFA's remit is 'cooperative extension', in which departments of land grant universities work directly with producers to adapt and implement scientific research in the field.

In 1988 the UK government unexpectedly shifted UK research funding away from so-called 'near-market research', imperilling the kind of strategic research of value to industry characteristic of many agricultural institutes (Read, 1989). This was a culmination of a process from the early 1980s that in the opinion of John Webb (interview data), "meant that [industry] became a dirty word". This change in the UK funding environment displaced attention towards the increasing levels of funding available from the European Commission (EC).

EC genome sequencing projects and industry collaboration

Starting from what the industry perceived as a competitive advantage in livestock breeding in Europe, at the turn of the millennium the Farm Animal Industry Platform (FAIP; see below) argued for continued investment by the EC in genomics research to maintain that competitiveness against USA, Japan and China, as well as private companies such as Monsanto who had recently entered the pig breeding business. FAIP posited that no one single company had sufficient funds, facilities or knowledge to undertake the work on their own (FAIP, 2000). Indeed, in developing their technical genetics expertise, the challenge for pig breeding companies was that this science was expensive but the margins from pig sales were low. Therefore, profits were too low to allow individual pig breeding companies to invest in developing capabilities in this area.

Although the companies competed, collaborative work was therefore necessary to begin to realise the benefits of the 'genomics revolution'. As Chris Warkup notes, moving from quantitative genetics to using molecular genetic information required a paradigm shift from the companies (interview data),

> These businesses didn't have big R&D Departments that could talk to each other about how they should handle this, they didn't have big consultancy budgets, they worked their way through it by actually having conversations with their competitors, how are we going to do this?

The first porcine genome mapping initiative funded by the EC was PiGMaP (1991-1996). The aim of PiGMaP was to populate maps of pig chromosomes with various kinds of genetic markers, and to develop molecular, statistical and informatics tools to be able to more densely populate these maps and then to identify areas of the genome associated with variation in measurable traits (Lowe, 2018). Chris Warkup (interview data) suggested that for breeding companies, joining in with PiGMaP was "the cost of staying in business … You will go out of business if you do not invest in the latest technology".

Hervé Bazin, a scientific staff member in the EC's directorate-general XII for research (DG-XII), was instrumental in guiding and advising the nascent PiGMaP collaborators in the development and approval of their project, indicating additional opportunities beyond PiGMaP to develop the work still further. He encouraged leading academic drivers of PiGMaP such as the Roslin Institute's Alan Archibald and Chris Haley to seek out industry support as well as academic collaborators. Industry support played a role in securing funding from the project from the EC. Furthermore, an initiative driven by breeding companies and Roslin Institute resulted in the importation of a small population of Chinese pigs of the Meishan sub-breed into the UK in 1989. These pigs were critical to the reference populations at the heart of PiGMaP, along with separately established populations of Meishan pigs in France and the Netherlands, and wild boar populations in Sweden and Germany. Just as no single institution could obtain sufficient national funding to map the pig genome, no one institution could perform the different kinds of mapping and analysis required, so tasks were divided and coordinated across 21 institutions (most, but not all, in Europe).

The outputs of PiGMaP and succeeding EC-funded projects represented the creation of platform technologies (e.g. Kim and Kogut, 1996) accessible by pig breeding companies. This built on existing practices of free sharing of statistical software applications for animal breeding and genetics (Rothschild et al., 2003). The way in which

the genetic information from PiGMaP was used to create market value remained, however, in the control of individual organisations.

Across academia, industry and DG-XII, several individuals helped to adapt livestock genetics research to the changing funding and policy environment. Old niches had to be abandoned, and new ones constructed and occupied, which entailed forging both deeper collaborative relationships across sectors and borders, as well as reorienting institutions to make them more responsive to collaborative opportunities whenever they might arise.

Early in the formation of PiGMaP, Roslin Institute director (1988 to 2002) Grahame Bulfield attempted to secure funds to create an academic 'Network for Farm Animal Genetics', which failed. In its stead, on Bazin's advice, to foster further post-PiGMaP projects and to establish a body with which dialogue with EC bodies could be initiated, the Farm Animal Industry Platform (FAIP) was inaugurated in 1995, with considerable impetus from Graham Plastow of the company PIC, Gerard Albers of Nutreco and Jan Merks of Topigs (who initially led FAIP). Informal brokers such as Bazin were central to this innovation ecosystem. Furthermore, this developing set of relationships depended on leadership from multiple people (as per Dedehair et al., 2018; Sotarauta and Mustikkamäki, 2015).

Knowledge intermediaries have been identified as key actors in innovation systems (Klerkx and Leeuwis, 2008; Klerkx and Aarts, 2013). The founding of the Genesis Faraday partnership in 2003 as a knowledge intermediary organisation, was another key governmental intervention. It was one of 24 Faraday Partnerships introduced by the then UK Department of Trade and Industry, driven in particular by Science Minister Lord Sainsbury to improve the commercialisation of UK research. The initiative was described by Chris Warkup, the CEO, as providing a "centre of gravity", a link with government and a source of encouragement for a livestock industry that at the time felt beleaguered as agriculture – and livestock agriculture in particular – had faced declining research funding and political importance with the merging of the AFRC into the Biotechnology and Biological Sciences Research Council in 1994, and the Ministry of Agriculture, Fisheries and Food into the Department for Environment, Food and Rural Affairs in 2001.

From single-gene hunting to marker-assisted selection

The mapping of the pig genome held the promise of ever more fine-grained resources and tools for the localisation of genes and mutations that may be implicated in particular traits of interest to the industry. This promise was considerably fuelled by research that led to the discovery of the Halothane gene which led to quickly-implementable tests and economic gains in the industry.

In the 1970s, the pig industry had started to struggle with poor quality meat and the sudden death of pigs when stressed (porcine stress syndrome). Inadvertently, selection for pigs with large hams led to selection of a linked mutated gene that caused both poor meat quality, and a predisposition to sudden death. Termed the halothane gene, because an early test for presence of the mutation was to administer halothane anaesthetic to the pig and to observe any resulting rigidity in muscles, the gene causing this effect was identified by a Canadian group in 1991 (Fuji et al., 1991). The discovery of the halothane gene enabled pig breeders to identify pigs which carried the mutation and use genetic tests to remove them from their populations. In the view of many of our interviewees, this provided a real, commercial advantage to using genetic information on a single gene.

The identification of a single gene raised the question of patents. The relevant gene (*ryr1*) was patented by academic and hospital-related organisations (the gene variant is also present in human populations), but individual breeding companies were unable to obtain exclusive licenses for testing for the gene variant. The result (according to multiple interviewees) was that tests for the gene were quickly and widely adopted across the pig breeding industry, giving the sector a large economic and animal welfare advantage.

In the 1990s, according to one of our industry interviewees, some companies felt that patent protection would enable collaborating researchers to publish their research and thus create a win-win scenario, where both parties were satisfied and

could continue to collaborate. Peer-reviewed publications were also seen to be important by industry, not only to maintain collaborative relationships with academics, but also in order to establish credibility for both marketing and further staff recruitment.[3] Patented pig genes include HAL 1843™ (halothane gene), *ESR* gene polymorphisms to improve litter size and the *KIT* gene. Breeding companies also used copyright protection e.g. PIC held rights on Berkshire Gold™ for pigs that were 100% Berkshire breed in origin, and PICmarq™ to indicate that gene marker information was used in the selection of these pigs (Rothschild et al., 2003). The high prevalence of PIC named in patents in part reflects PIC's (and its later identity as Sygen) listing on the stock exchange where the number of patents held was one of the metrics communicated to investors.

Our interviewees from different breeding companies suggest that the trend towards patenting did disrupt the innovation ecosystem, particularly when Monsanto entered the pig breeding sector in the USA when it took over DeKalb Genetics in 1998, and started to patent not just genes but also breeding practices.[4] The European industry reacted by setting up a 'patenting watch' through the European Forum of Farm Animal Breeders (EFFAB; this superseded FAIP in 2004) to ensure that they were aware of developments. In the event, breeding companies found patents too cumbersome to maintain and resorted to trade secrets instead (focus group data), and Monsanto withdrew from the pig breeding sector. Multiple interviewees identified patenting as not significant in their current practices. The patenting that could have created a strong selection pressure and positive feedback loop advantaging particular companies proved not to be a mechanism that worked well in the context of the pig breeding industry. The private holding of data concerning the pedigrees and performance data on the pigs in their possession, and the holding of those pigs themselves in biosecure nucleus herds are other long-standard and significant proprietary practices in the industry.

The halothane gene mutation stimulated commercial interest in single genes. As a focus group respondent related, "people began to think what else could be segregating that would be amenable to using genomics." In the event, apart from the halothane gene, single gene effects were mostly restricted to genes of local national interest such as *RN-* gene concerning meat quality of French Hampshire pigs.

As single genes of large-effect proved difficult to identify, the industry (and academic researchers) resorted to attempting to identify genetic markers that were associated with traits of interest. There was initially a great deal of enthusiasm for adopting what was termed Marker Assisted Selection (MAS). However, moving from the PiGMaP resource populations to using genetic tools in commercial populations proved not to be as straightforward as first envisaged due to differences between the mapped populations and the breeding company herds, and the still sparse maps meant that markers could be distant from causative genes.

MAS later proved not to be helpful as originally hoped, as relationships between markers and genes broke down over generations. Additionally, it proved too difficult and costly to identify markers closely linked to individual genes, most of which had but small effects on the production traits of interest anyway. In this period, one former industry scientist retrospectively reflected that "the power of genomics was overestimated except for its marketing impact; we were victims of the success of the halothane gene".

Although PiGMaP produced little implementable results directly, it and other contemporary mapping projects were essential for subsequent developments. The entry of new companies to the innovation ecosystem, and the development of SNP chips, constituted another crucial stage in the development of the innovation ecosystem.

Introduction of SNP chip companies to the ecosystem

Single Nucleotide Polymorphism chips (SNP chips) are slides with specific DNA sequences attached to them. They are used to detect the presence or absence of complementary strands of DNA in samples run through them, therefore *genotyping* the source of the sample for the set of markers (SNPs) contained on the chip. In livestock, the first

commercial SNP chip was produced at the instigation of the USDA for cattle in 2007, by Illumina. It contained 54,001 SNPs, and was used in genomic evaluations of American dairy cattle.

The value of such a chip for pigs was apparent to academic researchers. Representatives from Illumina and another chip manufacturer, Affymetrix, presented their case to the researchers at the Plant and Animal Genome conference in January 2008. Illumina won out, in part because of the lessons they had learned with the cattle chip. The eventual product of this collaboration between established pig genome researchers and a company that had only just entered this particular innovation ecosystem from an entirely different industry, was the 62,121 marker 'PorcineSNP60' (Ramos et al., 2009).

This marked a move towards evaluating breeding value of individual pigs on the basis of both physical and genomic data. Its advent was enabled by, and made use of, the masses of sequence data arising from projects to sequence the whole genome of the pig, producing a 'reference genome'. In this respect, it represents the creation of a technological platform and standard that itself derives from the platforms and standards established in genomics.

The creation of standards and platforms have been a central feature of the development of genomic infrastructures (Hilgartner et al., 2017; Strasser, 2019). The platforms include genome mapping and DNA sequence databases (Maxson Jones et al., 2018). The standards include the ways in which data and metadata are recorded in databases, the norms of submission and release of data, and ways of representing data (Hilgartner et al., 2017; Maxson Jones et al., 2018; Stevens, 2018). For example, the annotated reference genome for the pig (itself a standard), is represented for use by researchers on a platform (the Ensembl genome browser), which itself incorporates multiple standards and makes use of the data held by databases. The infrastructure of genomics represents a kind of platform ecosystem, "a system or architecture that supports a collection of complementary assets" (Thomas et al., 2014: 200). One of those complementary assets that it supports is the formulation and production of a SNP chip. A SNP chip is also a technological platform, and manifests as a standard, if accepted and widely distributed. This was the case for PorcineSNP60, due to the upstream involvement of multiple members of the pig genomic research community and industrial actors.

The technological artifact of the SNP chip was essential in being able to identify a large number of genetic variants simultaneously, rather than relying on testing for individual genes or markers, or mere dozens thereof. In the view of our interviewees, even though the first reference sequence was far from perfect, and was missing portions of the genome, the first 60k chip was extremely useful for industry. One of our focus groups noted that SNP chips made their work a lot easier, as one interviewee commented: "just squirt on (effectively) the DNA and suddenly you get the genotypes".

At the same time, theoretical developments from academia provided a basis on which this information could be used for pig breeding. This involved combining the information from thousands of SNPs to evaluate the breeding value of a pig, without knowing the functional implications of the individual SNPs. One industry interviewee described how a seminal theoretical paper by Meuwissen, Hayes and Goddard (2001) was originally treated with scepticism, and the theory of 'genomic selection' took a while for industry to accept. But once accepted, it became a valuable next step for the industry in using genetic information to complement physical measurements.

The first published data analysis from SNP chips came from academia (Ramos et al., 2009). What happened next is described by a focus group member:

> First there was the map, then eventually the SNP chip and then everything just took off. The SNP chip took off because we had the initial sequence in 2008 and that led to the SNP discovery that led to the chip and then things took off.

The use of SNP chips has had a significant effect on the structure of the pig breeding industry. The predictive models of genomic selection are more accurate when the reference populations used to generate them are larger. Access to more animals, more data on their performance and pedigree, and ability to invest in expensive genomic tech-

nologies, provide a competitive advantage. Consequently, breeding programmes became more expensive to run and therefore accelerated industry consolidation.

SNP chips have been adopted in the pig breeding industry on a short time-scale, especially compared with biomedical innovations. As described by one of the focus group members:

> The distance between research and application is extremely short in comparison to what you have to do to prove a drug works or whatever. It takes years of validation, you also have regulatory oversight from governments…In this [pig breeding industry] case we're working directly with industry, once industry knew that it was working and they could adopt it, boom, they took it and they would run with it faster than what the researchers probably could keep up with.

Table 2 provides a summary of the interactions within this innovation ecosystem, following environmental challenges. It shows a simplified schematic of flows of knowledge (indicated by arrows) concerning the use of genomic information to create value.

As well as the theoretical development, modelling, statistical methods and matrix algebra required to establish selection using SNP chip information, other developments were also important for enabling this innovation, including increases in computing power. There were also biological requirements such as pedigree structures appropriate to enabling the adoption of genomic selection. This, in turn, benefitted from the development of artificial insemination, which the Meat and Livestock Commission had an important role in developing, providing yet another link between industry and research.

Although genomic technologies were rapidly adopted by industry, the industry view was that pig farmers would not pay any extra for the harnessing of these advances. However, in order to remain competitive, genomic technologies were needed. This market pull, if indirect, had a real impact on the relative market share of different pig breeding companies.

Link between scientific possibilities and commercial realities

Internal company processes, and in particular the role of key individuals (both in academia and industry) has had a strong influence on innovation trajectories. Choices made by technical directors and chief executives did affect the direction of travel of different companies.

Instituting a genetic selection programme does not usually visibly affect the resulting pig. Furthermore, genetic changes tend to be gradual and not easily perceived in the short-term, although because they are cumulative, over the longer-term changes can be substantial. Our interviewees emphasised how trust in the person advocating the technical process was key to genetic programmes being accepted. As one of the focus group members put it (their emphasis): "somebody has to <u>believe</u> genomics is going to help the world". This trust was also described as a cumulative process, and while economic arguments were often needed, the key was trust in the person making the proposal.

Individual company history can also have a big influence on the direction of innovation. A clear example of this is the relationship between the pig breeding company PIC and Dalgety plc. Originally an initiative of four Oxfordshire pig farmers in 1962, PIC needed extra investment to continue to grow and was bought out by Dalgety in 1970. Dalgety had a range of different agricultural interests which included a biotechnology lab loosely associated with Cambridge University. This established a link between PIC's pig breeding expertise and the molecular methods deployed in biotechnology. This relationship influenced PIC to become involved in molecular genetics, and was instrumental in PIC looking to apply biotechnologies to the pig business in ways that other companies were not. PIC, under its new owners Genus, have continued this focus on biotechnology and have publicly announced that they have entered the era of genome editing, intending to introduce genome-edited disease resistant pigs to China (Genus, 2021; Whitworth et al., 2016, Burkard et al., 2017).

Not all the companies that expected benefits from genomics continued to be successful. The giant of genetically modified crops, Monsanto,

Table 2. Summary of interactions within the innovation ecosystem

Timeline	Outputs	Academics	Industry	Environmental change
1980s	Advice on breeding programmes			
1988				Public funding of near-market research axed
1989				Introduction of Meishan breed to UK
1990-2003				Human Genome Project
				EC Funding
1991-1994	PiGMaP resources			
1991		Halothane gene identified		
1995				Farm Animal Industry Platform established
1997-2013	Projects to identify Quantitative Trait Loci linked to phenotypic variation and enable MAS			EC funding
2001		Seminal academic paper on use of multiple SNPs		
2003				Genesis Faraday Partnership established
2007				SNP chips developed
	Genomic selection undertaken			

also entered the global pig breeding frame after it bought the US company DeKalb Genetics in 1998, which included a pig breeding arm. However, after a short time, Monsanto withdrew from the pig breeding business. The well-known human biotechnology firm, Celera, also developed an agricultural arm, Celera AgGen, which was subsequently sold to private company MetaMorphix. The company offered a 'Whole Genome System™' to test for genetics of production traits. MetaMorphix subsequently went bankrupt. It seems that being a large company, with expertise in genetics and genomics in other species, is not sufficient to successfully compete in the pig breeding ecosystem.

Having the genetics and genomics expertise is only one part of the package needed to compete in the ecosystem. This knowledge needs to be implemented and allied to a distribution network and appropriate business model. Samples have to be taken from the pigs and then stored, animals have to be identified, and data have to be processed. Van der Steen et al. (2005) describe some of the processes adopted by PIC. One of our industry interviewees indicated that sometimes appropriate compromises have to be made from 'book practice' to practical application, and knowing which compromises can be made is part of the craft of pig breeding.

Current status of the innovation ecosystem

There has been considerable consolidation among the pig breeding companies in the UK, with three major companies remaining: PIC, JSR-Topigs Norsvin and Rattlerow. A number of smaller independent breeders also continue to exist. Consolidation has been allied to a drop in the number of UK pig producers, attributed to competition from lower cost countries such as Thailand and Brazil, regulatory constraints related to animal welfare, feed regulations to limit diseases, and also as a result of disease outbreaks, notably Foot and Mouth Disease. Pig production chains have become integrated with meat processors with the result that interactions with individual farmers have been in part replaced by interactions with large integrators, who are internally able to compare the performance of pigs from different breeding companies. Pig production in the UK has been through periods of poor profitability and is very cost-conscious.

The relationship between academia and industry has also changed, though interviewees varied in their evaluation of the extent of the changes that have taken place. The research side has become very data hungry, with demands for pedigree records and physical measurements (the phenotypes) on 10,000-30,000 animals in order to undertake genomic research. It is unrealistic for publicly-funded research organisations to keep such large numbers of animals and therefore researchers rely on collaboration with industry in order to gain access to these animals. As one of our academic interviewees pointed out:

> Once the genomic tools were available the valuable entities were the phenotypes, so the companies have the phenotypes, why should they give those up to other people.

A second change has been the increase in speed at which novel developments are adopted. People in industry are hungry to keep at the forefront of breeding research and have adopted an ad-hoc, opportunistic approach. Alan Archibald, one of the key people involved in getting together the PiGMaP consortium, suggested that the era of the research consortium has passed because the gap between doing the experiment, getting the results and implementation is so short, so it is no longer pre-competitive research. Personal links, however, remain important. Industry personnel network by attending conferences and use personal contacts to become aware of academic research before publication. Bigger companies are able to maintain these interactions, but smaller companies that need it most may not have the resources to do so. Ideas from industry to research groups are also spread through these informal interactions; industry technical staff know the academics who are publishing and are able to keep up to date.

From our interviews, it is apparent that the relationship between academics and industry has changed. What is less clear is the nature of the change, as there is disagreement in the descriptions of our respondents. This suggests that there is more heterogeneity in the relationships than in the past.

It seems that much research has transferred from the public sector to the private sector. However, industry respondents that indicated they also felt academics have become more secretive because of a heightened need to publish due to the increased competitiveness of grant applications, the ever-rising importance of academic metrics and, in the UK, the Research Excellence Framework and associated impact agenda. An alternative viewpoint felt academics have become more reluctant to share their work because research institutions have become more competitive, developing spin-off companies that companies had to buy into in order to get a share of the research. Others thought that it started to become difficult for industry to work with academia when chip technology became available. There was also a suggestion that the nature of relationships between industry and academia have changed from the personal to the transactional. Others disagree. One academic interviewee argued that the "whole community is a translational community".

The future of the pig industry looks challenging, with social concern about pig production methods, challenges to the abattoir sector from shortage of workers, inflationary pressures particularly on feed and energy costs following war in Ukraine, the imperative to maintain pig health with minimal recourse to antibiotics and, in the UK context, changes in trading relationships due to Brexit. It remains to be seen whether continued advances in biotechnology can enable pig breeders to aid producers to maintain resilience in the face of such challenges.

Conclusions

This case study describes some of the dynamics of competition and collaboration among pig breeding companies in the UK, as they have sought to capture the benefits of the genomics revolution. It demonstrates both the complementary and substitutionary effects of innovation (Granstrand and Holgersson, 2020). Innovation based on genomics both complemented existing approaches to pig breeding based on quantitative genetics (for example, concerning the structure of breeding herds and measurement practices), and inaugurated genomic selection, which has the potential to displace many existing breeding approaches and practices. Supplementing Papaioannou et al. (2009), we provide an example of a case where innovation was far less driven by a social history of division of labour and market forces, and far more by a social history of interaction and collaboration. Much of the subsequent innovation was driven by necessity, the low margins and high cost of research, by the limitations of biology (many genes have such small effects to make identifying them barely worth the time and expense) and by individuals who drove the processes of collaboration and convinced their company leaderships to invest in a product for which the benefits would not be apparent in the short-term.

Unlike some hub ecosystems (e.g., Nambisan and Baron, 2013) innovation was not driven by a single firm acting as the leader. However, individuals in academia, such as Alan Archibald, Chris Haley and Max Rothschild, individuals in industry such as Graham Plastow, and numerous others, have had critical roles in this innovation ecosystem at various times. In large part, this has been due to their combined focus on the possibilities arising from cutting-edge science and their appreciation of the practicalities of applying this science. Archibald and Haley were able to influence the course of events by bringing together groups of actors, using what Sotarauta and Mustikkamäki (2015) call "network power". These were not individuals *given* a role within an organisation, but rather individuals who took it upon themselves to stimulate interaction.[5] Of course, successful interaction would have been impossible without the positive contributions from many others. Innovative people inside the breeding companies were embedded in social networks outside the companies (Bagchi-Sen et al., 2011) enabling them to co-create knowledge that was immediately transferable to the commercial setting. It is also clear that one individual, Hervé Bazin, was critically important in facilitating (European) public funding at a crucial stage.

The social networks in this innovation ecosystem are not geographically bound, but depend on a history of interactions that spans decades, and in turn extends to global markets. Sharing knowledge and co-innovation (Dedehyir et al., 2018) in this case study has not depended

on co-location, but on a shared focus on a product and ability to leverage the 'genomics revolution'. Using the terminology of Russel and Smorodinskaya (2018), interactions among SMEs and academics took place at a number of different levels from networks, through co-operation to formal collaboration, and back again to networking and co-operation, at varying times during the period of our case study. These links were iterative and did not move only towards closer collaboration.

The case study traces how ecosystem entrepreneurs have created and obtained important resources, such as maps and DNA sequences of the pig genome, together with the infrastructures, expertise and knowledge of biological processes necessary to create value from new scientific developments. It further demonstrates how this was only possible by individual companies working together, even though individual companies have taken different pathways to capture this value. The entry of new ecosystem actors, namely companies providing SNP chips, has been critical to this process. The co-evolution of SNP chips and new statistical methods have provided a selection pressure in the ecosystem. The willingness of executives to invest in these technologies and the availability of research funding at critical moments have proved essential. This ecosystem was not driven by market demand. Pig farmers were not necessarily even willing to pay for genomic selection, let alone demanded the approach. Rather it was driven by a scientific possibility that was recognised by companies, who worked together because they were also competitors and feared losing out if they did not collaborate. In contrast to the crop breeding industry where SMEs feared being taken over by Monsanto (Bagchi-Sen et al., 2011), pig breeding companies were able to maintain their competitiveness, and indeed, Monsanto itself failed to compete.

The ecosystem has benefitted from being a small industry, where people know each other, and the presence of highly technically skilled staff in industry has enabled continued close collaboration between academia and industry. There exists a porous boundary between academia and industry, a long history of collaboration with established research organisations and a culture of sharing, including in sector-specific closed meetings. This has also benefitted from actions of knowledge transfer organisations, such as the Meat and Livestock Commission, the Genesis Faraday Partnership and collaborative organisations at the European level, enabling collective action in support of the industry.

As a single case study, general conclusions have to be drawn with care. However, the case study suggests that enabling long-term networking relationships including relevant academics, funders and knowledge brokers has the potential to engender an innovation ecosystem that can respond effectively to a range of environmental challenges. Its further suggests that these relationships are fluid, and change as the ecosystem itself responds to change. Of course, such long-term relationships could stagnate and fail to respond to environmental challenges, which may result in the collapse of the whole sector.

In conclusion, this case study demonstrates how economic value has been created from basic scientific research and the interactions among scientific developments and individual commitments that were instrumental in bringing this about. In particular, given the gradual and long-term nature of genetic change in a breeding programme, the key role that trust has played in these processes cannot be underestimated.

Acknowledgements

We would like to thank Joyce Tait and David Wield for their comments on a draft. We would additionally like to thank all those who have participated in oral history interviews and focus groups, and to those who have allowed us to see their personal documents. The research for this paper was conducted through the 'TRANSGENE: Medical translation in the history of modern genomics' project, funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 678757.

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Notes

1 As of October 1990, the membership of the British Pig Breeding Companies Committee was as follows: ACS, Cotswold Pig Development Company, JSR, Masterbreeders (Livestock Development), Meteor Pigs, National Pig Development, Newsham Hybrids, Peninsular Pigs, Pig Improvement Company, Pig Link, Premier Pigs, Rattlerow Farms and UPB Porcofram; all but the latter (a plc) were limited companies. Source: letter from Rex Walters to Alan Archibald, 10th October 1990; in 'FP3 BIOTECH' partition, Alan Archibald's personal papers.

2 This does not, of course, apply to the substantial regulations concerning the treatment and welfare of animals under the care of breeding companies, merely that the breeding process itself it not subject to significant regulation.

3 Though company authors do not seem to have been quantitatively important in pig genomics publishing compared with the community as a whole.

4 This takeover, which begun in 1996 with the purchase of a minority stake, was more concerned with DeKalb's work in breeding and selling seed corn. Upon the takeover, Monsanto realised the potential of the hybrid swine breeding section of the company and sought to develop it.

5 One example would be the key role of Grahame Bulfield, Roslin Institute director from 1988 to 2002, in fostering genomic research and links between multiple actors concerned with farm animal genomics, including those in industry, from the late 1980s.

The Production of Infrastructural Value and the Extension of the Electricity Grid: Demand-Side Response and Aggregators as Temporal Prospectors

Mette Kragh-Furbo

DEMAND Centre, Lancaster Environment Centre, Lancaster University, UK/m.kraghfurbo@lancaster.ac.uk

Gordon Walker

Lancaster Environment Centre, Lancaster University, UK

Mitchell Curtis

School of Built Environment, University of Reading, Reading, UK

Abstract

Infrastructures have recently been conceptualised as in process and dynamic rather than fixed and obdurate. We introduce the notion of infrastructural value to draw attention to the specific value that can be produced in something in relation to its participation in an infrastructure, its operation and management. We analyse demand-side response (DSR) as a case of infrastructural extension where value is produced in already-existing electricity consuming devices, generating a return for their response to the ends of grid management. We track the work of aggregators who enrol clients and their devices into providing combined synchronised responses contracted with the grid operator. This involves aggregators in activities of temporal prospecting, legitimation, optimisation and coordination. We argue that the notion of infrastructural value helps to articulate the relations between the fluidity and flexing of infrastructural boundaries and value making practices and consider other ways that this category of value might be explored.

Keywords: Infrastructure, value, electricity grid, aggregation

Introduction

While apparently obdurate and firmly in place, infrastructures have in recent re-conceptualisations been positioned as thoroughly in process and emergent, embodying dynamism rather than statis (Haarstad and Wanvik, 2017; Harvey et al., 2016; Shove and Trentmann, 2019). Electricity grid infrastructures are a case in point, with a variety of authors rejecting their conceptualisation as stable forms, including as 'large technical systems' (Hughes, 1983) made of component parts locked together, and instead opening up their dynamic qualities. As Graham (2009: 11) states "… any

coherence that the electrical assemblage achieves as an infrastructure must never be assumed or taken as permanent and inviolable", while for Harvey et al. (2016: 7-8) electricity grids exist as a complication "of technologically mediated relations [that] pivot on their potential extendibility and the ways in which they *fold together* heterogeneous entities in networks". One of the implications of moving away from seeing infrastructures as 'fixed facilities' (Blok et al., 2016) in such ways, is that attention should turn to the processes through which flexibility, extension and reconfiguration are enacted and more 'fluid' forms of infrastructure emerge as a result.

In this paper we introduce the notion of infrastructural value as a way of opening up the relations between the production and distribution of value and the extension of infrastructural boundaries, and it follows, the reach of mechanisms of infrastructural management. Given that many, if not most infrastructural networks internationally are 'neoliberalized' (Narsiah and Ahmed, 2011; O'Neill, 2013), organised into variously competitive arrangements of private ownership and markets, along with state regulation to address 'overflows' of economic framings (Silvast, 2017), we should expect the ongoing dynamics of infrastructures to be closely linked to the production, configuration and distribution of economic value. There has however been little explicit analytical focus on the ways in which contemporary value-making processes have provided opportunities for boundary flexing and the extension of the disciplines of infrastructural management into new spaces.

We argue that working with the notion of infrastructural value - which we define as the assigned and realised value in something due to its participation in an infrastructure, its operation and management - helps to clarify and articulate relations between infrastructural extension and value making practices. Following approaches seeing value as social practice (Muniesa, 2012; Birch, 2017; Kornberger et al., 2015), as the "outcome of a process … and the result of a wide range of activities … that aim at making things valuable" (Helgesson and Muniesa, 2013: 6), we see infrastructural value as being actively produced, not a latent quality in material things, but an "achievement that entails bringing materialities, relations and discourses into alignment" (Bridge et al., 2020: 729). While infrastructural value might appear to be self-evident in an entity, this particular form of value is always produced in relation to its coherence with other infrastructural elements. A distinctly infrastructural value may be produced in an entity alongside other values it carries, may come and go over time, and be contested within processes of valuation. Both material things and those who own or manage them may be compliant with being valued for their participation in an infrastructure, or resist becoming 'infrastructured' in these terms.

We focus on the electricity grid as an example of marketised infrastructure, but also one that is very much in flux as a result of pressures for change as part of low carbon transition (Bridge et al., 2013; Kuzemko et al., 2016; Bolton et al., 2019). An important part of this transition are new mechanisms for keeping the grid 'in balance' through managing the level of demand to match the availability of low carbon supply. In so called 'demand side response' (DSR), some degree of time de-limited responsiveness in the scale of demand is sought after to the ends of grid coherence (Torriti, 2016; Torriti and Grunewald, 2014). Whilst what has also been termed achieving 'flexibility' in the timing of demand (Cardoso et al., 2020; Powells et al., 2014) can take various forms, in this paper we examine a particular DSR variant that is well established in the UK. This involves large scale industrial and commercial users of electricity becoming responsive to the needs of 'the grid' (nationally and sometimes regionally), in some cases through contracts made directly with the grid operator, National Grid, but more frequently now through the work of intermediary organisations known as 'aggregators' (Curtis et al., 2018; Langendahl et al., 2019), who accumulate the responsiveness of multiple clients into 'packages' that can return a profit by being responsive, at scale, to what the grid operator requires.

We take DSR as a case of infrastructural extension, working with the concept of infrastructural value to demonstrate how elements of wider contemporary value-making practices are important to innovations in how infrastructural extension is being achieved. Bowker et al.

(2019) observe a shift from large-scale material infrastructure investments in roads, rails and wires to investments in 'thinking infrastructures' such as categorisation, classifications and other forms of 'sorting out' (Bowker and Star, 1999) that structure attention, shape decision-making and guide cognition. We can also think of these types of investments as now integral to infrastructural extensions that produce or redistribute value in existing materialities. In the case of DSR it is through the contemporary value-making practice of aggregation that infrastructural value can be realised in widely-distributed, mundane and already-existing electricity consuming devices - such as water pumps, air conditioning systems and freezing and heating technologies. Whereas the consumption of electricity by such devices generates extant economic value for the electricity supplier and costs for the user, through the variant of DSR we consider they become re-categorised and re-valued for their participation in the management of the grid, bringing income to the user with aggregation crucial to enabling this redistribution of value to diffuse and grow in scale. Aggregators actively extend the grid through forms of 'sorting out' (Bowker and Star, 1999) that are distinctively temporal in character, and through which the infrastructural value of already existing electricity-consuming devices can become newly established.

Our empirical research, undertaken through interviews, observation and document analysis, focuses on aggregators and identifies a practice of aggregation composed of four interrelated value-making activities. First, *temporal prospecting* for DSR potential across a very wide field of electricity-using organisations and devices, enabled by the network space of the grid, but constrained by temporal needs; second *legitimising* the possibility of responsively turning down or up consumption and dealing with resistances this encounters; third *optimising* return and profitability through detailed temporal assessment and algorithmic prediction; and fourth *coordinating* the timing of response through the affordances provided by digital infrastructures. In discussing each of these activities we make connections to tools and techniques of producing market value across other domains, but also reveal a temporal distinctiveness than relates to their application to infrastructural ends and to electricity as a resource flow that has particular material qualities. As we shall make clear, making infrastructural value in this case involves "aggregating hitherto unsuspecting geographies" (Leyshon and Thrift, 2007: 109), but doing so in a way that foregrounds the temporal far more than the spatial.

In so doing we make a distinctive contribution to existing literature on DSR which has largely focused on its technical and practical features (e.g. Li et al., 2016; Curtis et al., 2018), its role in relation to the broader transformation of electricity systems into smarter forms (Langendahl et al., 2019; Siano, 2014; Spence et al., 2015), its nascent extension into the domestic sector (Goulden et al. 2018; Powells and Fell, 2019; Calver and Simcock 2021) as well as market opportunities and barriers to DSR (Cardoso et al., 2020; Lockwood et al., 2020). In addition, our broader contribution is to bring the notion of infrastructural value into play in work on infrastructural dynamics, as well as to encourage more attention to value dimensions of infrastructure beyond its financialisation (e.g. Clark and Evans, 1998; Torrance, 2008; O'Neill, 2013; Knight and Sharma, 2015) and the reconfiguration of charging regimes (e.g. Brown and Pena, 2016; Loftus, 2006).

We begin by explaining more about DSR and its development in the UK, before then drawing on our empirical research to focus on the work and practices of aggregators in producing and distributing infrastructural value.

Balancing the grid and demand side response in the UK

Conventionally it may be thought that the electricity grid has an obvious end point, located where distribution ends and connected consumption begins, delineated by a property boundary and/or a device for metering flow from supply into use (Kragh-Furbo and Walker, 2018). Various conceptualisations, however, see users and the technologies through which resources are consumed as integral elements of infrastructures (Shove et al., 2015; Harvey et al., 2016) and in a number of recent developments as part of transitioning the grid into low carbon and smarter forms, any sense of a fixed boundary between an infrastruc-

ture managed in order to supply and consumers generating demand has become particularly blurred (Grandclément et al., 2019). This is not only through so called 'prosumption' in which consumers are also microgenerating producers of power (Olkkonen et al., 2017; Smale et al., 2019), but also by the extension of active moment-to-moment grid management into the dynamics of electricity consumption.

This need for moment-to-moment grid management comes from the distinct material qualities of electricity as a 'vibrant' energy form (Bennett, 2009), which means that it must (at scale) be consumed as fast as it is produced to avoid system breakdown. This imposes specific demands on the managed relation between electricity supply and demand within grid infrastructures and from the very beginning of grid formation has posed major practical challenges for system operators (Hughes, 1983). In the UK, throughout the period of a nationalised electricity industry from 1948-1989 (Hannah, 1979), sustaining balance and system reliability was achieved through mechanisms of central planning. Supply was orchestrated to meet variability in demand, with power stations turned up and down under instruction; and at times of really strong daily/seasonal peaks in demand, requests were sometimes passed to other nationalised industries such as steel works to temporarily limit their consumption in the (public) interest of system stability. During this period the electricity industry also took a number of initiatives to manage the timing of household demand, including calls for consumers to 'time-ration' their use of appliances, the promotion of off-peak electric heating in the 1950s and 60s (Carlsson-Hyslop, 2016), and from 1965 the availability of Economy 7 and other variable consumer tariffs (Hamidi et al., 2009) which through hardwired metering systems provided a differentiation between the cost of day time and overnight electricity use.

In 1989, and over subsequent years, the electricity system was transformed by moves to privatise and liberalise in an early example of infrastructural marketisation and state regulation (Mitchell, 2008). What had been an integrated system was taken apart, with separate units of generation, supply to consumers and grid operation, operating and interrelating through electricity market structures within the rules and oversight of the regulator Ofgem. The grid through this period rapidly folded in new actors (including new smaller generators and suppliers), new ideas, principles and rules that fitted with a different vision of what it would now be and how value would be distributed across its different elements. Competition and profit-seeking replaced an 'ethic of public service', but regulatory obligations meant that suppliers could not just 'merely spin meters' to increase profit (Guy and Marvin, 1995: 50).

For grid balancing specifically, privatisation meant that this role was now with National Grid, a private company. It had to sustain a functioning grid through the development of market-based mechanisms in which both core generation capacity and 'balancing services' - available to be drawn on when the grid was under particular pressure - were contracted and procured from multiple companies participating in the energy system. This implied a greater openness to how balancing might be achieved. As Guy et al (1999: 198) comment, the splintering of electricity industries, challenged the "extremely powerful supply-oriented logic of network development" with new approaches beginning to emerge. Amongst other things, this meant giving more attention to the possibility of intervening in the dynamics of demand as a cost-efficient and competitive alternative to seeking balancing services from supply-side operators turning up and down generation. In the early 2000s, a decade or so after the initial privatisation of the system, Ofgem (2002) sought to actively stimulate such thinking, setting up the 'Demand-Side Working Group' with the aim of reviewing the options available for demand-side participation in trading arrangements.

Other pressures also played into this shift to seeing demand as potentially malleable. So called 'peaking plants' deployed at times of high demand, provided electricity at a premium cost and were also typically high carbon emitters. As attention to carbon mitigation began to flow through energy policy, the case for seeking alternatives was strengthened further, and to some degree forced by the closure of large coal plants coming

Table 1. Summary of National Grid's 'Balancing Services' for frequency and reserve with their requirements and relative value (adapted from National Grid, 2016)

	SCHEME	MINIMUM SIZE	NOTICE PERIOD	DURATION	REGULARITY	VALUE
FREQUENCY RESPONSE SERVICES	Firm Frequency Response	10 MW	30 sec	Max 30 min Typically 5 min	10-30 times per year	££
	Dynamic Frequency Response	10 MW	2 sec	Max 30 min Typically 3-4 min	Daily	£££
	Enhanced Frequency Response	1-50MW	1 sec	Max 15 min Typically 3-4 min		£££
RESERVE SERVICES	Short Term Operating Reserve (STOR)	3MW	20 min	2-4 hours Typically <20 min	Able to deliver 3x per week	£
	Fast Reserve	50MW	2 min, reaching 50MW in 4 min	15 min		£
	Demand Turn Up	1 MW	10 min,	Min 30 min		£

to the end of their working life, or breaching new emission limits. By 2015, National Grid noted coal plant closure as "[t]he single and largest driver" of the need to "grow balancing services" (National Grid, 2015: 2). What was replacing carbon-heavy generation did not intrinsically help with grid stability, with wind and solar power adding much more complexity and intermittency into supply profiles. It was therefore argued that only by bringing DSR into play in more sophisticated ways, as part of a general 'smartening' of the grid (Clastres, 2011), could these newly dynamic elements of generation be integrated in the grid without it collapsing into chaos. As National Grid saw it, the grid was "continu[ing] to become ever more sophisticated and complex" with more intermittent generation meaning that "system needs are becoming less predictable and more volatile" (National Grid, 2017: 1). The procurement of DSR balancing services was initially focused on reducing demand, incentivising responsiveness by giving value to turning down electricity consumption when supply is under stress. Recently, however, the service of demand 'turn up' has also been procured to respond to situations when there is a surplus of low carbon supply, thereby giving value to users increasing electricity consumption at a particular point in time. Such flexibility, in its different forms, has been characterised by Angel (2021) as a 'socioecological fix' for the threat that the increased integration of renewable generation into the electricity system poses for prevailing capitalist logics of energy supply.

Opportunities for DSR to compete in providing balancing services were gradually introduced by National Grid from 2002 onwards, such that at the time of undertaking the research a suite of opportunities were being advertised[1]. Table 1 summarises the key specifications of each of the DSR services being procured, distinguishing between 'frequency response' and 'reserve services'. It is immediately apparent how important temporal conditions are, with frequency response (keeping the oscillating frequency of AC supply within an acceptable 'bandwith') particularly demanding in terms of the 'notice period' or speed of response (measured in seconds), compared to the slower 'reserve service' (measured in minutes) called on to cover more predictable peaks in system load. 'Duration' and 'regularity' are also specified and differentiated across the schemes and when combined with the minimum size of contracted response (in MW) produce a range of potential monetary values for participating organisations (as indicated in the final column of the Table). Those participating are paid both for being ready to be responsive (an 'availability' fee) as well as for actually responding (a 'utilisation' fee) within the contracted terms of their participation.

Through contracting for demand-side balancing services in these ways National Grid

were purposefully extending the management of grid balance into spaces of electricity consumption, and by doing so constructing a market opportunity for those able to provide a service to the system within closely defined parameters. The minimum size threshold in column 2 of Table 1, set at MW levels, keeps the transaction costs for National Grid at an acceptable level, but also limits the contracting opportunity to those consuming electricity (and therefore able to switch off) on a substantial scale. Notionally this meant only bigger industrial operations could participate, however, these thresholds could also be reached by combining together small packages of responsiveness amongst a wider diversity of consumers, *if* they could be coordinated to respond together. Entrepreneurial demand response aggregators emerged to exploit this business opportunity, acting as profit-seeking intermediaries and new 'market agents' (Randles and Mander, 2011; Bessy and Chauvin, 2013). The first aggregators in the UK appeared in the late 2000s, and today there were 18 in operation (National Grid, 2021), largely stand-alone independents which have grown into substantial operations, but also established electricity suppliers who have also ventured into aggregation. In 2019, stand-alone aggregators provided 60% of contracted DSR capacity to National Grid, making clear their crucial role (The Energyst, 2019). Aggregators also bid into DSR contracts with distribution network operators (DNOs) that since 2018 have grown their flexibility services to help manage congestion on local electricity grids. However, National Grid, as the Electricity Systems Operator (ESO), remains the dominant actor in this market, as they procure more than 10GW of flexibility (projected to increase to 30GW in 2030 and 60GW in 2050) in comparison to the 1GW of flexibility procured by DNOs in 2020 (National Grid, 2020b; BEIS, 2021).

Methodology

The empirical data for this paper stems from a research project on the governance of energy demand that explored the ways in which the agency to govern energy demand has become distributed in new configurations across networks of actors, material technologies and infrastructures of different forms and devices of knowledge management, data processing and data representation. We focused on DSR as an increasingly vital space for the active governance of energy demand and zoomed in on aggregators as playing an important role in creating and realising these new configurations. While aggregating is clearly the headline task, the work involved in producing infrastructural value is multi-faceted. In order to understand this, we collected a variety of empirical data, including from two sets of semi-structured interviews, along with observation of industry events as well as collection and analysis of relevant documentation.

The first set of interviews were undertaken with representatives of four different stand-alone aggregators, operating in the UK; two of which were well-established and two smaller and more recently active in the market. The aim was to understand their role in developing demand response activity and the processes through which they engage with their clients (interviewees A1-A4). The interviews were carried out by MKF. Ethical approval for the study was granted by the Faculty of Social Science Research Ethics Committee at Lancaster University. A second set of interviews was undertaken with ten employees working for a single well-established aggregator, operating in the UK. They included employees working in sales as well as site operation. This set of interviews enabled a more detailed examination of the different aspects and stages of an aggregator's work (interviewees B1-B10). This second set of interviews was carried out by MC, as part of his PhD on demand response aggregators. We included this set of interview data in the analysis, as in combination, the two sets of data enabled both breadth and depth to be achieved within the analysis of aggregators' work processes. Ethical approval for this study was granted by the Research Ethics Committee at the University of Reading. See Table 2 for details on the interviewees.

Observations of five industry events and meetings were undertaken by MKF and GW, where DSR and aggregators were being discussed. This included the annual trade event for the UK energy management industry focused on metering, monitoring, technology and energy services, and a

Table 2. Interviewee characteristics

Interviewee ID	Role	Company ID
Interviewee A1	Co-founder and Executive Director	Company A
Interviewee A2	Commercial analyst	Company B
Interviewee A3	Operations manager	Company C
Interviewee A4	Chief technology officer	Company D
Interviewee B1	Sales – senior	Company D
Interviewee B2	Sales – junior	Company D
Interviewee B3	Sales – senior	Company D
Interviewee B4	Sales – junior	Company D
Interviewee B5	Sales – junior	Company D
Interviewee B6	Sales – junior	Company D
Interviewee B7	Sales – intermediate	Company D
Interviewee B8	Sales – intermediate	Company D
Interviewee B9	Sales – intermediate	Company D
Interviewee B10	Technical – senior	Company D

regional event organised by the same trade body, as well as a one-off industry event on sustainable building and building management. Fieldnotes were taken for each event. A variety of documents were also collected, focused on National Grid reports on DSR and flexibility, including from their Power Responsive campaign as well as minutes of their Demand Response Working Group meetings.

The data collected – integrating across interview data, fieldnotes and documents – were analysed both deductively, with a focus on aggregators and their work processes and role in identifying and developing demand response activity, and inductively enabling scope for unanticipated themes to emerge from the analysis.

Aggregators and the production of infrastructural value

Aggregation has arguably always been integral to (economic) value making, but has taken on new forms within the digital economy. Leyshon and Thrift (2007: 103) position aggregation as an important spatial tactic in the development of new asset streams, in which there is "the identification of a regionalization of value that would heretofore have been considered of little worth" with digital systems making "these new aggregations sufficiently visible to be operated on". The key activities of aggregation are thus 'searching out' new asset streams, on the back of new forms of expertise, and operationalising these through "computer software that enables [devices, individuals etc.] to be assessed, sorted and aggregated along dimensions of risk and reward" (Leyshon and Thrift, 2007: 108). Today, aggregation is part of the value work produced by many digital platforms, such as those focused on housing markets (Fields, 2019), crowdfunding (Langley, 2016) and the accumulation of consumer data (Thatcher et al., 2016).

In the case of DSR, it is through a practice of aggregation and its interrelated value-making activities that infrastructural value can be realised for the purpose of grid balancing. Temporality is a key feature in realising this value, as any device's infrastructural value can only be actually realised if the device is switched *on* at the point in time that National Grid or a DNO needs demand to be cut; or, in the case of demand 'turn up', if demand can be 'shifted' and 'turned up' at a point in time when demand is low and renewable generation capacity is high[2]. Crucially, to be countable as enacted DSR, this 'response' must be evidenced as having taken place. Across all of the millions of electricity-powered devices in businesses and organisations distributed across the UK, there is evidently already much turning up and down, but it is only at those sites and moments at which precise, controlled and contracted responsiveness is made possible and then enacted and evidenced, that infrastructural value can be realised. For aggregators putting together packages of 'distributed responsiveness' that can be sold to National Grid or DNOs, the very particular conditions mean that there are significant challenges in identifying DSR potential, establishing and operationalising responsiveness and evidencing its performance. Over following sections, we show how aggregators establish the infrastructural value of already existing devices, putting working arrangements in place and establishing DSR aggregation as a profitable business opportunity. In turn, these are practices of prospecting, legitimising, optimising and coordinating.

Temporal Prospecting

In their discussion of the future of finance and capitalism, Leyshon and Thrift (2007: 98) use a prospecting metaphor (see also Mezzadra and Neilson, 2017) to convey how new asset streams are hunted down, and while the end goal is differently oriented, this term fits well with the initial task that aggregators undertake. Just like mineral deposits, electricity consuming devices with DSR potential are widely distributed across space, hidden within the material form of the operating sites of businesses and other large organisations and not immediately knowable. However, unlike mineral deposits their specific geographic location is largely irrelevant to their viability, given that all these devices are materially connected through the wires and cables of grid infrastructure, making the spatiality of DSR strongly networked at a regional and national scale. As explained earlier, electricity has a material instantaneity which means that wherever supply or demand is enacted within a networked electricity infrastructure, it is very immediately registered by the system in terms of overall balance. The physical, cartographic location of particular instances of supply or demand is, at this system scale, largely irrelevant to National Grid, although for DNOs regional or local area geographies of DSR potential can be important. Aggregators therefore have a large spatial geographical field across which they can hunt out opportunities. To do so, aggregators have to use bespoke classification systems to direct their attention to where potentially exploitable 'seams' of devices might lie (to continue the minerals analogy). In their accounts they draw on accumulated experience and know-how on which some basic assumptions about capacity and potential return can be built:

> For example, I know from experience that cold store warehouses often state how many pallets they can hold on their websites, so I check and if they have only 10,000 pallet storage then I don't bother as the potential is too low, if they have 100,000 then I contact them (B1).

As in this example, much of the initial categorisation of potential is done around scale in relation to the kilowatt (kW) capacity of each device, or the site's total capacity to provide response. Interviewees used various rules of thumb when asked about what the minimum kW capacity for participation, for example one indicating 'around 200kW' adding that "I think we can go lower but it's hard to know if it will be profitable or not so I tend to avoid assets with anything less" (B6), while another made clear the importance of how consumption is distributed "if they have 500 assets at 1kW each, then not worth it" (B2).

DSR infrastructural value is however not just about scale, as emphasised earlier, temporalities are crucial. The initial stage of prospecting based on theoretical kW capacity and identifying potential in place is therefore followed by a set of temporally structured assessments of site-specific operations. This includes the frequency of use of an electricity consuming device, how long at a time it is in use and how predictable and routine this is. As assessors learn more about temporal patterns, the potential resource available for demand response might change. An interviewee explains:

> Sometimes the client uses a faceplate value, like a 500 kW chiller, but its usage is very small, only 20 kW, which means it's not worth it (B3).

Developing some degree of knowledge of the temporal structure of a site's operation and electricity use as part of the prospecting stage is therefore important, informing whether to continue the assessment process, even though it is only when tested and optimised (see later) that this potential becomes fully material. Prospecting is therefore only a partial process, contingent on material and temporal specificities that can only be thinly evidenced by general classifications of site characteristics and rough approximations of patterns of electricity use.

Legitimising

Legitimation refers to the shared recognition of the value of an entity (Lamont, 2012), in this case the potential infrastructural value of a device in addition to its existing use value. When entities have more than one value status in this way, there is scope for conflict between them (Helgesson and Muniesa, 2013) and for one form of value to be

seen as more legitimate, more worthwhile or significant than another. For aggregators negotiating this potentially difficult territory and legitimating what constitutes a novel and rather peculiar form of value is a significant challenge (Torriti, 2016). This means that when talking to potential new clients, the aggregator usually has to take time to carefully explain what demand response is and to deal with initial reactions to what is proposed. At the centre of these reactions can be a conflict between the temporal continuity implicitly assumed in operating the technologies that are part of an organisation's ongoing operations and the 'arrhythmic' disruption (Walker, 2021) to this continuity that appears inherent to demand response. As an interviewee explains, the initial assumption is typically that continuity is given and essential:

> No one in a business thinks anything can be turned off. It's all needed. There is no operations manager who will say to their boss that 30% of their equipment could be turned off (B6).

Another interviewee explains how it can take some time to work around these concerns:

> The people you really need to win over are the site managers, the people in charge of actually operation of the assets because they are the ones with the biggest concern around any kind of negative effect or damage that can be caused by switching an asset on or off. So we go on a very long journey with our clients (A2).

Legitimation of what is being proposed has then to address the apparent conflict involved in proposing that a device can temporally be 'rented out' to an aggregator (and in turn National Grid) for the purposes of grid management, and the loss of control that this implies. As an interviewee describes: it can be difficult "getting around the idea that someone else can start up or shut down their assets, outside of their control" (A4) and such concerns have to be managed carefully. Some devices are also more compliant to becoming infrastructurally valued, others more resistant. For example, air conditioning systems and freezer systems have an inertia in their outcomes (the air stays acceptably cool, the freezer contents stay frozen), which mean that the service they provide is not significantly degraded by being switched off for a short period (Curtis et al., 2018). Lighting systems in contrast have no inertia in their service (the light is instantly lost) and switching off can have problematic consequences. Other devices such as water pumps, may already do their work in a non-continuous way, such that the service they provide (water moved from one place to another) can be shifted in time. Aggregators therefore have to sort through the sets of electricity using devices in place and legitimate the value that some of them can realise in comparison to limited degree of disruptive impact, while also persuading clients of the potential temporal flexibilities in their organisation's operation.

Optimising

Optimisation in valuation processes refers to a pattern of rationalisation, typically through numerical calculations, oriented to particular ends, often to find the 'best' balance between what might be contradictory aims (Chiapello, 2018). For the aggregator, optimising is very much a financial decision based on what is profitable given the level of constraint or risk involved. To work out how to optimise financial return, aggregators draw on various kinds of data, including past patterns of electricity consumption from existing meters:

> There is quite a lot of research that the sales team is going into about the characteristics and processes around these different assets. So once they understand you know that a chiller can be turned off for a certain amount of time, once they understand what the customer is going to see, they can develop a picture around that (A4).

Such a 'picture' of potential and optimisation is again very much temporally framed, taking into account not only usage patterns but also the 'control variables' for each asset (variables which are already wired into the pattern of its operation) meaning that for a bitumen tank a shift in measured internal temperature, or a water pump a change in measured water pressure, would override its switching off for demand response purposes:

> For a water pump it might be pressure, various monitoring of pressures on either side, if there is a difference, it would suddenly turn on because that's its job, and then determines our range of flexibility that we can operate within (A2).

Availability of a device may also be affected by other factors such as weather conditions, for which the aggregator will have to assess the scale of constraint on possible revenues. This involves developing detailed insights into exactly how devices operate in order to work out what return can be achieved and how to optimise revenue:

> So water pumps make up a large part of our portfolio, so whether it rains or not will determine whether or not they actually turn on, so the first application of machine algorithm really was around historical data to provide forecasts, a week ahead or a month ahead (A2).

As the interviewee explains, tools and techniques like algorithmic machine learning – processing historical data to make future-oriented assessments - have become increasingly important to their optimisation processes, given that these are necessarily attuned to the temporal structures of the balancing services market. Aggregators have to bid for contracts and regularly update the National Grid on availability of capacity and are therefore constantly having to make assessments of the electricity use that they anticipate can be responsively avoided in the future across their portfolio of clients. Becoming more sophisticated in these temporally structured assessments, taking better account of the contingencies they can foresee in the performance of the assets and income they have created, and learning from past discontinuities between anticipations and enactments is therefore central to their business model. In such respects, they therefore share much in common with other financially oriented actors also using algorithmic technologies to attempt to better know the future from the performance of the past (Pasquale, 2015; Leszczynski, 2016).

Coordinating

As noted earlier the spatial possibilities of infrastructural value are enabled by the connectivity and instantaneity of the grid, but alongside this, digital infrastructure is also required in order for information to be exchanged and acted on and for aggregation to be achieved. First, aggregation only works if there is a synchronisation of multiple clients cutting their consumption at the same time, so that a 'package' of coordinated responsiveness is mobilised. This means that aggregators need to distribute a signal to their participating clients when National Grid indicates a response is needed because of a system balancing need. Typically, aggregators install control units on a client's site, which receive an instruction signal from the aggregator and use these to either automatically switch off or on specific devices, or to request local operators to manually do so. How, when and which control units are activated is worked out between aggregators and clients and written into contracts, for example, specifying how often an instruction will be issued and periods of the day that switch-off can and cannot be deployed. Such specific conditions also depend on the National Grid scheme being serviced and the specific parameters this mandates (as detailed in Table 1). For example, for 'frequency response' services, controls operate automatically so that switch off can happen very fast in response to a drop of frequency on the grid supply. Which units to activate when an instruction is issued is worked out through randomisation, as an interviewee explains:

> So each asset is effectively controlled locally so we are not saying this one and this one. The way it works is that it is randomised, so if the frequency goes all the way down to 49.7, all of them will switch off, but if it goes down to 49.5, they will all flip a coin and half of them will get heads and turn off and half of them will get tails, so when you aggregate enough, those statistical variations sort of cancel out and you do get a perfectly linear line, and everything is done on site (A2).

In the case of 'reserve' services, the speed of response required is slower and instructions can be relayed through local operators. Regardless, the installed control units enact the terms and conditions for the response of electricity-powered devices, coordinating switching off across the aggregator's multiple clients and making demand response operational.

The second form of coordination necessary centres on the provision of disaggregated evidence of the specific responsiveness that has been enacted. Advanced digital metering technology enables measurement of electricity flow at specific points on-site, granulated into temporal units such as consumption measured per half hour, minute or second (Kragh-Furbo and Walker, 2018; Bedwell et al., 2014). Whilst in some cases data can be drawn from existing metering systems to evidence drops or increases in consumption, the specific temporal conditions of responsiveness generally mean that additional metering infrastructure is installed. For example, to participate in 'frequency response', it is necessary to install temporally intense and exact metering, as an interviewee explains:

> You need to respond within seconds and then therefore to provide that service and prove that we have delivered that service, we need to install our own second by second meter on every asset. [...]. So if you'd need to do frequency response, you specifically need 0.1 hertz metering so that's 10 times a second (A2).

Such temporally precise information on changes in electricity consumption provides the basis of the calculation of income to the client from the aggregator - along with a baseline fee for being 'on call' and potentially available to be responsive. And when pooled together with information from other clients, also provides the basis for establishing proof of speed and scale of responsiveness under the terms of contract established between the aggregator and National Grid. In these ways, technologically mediated and enabled information flows are intrinsic to demand response operating and becoming parcelled together and to the income that is derived from the infrastructural value established in a device.

Discussion

We have explained how in DSR the extension of the electricity grid and the balancing discipline of grid management is entering into organisations that do not in any way have that as their central role, and into devices that are not normally operated to the ends of infrastructural coherence. We have used the notion of infrastructural value to engage with the way in which this shifting of the boundary of the grid is being realised, with electricity-consuming devices newly valued, newly generating an income flow, because of what they can contribute to grid balancing. We have emphasised that producing and diffusing this form of infrastructural value is very much an achievement whose realisation is dependent on a set of specific interrelated practices enacted by value-seeking aggregators. National Grid established DSR as part of the electricity system, but only by aggregators prospecting, legitimising, optimising and coordinating infrastructural value, has the enactment of many thousands of synchronised moments of devices responding to signals been able to grow in scale, becoming a significant part of how grid balance is sustained, with substantial further growth intended. Currently, industrial and commercial DSR amounts to 1GW of contracted 'turn down' capacity, with National Grid expecting this under various scenarios to double within 2-3 years and grow potentially to 13GW by 2050 (National Grid, 2020a). Where this capacity happens and where therefore the managed grid extends to, is significantly contingent on the infrastructural value-producing work of aggregators and their ability to hunt out and realise new market opportunities.

Through our discussion we have pointed to how the four set of activities involved in producing this specific form of infrastructural value are also associated with other arenas and end-goals of contemporary market making and functioning. Prospecting for value, legitimising its status, optimising returns and coordinating information flows have become established aspects of value-making practices, but they take on a distinctive character in being applied to DSR and the ends of establishing infrastructural value. As we have emphasised, what is most distinctive is how temporality is configured both in contracted DSR schemes and across the different activities performed by aggregators. Infrastructural value can here only be realised in precise and calculated moments of demand response that are contingent on and limited by real-time grid balancing needs and usage patterns; and at the same time, these moments of response must be prospected for and legitimised, optimised and their coordination

enabled in advance. There is some ongoing infrastructural value in fees paid for being available to be responsive, but this is only realisable in the mid to long term, if it is matched at some point by actually utilised time-coordinated response (although the relationship between availability and utilisation varies in the contractual arrangements for different DSR schemes).

This form of temporality, when digitally enabled, has connections to the temporalities of high frequency trading (Zook and Grote, 2016; MacKenzie et al., 2012), more than to longer term trajectories of return. What matters in DSR are precise enactments of the present; a willingness to respond and an enacted response at exactly the right time in relation to the structure of clock-time and its divisibility into precise units. What is primarily valued are the rate of response (speed) and duration of response. This valuation of the 'here and now' contrasts quite strikingly with the longer term returns normally associated with infrastructural investment and with entities that have a more intrinsic, stable or enduring infrastructural value. DSR may therefore be temporally distinct and unusual but demonstrates that producing infrastructural value can enter into novel temporal territory and may do so increasingly in the future.

In this respect there are links to the temporalities and valuation practices of the sharing economy. In Bardi and Eckhardt's (2012) terms, in the sharing economy consumption of shared materialities is 'access-based' with the consumer 'acquiring consumption time with the item', often paying a premium price for so doing, and in patterns mediated and enabled through digital technologies. Indeed, one of the tactics used by aggregators to explain their work is to draw analogies with well-known instances of the sharing economy, in particular Airbnb. Such analogies stand up to some degree, in that as with various examples of monetised forms of sharing, DSR involves achieving "higher utilisation of the economy's idling capacity" (Schifferes, 2013), with that 'idling' made temporally responsive to the needs of the electricity system. However, distinctly unlike Airbnb, there have not been multiple potential rent-paying actors looking to pay for accessing the temporary use of devices. This makes it a decidedly asymmetric example of the enrolment of a sharing logic into economic relations, if indeed it makes sense to think of it in these terms.

Having only few rent-paying actors – National Grid as the main actor, and the six DNOs providing some smaller, but growing market opportunities - also emphasises how infrastructural value in this case is a potentially volatile achievement. If National Grid decide to change the terms of their contracting, to withdraw specific DSR schemes, specify new minimum capacities or temporal criteria, then the calculative frame within which aggregators are working is readily de-stabilised. As we emphasised in conceptual terms infrastructural value is an achievement rather than a fixed quality and its enactment in a device may therefore be lost, but also gained anew as DNOs increasingly deploy DSR in order to manage pressures on regional and local infrastructural capacity. This could to some degree diversify the opportunities for aggregators to build a portfolio of contracts and protect against volatility, but particular electricity-powered devices can still become 'de-valued' by other means. For example, through a change in their ownership, through changes in the patterns of their use, or if they become more critical to an organisation's functioning and therefore less available for turning up or down at the behest of a grid manager. Hence the need to conceptualise infrastructural value – and the detailed topography of the extended grid - as an ongoing and contingent process, temporarily held in place by sets of contractual, material, spatial and temporal relations, rather than a permanent condition.

Conclusion

> And do things have several values? Yes, what things are worth can be manifold and change - and these values can be conflicting or not, overlapping or not, combine with each other, contradict each other. All, or almost all, depends on the situation of valuation, its purpose, and its means. (Helgesson and Muniesa, 2013: 7)

We have shown that the concept of infrastructural value is analytically useful in focusing on the specific value that can be produced in something in relation to its role in the ongoing operation and management of an infrastructure. We have posi-

tioned infrastructural value as an accomplishment achieved through practices of assessing value and holding sets of relations in place, and that, in marketised infrastructural systems, the fluidity and flexing of infrastructural boundaries can be directly subject to how infrastructural value is made and distributed.

Star and Ruhleder's (1996: 112) question "when – not what – is an infrastructure" is therefore particularly apposite, with grid extension enacted not as a fixed material addition as conventionally understood (new wires, cables, generating and transmission technologies etc..), but as a structured and systematic process of producing temporally transient infrastructural value in already existing materialities. To become 'infrastructured' (Blok et al., 2016) in this case is to be newly valued, forming an extension of the managed grid that in enabling intervention into the dynamics of demand, is becoming increasingly important to how low carbon transition in electricity systems is expected to play out.

Having introduced and exemplified the notion of infrastructural value in this way, what other analytical work might it do? In DSR specifically there are new directions in which infrastructural value is now being extended, including into domestic settings and smaller businesses with different scale, temporal and legitimation characteristics (Powells and Fell, 2019; Torriti, 2016; The Energyst, 2019), and enrolling new types of devices such as battery systems and electric vehicle charging networks. DSR is a particularly involved instance of infrastructural dynamics, but distinguishing infrastructural value from other forms, working through the details of its production and the conflicts and resistances entailed might be similarly productive in other cases. These could include other instances where the move towards 'smarter' infrastructures across a broad field involves the incentivisation of time-delimited responsiveness to digitally enabled information flows. How infrastructural value is produced within the diffusion of particular innovations could also merit analytical attention, with, for example, the existing materiality of building roofs becoming newly valued in relation to the development of solar technologies, and bike sharing systems distributing infrastructural value between bikes, docking stations and digital platforms in ways that are quite distinct to traditional ownership and use. Accounting for shifts in infrastructural value over time as extant infrastructures become de-valued, followed by their revaluing and repurposing - as with rail corridors turned into linear parks (Loughran, 2014), or public land and military facilities becoming commercial assets (Whiteside, 2019) – also gives attention to longer term dynamics in infrastructural valuation processes.

Working with infrastructural value could also readily move into more normative territory, asking questions about how this category of value *should* be assessed and distributed and the ends to which it is deployed. This has not been our focus, and the DSR variant we have discussed has not been overtly controversial. Even so there are questions to be asked about who is profiting and to what extent from the distribution of value in this way, whether perverse incentives are built into decisions about how and when to consume electricity for those participating in DSR and, more fundamentally, whether seeking flexibility and responsiveness within the electricity system is how a low carbon transformation should be achieved. Case studies of DSR in practice may well be able to answer some of those questions as well as further research on the political economy of DSR and the flexibility markets. For Angel (2021), flexibility as currently being pursed is simply a way of sustaining capitalist imperatives of accumulation, doing nothing to challenge its underlying socio-ecological contradictions. Seeing infrastructural value in more normative terms could therefore open up to possibilities of alternatively configured provisioning systems, including those which in Angel's (2021: 13) terms are open to "more liberatory spatiotemporal rhythms of socio-ecological life" and in which value is understood beyond its monetary form as part of market-based rationales.

Acknowledgements

We are grateful to our interviewees and for the insightful and helpful comments of reviewers. The article was supported by the Engineering and Physical Sciences Research Council [grant number EP/K011723/1] as part of the RCUK Energy Programme, and by the EDF as part of the R&D ECLEER Programme.

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Notes

1 In October 2020, a new frequency response product 'Dynamic Containment' was introduced to replace the dynamic and enhanced frequency response services. The min. size is 500 MW with a notice period of under 1 second with output sustained for 15 minutes. The service is procured day-ahead and paid an availability fee (National Grid, 2020b).

2 National Grid (2017: 3) notes that its 'Demand Turn Up' service encourages energy users to 'increase demand (through shifting, not wasting unnecessarily)'.

Constitutive Tensions of Transformative Research – Infrastructuring Continuity and Contingency in Public Living Labs

Andrea Schikowitz

Department of Science- and Technology Studies, University of Vienna, Austria/ andrea.schikowitz@univie.ac.at

Sabine Maasen

Faculty of Business, Economics and Social Sciences / Knowledge Exchange Agency, University of Hamburg, Germany

Kevin Weller

Department of Science, Technology and Society (STS), Technical University of Munich (TUM), Germany

Abstract

Living labs and *Reallabore* are policy attempts to provide infrastructures for societal transformation towards sustainability. They attempt to do so through facilitating experimental modes of societal learning and innovation in inter- and transdisciplinary environments. We suggest that building and maintaining such infrastructures includes simultaneously rely on continuity by following conventions of knowledge production and allow for contingency as a resource for surprise. Both are necessary, inevitably prompting a 'constitutive tension'. Based on a study of two living labs on urban mobility in Austria, we ask how specific labs inscribe continuity and contingency into their infrastructures. Our analysis shows that the living labs attempted to connect to diverse communities, providing a source for contingency. At the same time, however, we observe a tendency to mitigate contingency when the production of outcomes is at risk. Based on the discussion of this exploratory case study, we reflect upon the transformative potential of living labs.

Keywords: transformation, tensions, collaboration, innovation, infrastructure

Introduction – Living Labs as transformation infrastructures

Policy and research actors are prompted to develop ever new avenues and models for addressing 'grand challenges' (European Commission, 2009; Kuhlmann and Rip, 2014). They are faced with pressing, overarching and complex societal problems that can neither be clearly pinned down nor ignored. The ultimate goal becomes facilitating transformation towards more sustainable futures. To reach this goal, policy actors in particular (see European Commission, 2011) consider innovation to be indispensable (Felt, 2016; Van den Hove et al., 2012). Innovation is deemed "today's go-to resource for bringing about the future" (Pfotenhauer and Juhl, 2017: 85), with ever-new settings for facilitating innovation emerging and being experimented with. Living labs are one such example.

Acknowledging the increasing relevance of and political focus on living labs[1], this article puts an explicit focus on those labs' approaches toward facilitating innovation, such as enabling experimental modes of societal learning. The promise of living labs is to enable societal transformation by integrating different societal actors into the innovation process (see Engels et al., 2019; Liedtke et al. 2015; Rose et al., 2018; Schliwa and McCormick, 2016; Schneidewind et al., 2018). The selling point is to facilitate experimentation in real but adaptable 'innovation-friendly environments' (Dickel et al., 2019; Felt, 2016), which could be upscaled if needed. Indeed, some authors have argued that living labs not only test new technologies and solutions, but the readiness of societies to accommodate new socio-technical arrangements (Engels et al., 2019).

In this vein, we suggest that living labs establish specific infrastructures, understood as socio-technical arrangements (Bowker and Star, 2000; Slota and Bowker, 2017), which facilitate the production of transformative knowledge. By this we mean knowledge which contributes to societal transformation towards sustainability. Transformative knowledge implies a transformation of how such knowledge is produced. On the one hand, living labs rely on continuity with the sense-making conventions of the different actors involved (researchers, policy makers, citizens, practitioners, etc.). This is precisely what facilitates their engagement in unfamiliar participation and innovation activities. On the other hand, living labs aim to enforce contingency which holds the promise that things could be otherwise. Contingency, rooted in a proliferation of (mostly unknown) influencing factors, might cause uncontrollable and unpredictable courses of events, might yield surprising questions and observations and thus holds the potential to overcome lock-ins and established pathways.

This understanding of continuity and contingency as constitutive of innovation is not entirely new. It rests on Kuhn's (1977) 'essential tension of research' and on Rheinberger's (1997) and Hackett's (2005) use of the notion for analysing social and material research arrangements. In our study, we extend this idea to the workings of living labs. We ask how such 'constitutive tensions' are inscribed into their infrastructures. Following Bowker & Star (2000) and Slota & Bowker (2017) we understand infrastructures as spatially situated arrangements of interrelated organisational, material and symbolic elements which both facilitate and constrain lab activities. Throughout this paper, we argue that the constitutive tension between continuity and contingency may be regarded as a central socio-epistemic component of lab infrastructures. At the same time, however, the orchestration of infrastructural dimensions tends to make invisible the labs' tendency to temper contingency in favour of enabling useful solutions for specific actors.

By analysing how continuity and contingency are inscribed into lab infrastructures as constitutive tensions, we aim to advance existing literature on tensions in and of transformative research. Critical empirical contributions often describe transformative research as inherently contradictory and even paradoxical (Bijker and Bijsterveld, 2000; Felt et al., 2016; Maasen and Lieven, 2006; Polk, 2014). For example, in relation to inter- and transdisciplinary research, this literature mentions 'enduring tensions' (Parker and Crona, 2012), 'essential tensions' (Turner et al., 2015), 'inherent tensions' (Schikowitz, 2020) or 'border troubles' (Petts et al., 2008). A few studies (Engels and Rogge, 2018; Leminen et al., 2015) also address tensions in real world labs or living labs.

These authors agree that such tensions cannot be resolved but need to be dealt with or even 'embraced' (Engels and Rogge, 2018; Scoones and Stirling, 2020) permanently. We contribute to this literature by addressing not only political or ideological tensions inherent in participatory settings, but also epistemic tensions. We develop an analytical frame for analysing such tensions in a differentiated and comprehensive manner.

For this contribution, our empirical cases are living labs on urban mobility in Austria[2]. In particular, we analyse two contrasting cases in the same funding program, which focus on either participation or innovation as main leverage points for transformation. We use these two cases as a pilot study to explore different ways of infrastructuring, which we understand as building and maintaining infrastructures. According to the funder, the overall purpose of the living labs is

> [...] [to] increase the practical impact of research and enable societal transformation processes according to the program targets, the initiative urban mobility laboratories complements the program portfolio with a structural component. Urban mobility laboratories - in the sense of a "living laboratory" - should develop suitable spaces, structures and processes for this, and build a solid participation-, coordination- and cooperation platform for accompanying and complementing research and development initiatives. (5f)

Due to this positioning in particular, the Austrian urban mobility labs provide a fitting example for broader developments and reasonings for living labs as defined above (see also Liedtke et al., 2015). They have been introduced to support infrastructures for transformative research that go beyond single projects and should specifically facilitate cooperation between different actors in innovative research and development.

To summarize, the contribution of this research is threefold: first, by drawing on the concepts of continuity and contingency we advance a differentiated account of constitutive tensions in infrastructuring processes. In our view, their epistemic implications need to be acknowledged. Second, by combining the concept of constitutive tensions with a heuristic for analysing infrastructuring in its organisational, material and symbolic aspects, we provide the means for researchers and practitioners alike to analyse and reflect upon such tensions systematically. That is, we propose to work with them productively instead of neglecting, externalising, or even attempting to resolve them. As *constitutive* tensions, in our view, they cannot be resolved but must be processed. Third, building on tensions as potentially productive moments, we add an important implication to the concept of infrastructuring: we understand it as a process characterized by ongoing efforts to stabilise and standardise contingent elements, although contingency is explicitly sought in living labs.

Infrastructuring constitutive tensions - analytical approach & materials

In the following, we first develop our analytical approach. It combines the notion of constitutive tensions of continuity and contingency with the concept of infrastructuring. We then introduce our case and empirical material.

Through convening actors from different scientific and societal fields, transformative research aims to find new kinds of solutions as well as ask entirely new questions. According to our hypothesis, attempts to develop infrastructures for facilitating transformative research, such as living labs, inevitably include a tension between continuity and contingency – continuity with the communities included in the lab and their knowledge traditions, and discontinuity and contingency that arise from the limits of single disciplines and the inclusion of societal actors. We build this assumption on Kuhn's (1977) notion of an 'essential tension':

> I shall therefore suggest below that something like "convergent thinking" is just as essential to scientific advance as is divergent. Since these two modes of thought are inevitably in conflict, it will follow that the ability to support a tension that can occasionally become almost unbearable is one of the prime requisites for the very best sort of scientific research. (Kuhn, 1977: 226)

Kuhn describes tradition (meaning following the conventions and pre-formulated questions within

a specific paradigm) and innovation (understood as readiness to break with these conventions when they do not hold) as mutually constitutive: continuity with a paradigm and its conventions is the prerequisite to acknowledging its anomalies and discontinuities. Herein lies the seed for disruption and transformation. This 'essential tension' becomes even more acute in interdisciplinary research which is challenging "established intellectual doctrines founded in the classical disciplines" (Andersen, 2013: 3).

To address how the 'essential tension' is inscribed (Akrich, 1992) into living labs and their infrastructuring activities, we mobilise concepts which apply the notion to the organisation of research groups (Hackett, 2005)[3] and to experimental set-ups (Rheinberger, 1997; Hackett et al., 2004). Both of these are important elements of research infrastructures and can be understood as socio-material arrangements that facilitate specific kinds of research in organisational, material and symbolic ways (see below). Throughout our empirical research, we observed how living labs build infrastructures which are compatible with the sense-making conventions and practices of policy makers and funders on the one hand, as well as different research communities and societal participants on the other hand. These activities are based on an "ensemble of research technologies" (consisting of "materials, methods, instruments, established practices, and the like", Hackett et al., 2004: 748) and on an alignment with policies and the wider research field. While living labs serve as instruments to produce answers to established questions, thereby continuing established sense-making conventions (such as: does a specific technology work and how is it taken up and used?), they are, at the same time, expected to produce surprising observations, signpost new possibilities, and raise awareness that things could be different. In living labs, the encounters and interactions of different actor groups with their different stocks of knowledge, experiences, and values serve as a trigger for contingency and transformative knowledge (see Turner et al., 2015 on interdisciplinary research centers). How these interactions develop and which new questions and ideas are provoked is regarded as contingent.

Subsequently, each lab interprets and translates, for example, the funding criteria, the diverse conceptual literature they build on, and the heterogeneous actors' expectations. These expectations are then aligned with the lab's own ideas of what a living lab is or should be and should achieve. This sense-making process is materially inscribed into the lab infrastructure, which includes different ways of creating continuity and contingency. By implication, the labs themselves are permanently institutionalised *and* innovated. In that sense, we argue that tensions are important elements of the lab infrastructure itself instead of relegating them to the category of unwanted side-effects.

On these grounds, we suggest the term 'constitutive tensions'. These tensions are inscribed into living labs as transformation infrastructures, which operate as socio-technical arrangements (Slota and Bowker, 2017). Living labs create and employ an interconnected set of materials, technologies, people, practices, standards and classifications (Bowker and Star, 2000) which facilitate as well as constrain activities in both intended and in unintended ways. Drawing on pertinent research literature on infrastructuring, we identified three kinds of interrelated dimensions that make up infrastructures and which we used as a guiding heuristic for coding and analysing our material:

(1) Organisational and operational aspects, such as classifications and standards (Bowker and Star, 2000): adhering to certain standardised forms allows the use of infrastructure in the first place, but it includes moral and power relations. We thus regard the lab's organisational model as well as the standardised formats and methods which the labs develop and use as one part of their infrastructure. This also includes the personnel structure and the lab coordinators' and employees' roles.

(2) Material and technical aspects, such as place, buildings, tools and instruments (see Bijker et al., 1987; Winner, 1986; Amin and Thrift, 2002): the selection of the concrete physical places where the labs are located and how these surroundings are shaped and designed to provide a specific frame for the lab activities are crucial aspects of infrastructuring. Likewise, the physical lab venue and how it is equipped with furniture, decorative elements, and technology shape how and by whom the labs can be used.

(3) Symbolic aspects, such as visions, metaphors and stories, which imbue the labs with meaning and which guide and frame their activities (what Deuten and Rip, 2000; and Felt, 2017, describe as 'narrative infrastructures'): we consider the recited stories about the living labs and the aims and visions which we encountered in interviews, the labs' public communication at events and workshops, and their self-presentation on their websites and in brochures as part of their infrastructures.

Organisational, material and symbolic infrastructuring are of course overlapping and intertwined. We use the distinction of these three dimensions as a heuristic for directing our analytical attention but do not regard them as exclusive or exhaustive analytical categories.

In the following section, we apply these three dimensions in our analysis of the empirical case of the Austrian Urban Mobility Labs (https://mobilitaetderzukunft.at/de/artikel/mobilitaetslabore")[4]. The labs' double-purpose is to facilitate the participation of different stakeholders in research and innovation activities as well as to foster the practical (and market-) implementation of research and development outcomes. In so doing, the labs are also expected to create knowledge about co-creative transformation and innovation processes.

In this paper, we contrast two of the five funded labs[5], one of which focuses on participation while the other focuses on innovation. Empirical literature on living labs across Europe (Liedtke et al., 2015; Engels et al., 2019) suggests that these lab types occur regularly. The cases might offer insights into contrasting ways to infrastructure constitutive tensions with the intention to render research transformative. The main data collection for this paper took place throughout the year 2019 and was continued throughout the first half of 2020. The data collection took place in a phase where the conceptualisation and development of the lab structures had largely been finished and the first projects had started within the labs. Our empirical data therefore reflect exactly the passage between preparing the lab infrastructure and testing and adapting it with the arrival of the lab users. The material therefore provides valuable insights into the process of infrastructuring tensions.

The empirical material consists of semi-structured interviews with members of the coordinating team of each lab (1 interview with a member from lab 1, and 1 interview with 2 members from lab 2). We also conducted two interviews with members of a project which was based in lab 1, and one interview with a member of a project which took place in lab 2. The interviews were recorded and transcribed verbatim. This was complemented by participant observation during two field tests of prototypes in lab 1, and during one event in lab 2 where the lab and different projects and their prototypes were introduced and could be tested, as well as a citizen workshop for a project, which was organised and moderated by lab 2. Participant observation included informal conversations with lab and project members. From the participant observations, we produced observation protocols including field notes, photos, and ethnographic vignettes. With the arrival of the Covid19-crisis and the related measures and contact restrictions from March 2020 onwards, many lab-activities went online. We conducted participant observation of three online-workshops in lab 1, and one virtual European-level network meeting of different mobility labs. We also analysed lab documents and the labs' self-representation on their websites and in brochures.

While our interest in tensions and infrastructuring emerged from the initial empirical analysis, the conceptual frame for this article is based upon existing research in this field and is enriched by our empirical observations. For the focused analysis, we coded the materials in terms of organisational, material and symbolic aspects of infrastructuring, looking for the ways in which continuity with different actors as well as contingency was facilitated.

Findings

In the following, we first analyse how the two labs respectively inscribe constitutive tensions between continuity and contingency into their lab infrastructures. To this end, we present a 'neighbourhood lab', which attributed its main transformative potential to the participation of citizens, and an 'innovation lab', which, by contrast, attributed its main transformative potential to the

possibility of emergent disruptive innovation. We then compare the two labs based on our heuristics of organisational, material and symbolic infrastructuring and critically reflect on their modes of infrastructuring constitutive tensions vis-à-vis their transformational focus.

Infrastructuring a neighbourhood lab

Lab 1 is located in a city development area that is specifically configured as a model for creative and innovative city development. The area is located in the outskirts of the city and is currently being built and populated. Overall, the infrastructuring practices of lab 1 aim to create continuity with the knowledge-conventions of two main actor groups: a research community engaged in developing and systematically testing sustainable mobility solutions, and the local residents of the lab area whose awareness for sustainable mobility is being raised through their situated daily practices and personal relations.

The lab establishes continuity with the research community mainly through their organisational entanglement with a university and by providing a real but less complex material test area, technical equipment and services for supporting the users' research conventions. The lab is operated by members of two university departments, which are part of the consortium. However, the operating members are (for the most part) permanently located in the lab in a city development area while the lab coordinator goes back and forth between the university and the lab. The main users of the labs are research projects located at the same university, and sometimes individuals simultaneously work for the lab and are members of research projects using the lab.

To establish a material and technical test area for mobility technologies and solutions, lab 1 is mainly concerned with selecting and shaping its specific material features. Part of these material infrastructuring practices is, for example, to choose and prepare a fitting test route, and customise the local residents as a "test-population" (website of a project). In this case, the test route starts and ends at the lab venue, where the researchers are accommodated during the tests, where equipment is stored, and test subjects are prepared and briefed. On the route itself, obstacles which could disturb the tests in unforeseen ways are removed as best as possible – this concerns permanent and temporary physical obstacles like overgrown traffic signs or suppliers who park their trucks at the bike lane. The fact that the residents are used to seeing strange vehicles or people who carry tech-equipment on that route further constitutes it as a test area. Within the lab area, a material venue has been established, where the staff works and workshops as well as events take place, and which is accessible for local residents. Through providing a "basic set" (L1, coordinator) of material and technical equipment such as furniture, workshop and design materials, cables and technical tools, etc., which can be arranged and extended for different purposes, the venue constitutes a 'flexible basis' of the material lab infrastructure. The rationale for this material infrastructuring of a test area is threefold: it tests the technical functionality of mobility solutions, monitors and evaluates their social uptake as well as acceptance by specific user groups, and abstracts these observations toward the creation of generalised knowledge.

Lab 1 has developed a repertoire of strongly standardised and regularly occurring workshop and communication formats and methods, defining most of the contacts between researchers and the residents of the lab area. These formats are controlled by the lab. It prescribes how the formats are announced and organised, how the material spaces in which the events take place are equipped and arranged and the lab employees act as hosts and moderators. According to the coordinator, this standardisation intends to create continuity and predictability for both the residents and the lab. In other words, standardised participation formats and spaces contribute to turning the residents into part of the lab infrastructure, as a pre-formed population, well informed to participate in a foreseeable way. In turn, completely unexpected interventions are rather unlikely as the lab-environment is infrastructured toward gradual increases in complexity but not towards prompting completely new perspectives or avenues. Contingency triggered by radically different or even subversive ways of discussing or using prototypes or mobility solutions becomes unlikely.

A prime route to create continuity with the local residents and their ways of knowing (in contrast to their role as compliant test-population) is by developing personal trusting relations. The lab employees interact and communicate with the lab's neighbourhood in a way that, ultimately, triggers "a sustainable mobility culture" (L1, coordinator) [6] and "awareness" (L1, coordinator). Developing awareness is hereby understood as internalized understanding, which impacts practices and routines in the long run, yet in ways that cannot be completely predicted but might unfold in contingent ways. Here, innovative mobility services and technical innovations serve as a means for "activating residents" (L1, coordinator). Residents and their awareness are regarded as a contingent factor that - acted upon by the staff, albeit respected as equals - might develop in potentially unpredictable ways. Making sense of sustainable mobility and its specific translation into everyday practices is being entrusted to the residents, yet remains based upon continuous exchange with the lab. As the coordinator explains:

> I mean, the residents, they do carry the lab to a degree – I'd say that without the exchange with the residents, the lab would not make any sense. This exchange, this level of reflection, those discussions, this input, that's our main asset, fundamentally. […] Which means that [a core team] are permanently present around the lab, working around the lab and acquire knowledge around the lab […] because then a different kind of profoundness develops, a profoundness in relation to the place, a relation to the residents as well, very strong personal relations actually. (L1, coordinator)

This quote emphasizes the central role of relations between the lab, its staff, the city quarter and its residents. Creating awareness does not only concern the residents, but also the lab. By gradually acquiring a high degree of local knowledge and a close understanding of the social dynamics, the awareness of contingencies increases as well. Despite the standardised nature of its engagement events, the personal relations between lab staff and residents provide possibilities to challenge routines, e.g. research conventions. For example, after an (online) event informing the participants of a field test about its outcomes, the participating residents voiced alternative explanations for certain data, based on their local knowledge of the city area and its material properties. Even though the format itself did not provide official possibilities to take on this feedback, the participating members of the lab made sure that it was forwarded to the project team and considered in the further interpretation of the data. Another example is the format of a competition for ideas, based upon strict criteria to evaluate which ideas, eventually, receive funding. Through the personal engagement of the lab staff, however, contributions which did not fit the format but were considered promising, still got recognised and were followed up on. In the coordinator's view, this relationship beyond engagement formats is precisely what distinguishes a living lab from opinion research in an isolated workshop-setting. The standardised formats which create continuity for the lab activities with a research community also serve as informal contact points with residents to enable more flexible exchange that could eventually lead to new ideas. In this way, contingency can emerge.

To sum up, lab 1 creates both continuity as well as potential for contingency. Continuity and generalisable knowledge are created with the research community that conducts user tests of mobility solutions. Meanwhile the potential for contingency is upheld by working with local residents who are developing situated and embodied ways of making sense of sustainable mobility. In this way, the lab acts as both a gatekeeper and a mediator between the research projects and the local residents. It brings them together but also keeps them separated. Standardised communication and engagement formats become a means to position both sides and to shape, yet not determine, the ways in which they can interact.

This dynamic explains the ambiguous impression we got from our empirical observations of lab 1: an apparent lingering between strict standardisation and more flexible mutual relations. The lab simultaneously mobilises the local residents as a predictable part of the test infrastructure for the research projects and as co-creative producers of contingent new questions. The constitutive

tension of lab 1 is between continuities with diverging actors and their potentially discontinuous ways of knowing.

Continuity with a research community contributes to comparable and generalisable user tests; continuity with the local residents leads to situated and embodied ways of sense-making that raises awareness for contingency and thus enables the emergence of transformative knowledge. However, while bringing the two groups together, the lab also keeps them apart by controlling their encounters. Manoeuvring between strict standardisation on the one hand, and encouraging personal relations and individual engagement on the other hand, leads to balancing acts on both sides. For instance, on the contingency-side, lab 1 allows informal individual engagements at the fringes of formal engagement; and on the continuity-side, it turns individual contributions into new standards. While embracing both sides, in lab 1, the constitutive tension is perceived as an uneasy state.

Infrastructuring an innovation lab

Lab 2 is positioned as an innovation lab. Overall, it creates continuity with the ways of knowing of one central actor group: the professional field of logistics. At the same time, it tries to challenge the field's established ways of thinking and of approaching problems, instead provoking disruptive and contingent innovations which would bring about the potential for transformation. Continuity with the field of logistics is created through the lab's material infrastructuring, which includes the physical location of the lab within a logistics area, through the inclusion of a logistics hub as a main sponsor and through providing services and technical support mainly for logistics actors. Furthermore, lab 2 follows a business logic in the way it expresses its self-understanding and language, including elements from the start-up scene and specific engagement formats and aesthetics.

Regarding the material infrastructuring, the lab coordinator argues that the location of the lab in a logistics area would make logistics - which is normally hidden - visible and obvious, with all the cranes, ships, and trucks standing around: "we are sitting in the middle of logistics here" (L2, coordinator 1). Such a surrounding constitutes a familiar environment for members of the logistics field. The physical venue of lab 2, where the employees work and where events take place, is located in one of the company buildings and resembles a start-up hub, with an exhibition area for prototypes, a stage, and an open kitchen. Some of the seating furniture is built from dustbins and parts of moving stairs, further leaning into the start-up aesthetics. As in lab 1, the room serves as a storage room of all kinds of equipment which can be flexibly combined and adapted to create different settings. What differs is the more explicit staging of prototypes and innovation projects within the room.

Lab 2 invested a lot of effort to compress its central mission into one single sentence, which is written onto the wall of the lab venue. This mission is described as "developing, testing and implementing logistic innovations in [the city]." Likewise, their understanding of innovation is an almost textbook-definition of market-innovation, which they relate to the definition of the European Commission. In their view, societal utility expresses itself in market success – as proof of something being wanted or needed – which would ultimately contribute to sustainability.

The lab established itself as a platform seeking to mainly support business actors through providing services, networking activities (e.g. bringing them together with researchers or other firms), and technical support, coordinated primarily by one individual with established expertise in the practice field. Accordingly, lab 2 built up a service infrastructure for supporting innovation processes and for connecting different actors. In the highly competitive field of logistics, lab 2 presents itself as a neutral platform to act as a trustworthy partner. When asked how they would describe themselves in the interview, their reply was:

> [as a] Network node in logistics, [as a] catalyst. There are firms approaching us, have an idea and we know, we understand their side and the other side, and we say: hey, you have an idea, and you have a solution, please talk to each other! We help to moderate this process. Or multiplier, that we spread ideas amongst people. And also translator, yes, that we can help firms or help people with ideas, so that others can understand their ideas

> who probably need a solution. And these are for me currently keystones of the lab, network node, multiplier, translator. And this is what we offer.[7] (L2, coordinator 1)

For cultivating the network, the main coordinator located at the lab venue plays a crucial and active role. He is, in fact, characterised as the primary representative and embodiment of the lab, as "a nucleus […] who collects, compiles and further mobilises from all kinds of groups and actors" (L2, coordinator 2). The main coordinator is also described as "strongly incarnate" (L2, coordinator 2) of the lab's mission, holding the crucial practice-based expertise that is needed to legitimately speak to practitioners and to betrusted by them. He explains:

> But – within logistics – I need to create this trust, so they know that I know down to the last detail how something works, why it works and what problem we have and how it works. Because only then, they will talk to me. […] And this is an essential point since I can only bring up provoking theses and question things once I understood them beforehand, because otherwise they might say that we have no clue what is actually happening out there. (L2, coordinator 1)

Here, the coordinator describes continuity with the ways of thinking of the logistics field as a basis for being able to "discussing provocative theses" (L2, coordinator 1). He is thus acting as *agent provocateur* who is triggering new ideas and challenging established ways of thinking. This more *provocative* and *radical* stance is meant to introduce contingency and put a counterweight to the more continuous and incremental improvements to existing technical solutions that they also foster. Passionate pleas for setting up 'radical experiments' for bringing about disruptive change triggered by technological solutions testify to the lab coordinator's vision:

> One just needs to do it, for once! One eventually needs to get radical. For my dream-scenario, I would find a city that said "Alright, we lock down the city for five years – Google, Amazon, come here everyone and live it up! I want 98% of my mobility to be autonomous within the next five years" […]. We could make huge technical progress if we created such a test-area and everybody came here. (L2, coordinator 1)

The coordinator bemoans political despondency as a key hindrance to having a chance to be and ultimate learn from being radical. Triggering disruptive innovation, *strictu sensu*, implies allowing for mistakes, detours and failures to occur and to learn from them. However, in the coordinator's view, policy makers lack courage to take these risks, only reacting to immediate affordances and engaging in nothing but "… continuous improvement process – I don't want to dismiss that, but this is not how we can achieve this, this shift." (L2, coordinator 1)

While lab 2 achieves continuity with the business sector and public policy concerned with logistics, they found it harder to create continuity with citizens as users of logistics. The lab strives to engage citizens, regarding their contribution to the logistics system as crucial to its transformation in a sustainable way. The lab does so for example through attending to (online) shopping behaviour, or through supporting and contributing to policies. However, the staff finds it difficult to get citizens to participate at all. This is despite their attempts to conduct citizen workshops in a location in the inner city that is easier to reach than the lab itself. Moreover, even when citizens take part, the lab struggles with how to engage them. In one instance they recounted, citizens fundamentally challenged the initiative at stake instead of discussing how it could be best implemented. The lab staff regarded this as a failure and tried to get the citizens back on track to respond to the prepared questions. In another workshop which we observed, citizens were guided through a closed questionnaire. In this instance, the staff wondered why no one spoke up when they were asked about ideas and questions afterwards.

The constitutive tension, which is inherent in the innovation-lab's infrastructuring, is mainly one between creating continuity with a specific professional field and their established ways of creating solutions which are of utility on existing markets, and contingency that might emerge from provoking these field to develop all kinds of new ideas in the hope that one of them would turn out as a game-changer. While this set-up

allows for triggering contingency through provocation and through strategies from the start-up scene, its vision of radical innovation is surprisingly centred on economic actors and technological innovation – Google and Amazon are explicitly mentioned, and in another quote, Elon Musk is named as a model innovator. Citizens do not occur in this vision, neither do they in the methodological arrangement. This might explain the difficulties to engage them in an active way which would trigger contingent ideas.

Comparative reflection of the cases - tempering contingency

In the following, we systematically compare how the two labs create continuity and contingency in relation to different actors. We first look at the organisational, material and symbolic dimensions of infrastructuring respectively, comparing the two labs' differences and similarities in each of them. Second, we reflect on how each lab orchestrates these three dimensions so as to allow for transformative knowledge to emerge, and how continuity and contingency are distributed across their organisational, material and symbolic infrastructuring activities. This comparison leads us to the insight that in both labs continuity and contingency do not occur in a balanced way in each of the three dimensions. While the labs' organisational and material infrastructuring focusses on the creation of continuity with specific actors' ways of knowing, introducing potential for contingency almost exclusively occurs on a symbolic level, and through the personal engagement of lab employees. In the current funding regime, this leads to a marginalisation of alternative ways of knowing and to considerably tempering contingency in living labs (cf. Discussion & conclusions).

To begin with, the *organisational infrastructuring* in both labs consists of convening a consortium of heterogenous partners who are anchored in specific institutions, and of allocating specific roles and responsibilities to the main lab coordinator and the employees. While for both labs, a university is the main institutional sponsor where most of the employees come from, lab 2 has a huge logistics hub as their second large sponsor while the main coordinator has a background in both research and professional practice. Accordingly, the main target group for which services are provided is research in lab 1, and the logistics field in lab 2. In lab 1, engagement formats as part of the organisational infrastructure are highly standardised. They consist mostly of workshops and discussion formats linking research projects to the local residents for testing and discussing mobility solutions and technologies. In contrast, lab 2 mainly provides consulting and networking to companies. It is the main lab coordinator who enjoys the trust and appreciation of the logistics actors. He plays a central role in cultivating a network and in connecting actors from business, policy and research, using engagement formats from the start-up scene.

Putting the organisational infrastructuring in a nutshell, lab 1 creates continuity with a research community and their ways of conducting user engagement in the development and testing of mobility solutions. It also mobilises the local residents as test population. Lab 2 creates continuity with the business field of logistics and their knowledge conventions via consulting and networking.

Regarding the *material infrastructuring* of the two labs, both are located in remote city areas – lab 1 is located in a new city development area and lab 2 in a logistics hub. Both areas are isolated from the inner city and appear as less complex in terms of density of buildings, roads and residents. Both labs are composed of permanent staff and lab venues that can be flexibly equipped and used. Lab 1 established a physical test area to be used by research projects as well as an accessible permanent location to establish cooperative relations with the local residents on site. By contrast, lab 2 is located in a logistics hub which is a familiar environment for their main target group from the field of logistics, but hardly accessible for citizens – both spatially and socially. The lab venue resembles a start-up hub and is the main location for the lab activities. While prototypes are staged in the venue and can be tried out there it is not a test area alike lab 1. Instead functions as a promotional space, resembling the exhibition of prototypes at a fair.

We can see that, in its material infrastructuring, lab 1 also creates continuity with a research

community and their testing practices. In addition, through being materially attached to the lab area, it establishes continuous relations with the local residents. Similarly, Lab 2 is clearly located in the field of logistics materially. The start-up style and aesthetics of the venue further create continuity with a business community. Although citizen workshops are conducted in the inner city to increase accessibility, this spatial outplacement further emphasises the detachment of the lab from wider publics.

When it comes to *symbolic infrastructuring*, both labs' central vision of their goals and contributions is of crucial concern. Lab 1 continually refers to an implicit "lab logic" (L1, coordinator), which needs to be acquired through relationship building by new staff and the users of the lab, i.e., the research projects. This vision emphasises the lab's relation to the local residents by means of supporting them in developing an awareness of sustainable mobility as a leverage point for transformation. By backing up its self-understanding with scholarly literature on transformative research and different lab types, lab 1 also creates continuity with research communities. Lab 2, in contrast to the more implicit sense-making of lab 1, condensed its central vision into one sentence, serving as their mantra and guideline. This vision is anchored in a market-definition of innovation. In addition, and more informally, they repeatedly express the hope for more disruptive innovation that might emerge contingently.

In sum, while the symbolic infrastructuring of lab 1 creates continuity with research communities and their theoretical ways of making sense of lab types, it stages the local residents as a source for contingency that might generate incremental transformation on a social and cultural level. By contrast, the symbolic infrastructuring of lab 2 creates continuity with business understandings of market innovation. It claims that pushing and provoking such innovations could bring about contingency, causing one of the innovations to overcome established pathways, leading to disruptive transformation.

Comparing the infrastructuring of the two labs vis-à-vis their organisational, material and symbolic aspects provides insights into their specific translation and inscription of the constitutive tensions between continuity and contingency. We take this as a starting point to critically reflect upon potentials and constraints of each case.

Lab 1 creates continuity with a research community and the local residents of the lab area. However, while the research community's way of knowing is mainly addressed through the lab's organisational and material infrastructuring (the creation of a test infrastructure), the local residents' ways of knowing are mainly addressed on a symbolic level (referring to the 'lab logic' of creating awareness). Both are, to a large extent, kept apart. The particular role of the research community as a customer who pays for a specific service might play a decisive role in hindering the engaged citizens to provide contingent ideas. As a result of this gap, lab 1 hesitates to disclose that 'its citizens' more often act as a passive test population than as co-creative participants. At the same time, however, the lab considers itself a protected space where researchers can engage in profound and trusting relations with the local area and its residents - apart from potentially conflicting confrontations with the research projects and their possibly diverging interests and knowledge claims. As a consequence, the lab's infrastructuring formally focuses on the standardisation of engagement and shifts the relation-building with residents to an individual and informal level. Thus, possibilities for contingency mostly occur at the fringes, depending on single individuals and their initiative.

We hereby conclude that, in lab 1, the infrastructuring practices and relations, which are less valued and hard to account for in the current funding regime, are pushed to the margins. They are included in symbolic and narrative infrastructuring and, by doing so, translated into individual values and commitments of the lab members. They are hardly built into organisational and material structures, or only in ways that can be more easily accounted for. The potential to introduce contingency is mainly ascribed to the local residents. Marginalising and taming their active involvement tempers contingency and thus the transformative potential of the neighbourhood lab while upholding contingency in their narrations.

Lab 2 creates continuity mainly with the business field of logistics in its organisational, material and symbolic infrastructuring. What is embraced are traditional values and conventions of the field, such as a strong emphasis on practical expertise, personal networks and a focus on the utility of innovations, but also new impulses from a start-up scene, such as risk-taking and allowing failure as part of the learning. The latter is expected to trigger contingent ideas and innovations. However, the start-up character is inscribed into the organisational and material infrastructure mainly by copying its formats and aesthetics, rather than by embracing a failure culture. It is mainly on a symbolic level, by taking on a provocative, radical stance, that lab 2 more actively tries to trigger contingency. The constitutive tension is engaged with in a more playful way, by giving subtle impulses and trusting in the momentum they might develop. Despite these creative moves, market logics, also with regards to societal values, are taken for granted as ordering mechanisms. Although lab 2 opposes the strong orientation on monetary value, which is prevalent in the logistics field, they take an understanding of the market as interface of supply and demand at face value.

As a result, we can see that lab 2 also tempers contingency when it comes to organisational and material infrastructuring and mainly addresses possibilities for disruption on a symbolic level. In addition, lab 2 embraces a market-based innovation model that assigns a merely passive role to its citizens. Doing so, the lab excludes citizens as possible providers of contingent ideas. This approach may also be related to the perceived lack of sufficiently radical and disruptive innovation thus far (according to the self-evaluation of the coordinators). Finally, one could ask if engagement with citizens in more active roles could enable contingency in the sense of challenging and providing alternatives to this market-based understanding of innovation, and thus trigger the creation of transformative knowledge.

Discussion & conclusions - epistemic and policy implications

Living labs promise to contribute to societal transformation through a double move. On the one hand, they are meant to facilitate and routinise innovation by providing an infrastructure that establishes continuity with different ways of knowing and innovating. On the other hand, living labs should allow for new questions and unexpected solutions to come up, for example by bringing diverse actors together as a source for contingent thought. It is the exchange of diverse stocks of knowledge, experiences and values that, according to contemporary innovation policy, holds the promise of novelty. In this paper, we analysed how – in the process of building up and maintaining living labs – this constitutive tension gets infrastructured in two specific cases. We observed efforts of including a diverse set of actors and ways of knowing to allow for contingency. However, a striking outcome of the analysis is that, ultimately, balancing occurs asymmetrically: a tendency towards continuity is prevalent and possibilities to allow different actors to introduce contingency are often marginalised.

Thus far the literature on living labs and transdisciplinary research institutions mainly addresses political or ideological tensions, and the call to embrace tensions is mostly based on a democratic argument as ample STS research on tensions in transformative research (see, for example Bijker and Bijsterveld, 2000; Felt et al., 2016, Polk, 2014, Schikowitz, 2020) and living labs (Engels and Walz, 2018; Leminen et al., 2015; Hillgren et al., 2011; Evans and Karvonen, 2011; Karvonen and Van Heur, 2014; Farías, 2016) demonstrates. We add the idea that it is not only political tensions, but also epistemic tensions that are constitutive for a lab infrastructure, if it is to produce surprising *and* legitimate outcomes. This idea is epitomized in the term constitutive tensions and operationalized with a heuristic for analysing the organisational, material and symbolic aspects of infrastructuring.

Empirically, however, we observed the tendency to temper contingency both epistemically and politically (which might, however, come along with its own contingencies and side-effects). Epistemically, the two labs we analysed invited and addressed different ways of knowing in the first place, but kept them strictly apart and mediated between them in the role of gate-keepers (which is a constitutive element of

'boundary organisations', as Guston, 2001, argues). Politically, both cases clearly endorsed participation as a crucial virtue, yet managed to circumvent the danger of contradictory values and political positions which could challenge research interests or innovation policy. Putting emphasis on maintaining continuity rather than contingency was especially the case when misunderstandings, conflicts and time-delay threatened to endanger the production of accountable output (such as publications, prototypes, or models of mobility solutions and methods) – which is the main currency both in academia and innovation policy.

Balancing the constitutive tensions towards continuity happened in three ways. First, the labs built up organisational infrastructures that create strong connections between the lab and different communities. The lab was placed between them as a mediator or 'obligatory passage point' (Callon, 1986), able to address and translate their interests separately. Second, the labs' material infrastructures were located in secluded venues, away from urban multiplicity and overlapping interests and spaces, with few options for potentially contingent encounters as well as broader resonance. And, third, the labs' symbolic and narrative infrastructure staged citizens either as drivers of contingency or as passively supporting business actors who would bring in contingency. This negates potentially controversial relations between different actors as a source of contingency. Yet in both cases, the lab staff and operators re-introduced ideas and impulses *they* got from encounters with different actors and knowledges as a source for contingency (the informal passing on of residents' ideas in lab 1, and the provocative spreading of more radical ideas in lab 2).

As we can see, analysing the labs' infrastructuring through the lens of organisational, material and symbolic infrastructuring allows us to notice how in each of these aspects there is a balancing between continuity with specific groups and possibilities for contingency. In our cases, infrastructuring living labs appears as a meticulous orchestration of its organizational, material and symbolic aspects so as to set the stage for participation and innovation, yet simultaneously taming and demarcating them again. Demarcating different actors and knowledges, however, happens in a more hidden way. The actors are brought together, yet not evenly distributed across all three dimensions of the lab infrastructure, and their interactions are strongly controlled and mediated by the labs. Despite all estimable efforts of single labs to navigate and balance constitutive tensions, including their epistemic ones, these insights suggest that meeting the various demands and expectations that policy makers and researchers amount on living labs is, in fact, a mission impossible. Previous research on tensions especially in boundary organisations (Parker and Crona, 2012; Turner et al., 2015) points to a similar direction. Parker and Crona (2012: 267) find that boundary organisations engage in a "continuous process of negotiating among tensions derived from inconsistent demands placed on the boundary organisation" by way of 'lingering' between addressing them at different times and in different ways.

Against this background, we encourage to refrain from attempts to optimise living labs for meeting all diverging demands at the same time, and instead to embrace agonism (Farías and Blok, 2016; Farías and Widmer, 2017; Karvonen and Van Heur, 2014; Björgvinsson et al., 2012). That is, we advocate to "host the tensions and the associated inconsistencies" (Engels and Rogge, 2018: 31). As Farías' (2015) work on architectural practice makes plainly clear: here, 'epistemic dissonance' is purposefully enacted in different situations to create alternative designs and solutions. Inspired by such approaches from design studies, we see potential to bring about agonism and allow for contingency especially in the material dimension of infrastructuring, which is often treated as merely instrumental to organisational and symbolic purposes. For example, we could ask how test areas and participation spaces might be less pre-structured and 'clean' to allow for unplanned encounters and questions to occur and irritate the interactions. This could be achieved through involving residents, users, and citizens not only in the use, but also in the design of such spaces. In this way, entrenched assumptions about what is tested, standardised ways of setting up tests and workshops, and underlying questions, could be challenged and alternatives could emerge. In addition, what may seem to be 'a failure' in one

lab, might be a constructive move in another lab – addressing another problem, involving other configurations of actors. Thus, careful documentation and analysis of infrastructuring constitutive tensions and its various instructive effects might raise awareness for 'riding the tiger' and the courage for admitting and embracing contingency.

However, more open engagement with tensions and openly learning from failure often lies beyond the scope for individual labs. Thus, this task must predominantly be relegated to the policy level. On the basis of this study, one might ask if these excessive and incompatible expectations vis-à-vis living labs do actually misjudge their transformative potential. Their unique selling point might precisely lie in their chance to create and probe incremental and situated changes that cumulatively yield alternative futures, brought about by carefully orchestrated lab infrastructures made to work with and not against the constitutive tension of continuity and contingency.

Acknowledgements

We want to thank the anonymous referees for their thorough engagement and helpful suggestions for improving the paper. Further, we are grateful for the detailed feedback on an earlier version of the manuscript by our colleagues Sascha Dickel and Nils Matzner, and for feedback and help with language editing by Bao-Chau Pham. Finally, we owe special thanks to our interlocutors, who granted us access to the labs' events and who shared their time and reflections with us. The research for this paper was funded by the German BMBF (Federal Ministry for Education and Research) and conducted as a part of the joint project "PROTOTYP – Zukunft materiell entwerfen. Prototypen als Kommunikationsmedien des Neuen" at the Technical University Munich.

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Notes

1 Here, we focus on lab initiatives which (1) show a commitment to public goals related to societal transformation (in contrast to e.g. product development in firms), which are (2) located in and address specific spatial areas (which can be a street, a city part, a whole region, etc.), (3) include the cooperation and collaboration of different actors (e.g. from science, business, public authorities, and civil society), and (4) in which (social and/or technical) innovations are developed and tested, often through experimental and prototyping practices (Dickel, 2019; Karvonen and Van Heur, 2014) and design methods (Engels et al., 2019; Gross, 2018; Hillgren et al., 2011). We are aware that the different terms are used and defined in different ways and that *Reallabore* and living labs are in some discourses distinguished as different concepts and used synonymously in others (see Schäpke et al., 2017). Respectively, those different terms put emphasis on different aspects. In this article, we foreground the general commonalities of these different forms and regard their specific realisation as an empirical question.

2 The five labs in operation during this research project received funding for four years (2017-2020) initially to deal with different aspects of sustainable and innovative urban mobility (e.g. mobility of goods and people, multimodality, autonomous driving, public transport, sharing models for bikes and cars, etc.). The UMLs are located in different parts of Austria and are organisationally separated from the research and development activities (conducted in projects or by companies) that are going on within them.

3 Hackett (2005) applies Kuhn's notion of essential tensions to the choices that research groups need to make. The tensions he describes include a discrepancy between continuity (with a wider field of research, with the group profile and 'safe' research lines) and contingency (of an independent group identity, of younger researchers' individual ideas and of risky lines of research).

4 They are funded by the Austrian federal ministry in charge of mobility within the framework "Mobilität der Zukunft" ('Future Mobility'; https://www.mobilitaetderzukunft.at). This program has existed since 2012 and the 7th call that was launched in 2016 included the UML.

5 While insiders may easily recognise the specific labs we analyse, we do not use their real names or concretise their location and member institutions, as we aim to put emphasis on lab types rather than exposing individual cases. Relatedly, we take special care not to disclose the identities of lab staff and organizers to whom we assured confidentiality.

6 Quotations from the interviews are labelled with L1 and L2 for the two labs. All interviews were conducted in German and the quotes were translated by the authors. If not noted otherwise, the direct quotes in this chapter are from the interview with a lab coordinator. S/he is member of a university department. The interview, which lasted over two hours, took place in a meeting room of the local neighborhood contact-point within the targeted city development area.

7 If not noted otherwise, the direct quotes in this chapter are from an interview with two members of the coordination team. The operating coordinator 1 has a university background but worked in the field of logistics for several years. Coordinator 2 is a university professor who only occasionally comes to the lab location. The interview lasted almost two and a half hours and took place within the event room of the lab.

Elliott Anthony (2023) Algorithmic Intimacy. The Digital Revolution in Personal Relationships. Cambridge, UK: Polity Press. 220 pages. ISBN: 978-1-5095-49818

Paul Trauttmansdorff

p_trauttmansdorff@msn.com

Algorithmic Intimacy, as Anthony Elliott claims, is *not* another contribution to the "soaring studies of the AI revolution" (2023: 1). Admittedly, this initial confession somehow strikes a chord as it has become increasingly difficult to keep track of such a prominent theme in the social sciences. A wide range of work in fields such as science and technology studies, sociology, political sciences, or communication studies now deals with the dangers, risks, benefits, or opportunities of different phenomena often subsumed under AI. The increasing attention to machine learning technologies in our everyday lives is not surprising—given the massive investments in AI by international corporations or the design of entire national strategies in which states project AI to build geopolitical futures (Bareis and Katzenbach, 2022). The difficulty of AI in public discourse lies in the combination of fuzziness, overuse, and its presumed technological power, which often clouds this notion with mystery or fear. The "Digital Revolution" is brimming with buzzwords; AI has long become its most prominent one.

Algorithmic Intimacy carefully avoids any mysteries, but neither does it downplay the transformative potential of machine learning technologies. The book describes the recent proliferation of automated and predictive algorithms that mediate our intimate ways of being with others. It aims to carve out elements for a critical social theory of intimacy in our digitized life. How are social bonds and interactions experienced and negotiated in the human-machine interfaces that connect people? How do algorithmic technologies shape our longing or desires to build ties to and with others?

It is a reasonable starting point to explore these questions with the book's somewhat counterintuitive title—Algorithmic Intimacy, which challenges some common assumptions about the nature of algorithms and human togetherness. While social intimacy seems to evoke physical proximity, personal experience, and emotional encounters, algorithms, by contrast, appear concealed or invisible, virtual, and mechanistic. What are the implications of considering intimate social relationships "in the face of machine-learning predictive algorithms and the emergent variety of intimate connections modeled in the image of computational code" (Elliott, 2023: 12)?

The book begins with two conceptually oriented chapters that lay out how algorithmic technology and automated platforms are transforming what sociologists once identified as the social cornerstones of intimate life: face-to-face interaction, lasting togetherness, profound knowledge of one another, sometimes also confidentiality. Elliott then proceeds by examining three main domains in which intimacy is algorithmically reconfigured and which form the book's main structure: "Relationship Tech," "Therapy Tech," and "Friendship Tech." Each chapter presents several examples of how technological products shape the intimate feelings of togetherness and connection: erotic engineering app claiming to match suitable dates or optimize sexual activity;

chatbot therapists and conversational agents cultivating self-care and improving mental health; various (social) media platforms connecting new digital friends. The book's examples illustrate the key features of algorithmic networking: automatization, machine rationality, and predictive analytics. Elliott explains these concepts convincingly, drawing on social theory and engaging in a dialogue with other recent work on AI, such as the books by Louise Amoore (2020) or Helga Novotny (2021)—two important scholars that are repeated points of reference.

A key priority for the book is individual agency, personal behavior and experience, as well as their embeddedness in specific social, cultural, and economic contexts. The efficacy of machine learning technologies and algorithmic products can, after all, only be explained by the concrete practices and decisions of users (or consumers). As Elliott argues, "women and men – and the existing institutions in which they live their lives – choose to respond to the opportunities and risks of digital revolution" (p. 162). His recurring insistence on reflecting personal experience and behaviors in AI fields such as big data, crowd psychology, and cloud computing makes this book particularly worthwhile to read. It provides the reader with a distinctly critical understanding of how automation and prediction engage users in personal digital intimacy projects: working on the self, consuming digital relationships, optimizing the psyche.

In Elliott's examples, erotic engineering in "Relationship Tech" usually creates a specific ideal of relationship that can be consumed easily, allowing to eliminate challenging decision-making and responsibility in choosing partners. In "Therapy Tech," chatbots and conversational agents provide digital users with permanently available therapists that reverse psychoanalysis' promise of personal liberation through continued self-reflection and engagement with the unconscious. Instead, they tend to exploit today's "confessional culture" (p. 105) of social media and offer therapy as manageable project of self-awareness. Likewise, in "Friendship Tech," the book emphasizes the rather simplistic emotional and (pop-)psychological foundations of friendships promoted and actualized by emotional AI chatbots. The problem with this ideology, one could summarize, is that it idealizes principles of self-care, affirmative and authentic selfhood, and emotional survivalism when in fact, in most cases, the visions of networked intimate bonds appear rather dubious and infantile. They promise a form of companionship that is constantly available, non-judgmental, and arduously affirmative. Elliott problematizes this as "pathological optimism" (p. 111)—a description that applies to many of the products of algorithmic intimate action and manifests itself in the incentives to share, like, or re-tweet personal opinions and authentic feelings as a seemingly inherent positive values of self-expression.

For most parts of the book, Algorithmic Intimacy is written in a sober diagnostic style, sometimes at the expense of a more detailed presentation of the cases that are at the core of its arguments. There is only little reported on the diverse types of infrastructural work, such as designing, monitoring, and repairing algorithmic systems, software programs, or apps. Who, and what exactly, is involved in these practices of infrastructuring? And what to make of the many failures, bugs, and errors of AI products that "the" user encounters? Also, we still lack a detailed engagement with the distinct categories of users or customers, which are so often subsumed under the black-boxed notion of "society." Algorithmic Intimacy is nonetheless a very important critical introduction to a broader field of research and convinces us to delve deeper into the digital revolution of what we consider our most personal spheres of life.

Elliott concludes with a chapter on "Versions of Algorithmic Intimacy," which reminds us that individuals perceive and experience intimacy in different ways—also, and especially, through algorithmically generated forms of connection. This final chapter might be read as a more forward-looking conversation about the (yet-to-be-realized) potential of multiple experiences, shapes, or forms of intimacy—a horizon of plurality that is so far only mimicked by the products of the AI industry. The dilemma of automated, intimate activity is experienced as what Elliott calls "a *living through* of the crisis of digital revolution" (p. 161), profoundly altering our relationships and social

bonds. The danger seems to be that algorithmically oriented lifestyles and intimate action, instead of creating new meaningful ways of togetherness, "automate or mechanize at the level of the individual subject what are, in actuality, social problems" (p. 103). They thus ultimately risk fueling alienation and loneliness in an increasingly networked world. If their focus remains so strongly on self-optimization and escaping the complexity of social life, these technologies lure the individual into magical belief that they can solve fundamentally social problems. Most of today's products of automated intimacy then appear to be more like the digital versions of what Adorno called the occultists, astrologists, and spiritualists: "With their blunt, drastic answers to every question, [… they] do not so much solve problems as remove them by crude premises from all possibility of solution" (Adorno, 1994: 167).

Algorithmic Intimacy is not a simple warning of a dystopian future of out-of-control machine intelligence. Instead, it is about the one-dimensionality of today's industrial AI products and their promises of simplicity and conformism in social relationships. It is therefore also an emphatic call to delve deeper into the multiple ways in which algorithms will shape the interior self, create new digital identities, and define our being-with-others.

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Pedro Robles
par13@psu.edu

Daniel J. Mallinson

Philosophy of science and technology presents critical arguments challenging the motives behind technological innovation (Sismondo, 2010). The accumulation of scientific knowledge also contributes to solving real-world problems (Fuller, 2005). Moreover, modernization theory envisions a social process coupled with economic improvement and, as a result of technological developments, that contributes to social development as well (Hälterlein, 2023; Misa et al., 2003). AI technology is applied science that offers social benefits through economic development (Biegelbauer, 1998). However, AI technology should not be the final determinant in enhancing human development (Cross, 2018). It can offer enhancements to decision making and resource allocation where there are human limitations (Hälterlein, 2023), but humans still play a pivotal role in making ethical decisions. It is this theme that pervades Darrell M. West and John R. Allen's *Turning Point: Policymaking in the Era of Artificial Intelligence*. Their work shows how the three threads from research on science and technology studies are pulled together with respect to emergent AI technology.

Artificial Intelligence has evolved as a transformative technology with the opportunity to revolutionize various aspects of our lives (West and Allen, 2020). Its capability to analyze vast amounts of data, recognize patterns, and learn from experience has significantly improved healthcare, transportation, and finance (Ben Yahia et al., 2021; Davenport and Kalakota, 2019; Xie, 2019). For example, AI-powered medical systems can provide personalized patient treatment plans, leading to better health outcomes and reduced costs. Self-driving cars promise to make transportation safer and more efficient (Amann et al., 2023; Stilgoe, 2018). Financial institutions use AI algorithms to detect fraudulent activities and make more accurate predictions (Goodell et al., 2021). However, as AI becomes increasingly capable, there are concerns about its potential risks and ethical implications (Charles et al., 2022). The rise of automation and AI-driven systems may lead to significant job displacement in some sectors, raising questions about how society will address this displacement and support those impacted (Howard, 2019). In addition, there are public concerns about the potential for biases in decision-making, particularly in areas such as hiring, lending, and criminal justice, where AI systems may perpetuate existing inequalities (Yam and Skorburg Joshua, 2021). As such, it is crucial that we carefully consider the development and deployment of AI technologies to ensure that they are designed and used in ways that align with ethical and social values (Elliott et al., 2021). It will require a collaborative effort from policy-

makers, industry leaders, and society to establish clear guidelines and regulations that balance the benefits of AI with its potential risks (The Anh et al., 2020). By doing so, we can unlock the full potential of AI while ensuring that it benefits everyone fairly and equitably.

West and Allen lay out in significant detail many of these benefits. However, they are not pollyannaish about AI. Another clear theme are the myriad social challenges presented by the technology. These include privacy concerns, ethical decision making, the role of humans in the AI chain of action, and much more. AI safety issues been raised across multiple fields, including healthcare and transportation (Winter and Davidson, 2019; Winter and Carusi, 2022). Each of these concerns presents thorny issue for policymakers, but also opportunities for governments to protect citizens against ethical problems, including discrimination, and promote transparency. For example, bias reduction in the education sector may require reformation of school system structures and technology training for educators. In terms of equity, everyone should have access to technology regardless of their economic condition. Drawing from Brookings Institution survey data, the authors reveal the degree of public concern about AI safety.

Success in maximizing the benefits of AI while reducing its potential downsides requires a suitable governance framework that establishes ethical guidelines and vertical and horizontal rules and enforces laws and appropriate regulations (Winter and Davidson, 2019; Winter and Carusi, 2022). West and Allen offer a variety of thoughts on regulation, including the issue of governments balancing not squashing innovation with properly protection the public from corporate and government excesses. To do so, government institutions should promote accountable processes and transparent methods within public and private organizations and with the public. In the private sector, some organizations, including IEEE and Microsoft, have considered integrating computer code that promotes ethical values like human safety, privacy, and fairness. There is a significant information asymmetry between private sector companies developing AI and governments trying to regulate a rapidly changing technological landscape. To do so effectively requires collaboration between the public and private sectors.

While the book is excellent in its broad scope and gives the reader a solid understanding of the current state of AI, it cannot do everything. The regulatory recommendations are specific, but understandably limited in their depth. The authors raise the need to balance innovation and regulation, but do not offer a prescription for how to do this. Further, save brief attention in the chapters on defense applications and building a responsible AI, there was little discussion of the use of AI in the criminal justice system (Wirtz et al., 2020). Given the stark inequalities in the United States and concerns about surveillance and over policing of minority communities, application of AI to the criminal justice system could stand its own chapter. For example, governments are considering integrating AI to assist lawyers in processing legal cases and research investigations on previously archived cases (Xu and Wang, 2021). In the courtroom, AI has been proposed to assist judges in reviewing cases and improving sentencing decisions (Xu and Wang, 2021). Finally, AI can analyze large volumes of unstructured data and images to support law enforcement (Xu and Wang, 2021).

Overall, the book is a valuable resource for anyone interested in understanding the potential benefits and challenges of AI integration in various sectors and highlights the need for ethical considerations and regulatory frameworks.

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Science & Technology Studies

Volume 36, Issue 3, 2023

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