The Changing Nature of the Information Supply Chain

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Abstract

Management faces replacement by automated processes. Workflow automation in the information processing sectors of the economy is changing the way information and knowledge workers do their jobs. I consider the changing nature of the information supply chain from the creation of knowledge in firms to the supply of information to consumers. The changing nature of data and the development of data science and machine learning methods that enable the analysis of unstructured data have meant that what was once viewed as tacit knowledge is now just a problem in information processing. The rise of workflow automation in the IT industries and the emergence of the reproducible research movement in the sciences is leading to increased automation of the production of information in both industry and academia and this has profoundly changed the nature of the information supply chain.

Keywords: information supply chain, knowledge creation, workflow automation, iPaaS, reproducible research

Introduction

The emergence of the knowledge and information society in which we live and work has had far-reaching implications on our lives. Knowledge and information workers as part of their daily routine are engaged in the production and consumption of knowledge and information.

The information economy has been long studied by both management theorists and economists (Drucker, 1959) (Machlup, 1962), (Stigler, 1961), (Marschak & Radner, 1972). However, despite this few have attempted to consider the production and distribution of information from a supply chain perspective (Sun & Yen, 2005).

In this paper I will discuss recent developments and future trends in the information supply chain: the interconnection of organizations from the production of information to its consumption and the role of information as a service. The key research question is how is the information supply chain changing in the face of workflow automation and how is this changing our understanding of knowledge and information processing in business and academia? The role of the knowledge creating company has been and is continuing to evolve in largely unpredictable directions. The rapid and disruptive development of information technology continues to change the nature of the information supply chain. Geva Perry has noted that:

> We are witnessing a seismic shift in information technology – the kind that comes around every decade or so. It is so massive that it affects not only business models, but the underlying architecture of how we develop, deploy, run and deliver applications. (Perry, 2008)

Since he wrote that in 2008 the pace of technological development in the IT industry has continued to accelerate in the direction he outlined. There are two main paths to this development the first is DevOPs a fusion of development and operations that is leading to shorter development time in the IT sector. The second major development concerns workflow automation and this underpins both DevOPs as well as other developments that we are seeing across those sectors of the economy that we deal with the production of knowledge and information. The key thesis of this paper is not in fact just about the IT sector but about a broader trend across a number of sectors involved in the production, deployment and delivery of information. While IT provides the infrastructure of the knowledge/information sector, the management of operations in this sector is not purely an issue of IT. Education for example is involved in the production, deployment and delivery of information and knowledge. The media in the form of newspaper, television, radio and internet media has a similar role. The key thesis is that the way in which business, researchers and others involved in information production and dissemination manage and process information is changing and that the degree of awareness of the extent and nature of these changes is relatively low. The aim of this discussion paper is to report on some of these developments and to relate them to the academic literature on the nature of knowledge and information processing in firms and organizations.

New technological developments such as integration Platforms as a Service (iPaaS) and network virtualization are enabling workflow automation to an extent we have not yet seen before, these developments along with the containerization of software products are leading to rapid automation of information development and production in automated information supply chains. At the same time at the upstream end of the information supply chain in research and development particularly but not only, in higher education there are increased calls for more transparency in research and greater reproducibility of results. Reproducibility of research requires greater automation of knowledge production as part of the research process. We are therefore seeing rapid automation of workflows across research and educations sectors as well as in the IT sector of the economy. In parallel with this, developments in machine learning and the management of "big data", and in particular the application of these methods to natural language processing and analysis of unstructured texts, the understanding of which is replete with tacit knowledge, means that we need to re-evaluate old models of the role of knowledge and information in business.

That the new technology considered in this paper is radically changing the way in which we produce, process and manage information seems beyond question; that it is likely to disrupt business processes and to a largely unforeseen extent seems plausible. In this paper I hope to outline some of these developments and theory, the implications for business and management, and the changing nature of the information supply chain and how the knowledge-creating company is evolving to an information-creating company in which even tacit knowledge is just a form of unstructured data that has been waiting to be processed by new methods arising from the merging of computer science and statistics, a new field that has begun to be termed data science (Anthes, 2010).

In this paper I will discuss the information supply chain from the production of information through to its dissemination through various networks and final consumption. In the next section I begin with a critique of the distinction between tacit and explicit knowledge and the view that companies create knowledge; indeed, I question the distinction between knowledge and information. I then go on in the following section to consider the standard conception of knowledge as justified true belief and try to relate that to the information theoretic definition of information. In this section I also discuss the incompatibility of Rylean and Polanyi characterizations of knowledge with the standard conception of knowledge as justified true belief. The following section considers some counterexamples to tacit knowledge in particular Polanyi's face recognition example by discussing how recent developments in face recognition technology and machine learning have made this an example of what Polanyi would call explicit knowledge rather than tacit knowledge. This discussion of the breakdown of the distinction between knowledge and information that is resulting from developments in machine learning is followed by an analysis of the role of workflow automation and the emergence of integration platforms as a service (iPaas). In parallel with this development the emergence of the reproducibility drive in the scientific research is discussed and finally it is concluded that we stand before major changes in the information supply chain due to radical changes in workflow automation based on new IT technology that has only really appeared in the last few years.

From Knowledge Creation to the Information Supply Chain

Nonaka (1991), drawing on Polanyi's concept of tacit knowledge, argued that the role of the firm, and in particular Japanese firms, was the production of knowledge. He contrasted Western concepts of information processing in firms and distinguished firstly between knowledge and information and secondly proceeded to break down knowledge into different sub-categories. The information processing model of the firm can be traced to work by Jacob Marschak culminating in the development of team theory (Marschak & Radner, 1972).

The idea that knowledge can be further subdivided is due to Ryle (1946); however, Polanyi's division into tacit and explicit knowledge is probably better known. Both Polanyi and Nonaka can be viewed as Ryleans in the sense that they distinguish between knowledge that is in some sense innate and not directly communicable with the external world and knowledge that is communicable with the rest of the world. Ryle's view of knowledge had however been challenged early on by Sellars (1956).

In the management literature there is a split between the two communities of knowledge and information management. Those authors writing on knowledge management make little reference to information management and vice versa. What is the difference between knowledge and information? While information has a rather precise definition (it can be defined mathematically) the definition of knowledge remains somewhat controversial. While there are numerous controversies and schools of thought the standard view in philosophy is that knowledge is justified true belief (Ichikawa & Steup, 2014), (Turri, 2012). On this account tacit knowledge cannot in fact be knowledge because one cannot justify something without articulating what one is justifying, so that Polanyi's definition of tacit knowledge as knowledge "that cannot be articulated" ("we can know more than we can tell") implies that tacit knowledge cannot be justified, which is not consistent with the standard account of knowledge as justified true belief. If, one grants then that tacit knowledge is not knowledge, although it may well be a true belief, then the epistemological model of the knowledge-creating firm is on somewhat shaky ground from a philosophical perspective. A better and more accurate term for tacit knowledge may simply be "gut feeling". Once we concede that firms are generating information and this information may be both structured and unstructured, the question naturally arises as how information should be managed from an operational perspective and how information flows fit into a service-oriented supply chain. The analysis of services is however sparse (Pinedo, 2009).

Sun and Yen (2005) appear to be the first to have applied concepts from operations management and supply chain theory and in particular supply chain management to information flows in business, and to have been the first to coin the term "information supply chain". They define an information supply chain as: "an information supply chain (ISC) fulfills users' information requirements by a network of information-sharing agents (ISA) that gather, interpret, and satisfy the requirements with proper information" (see Figure 1).

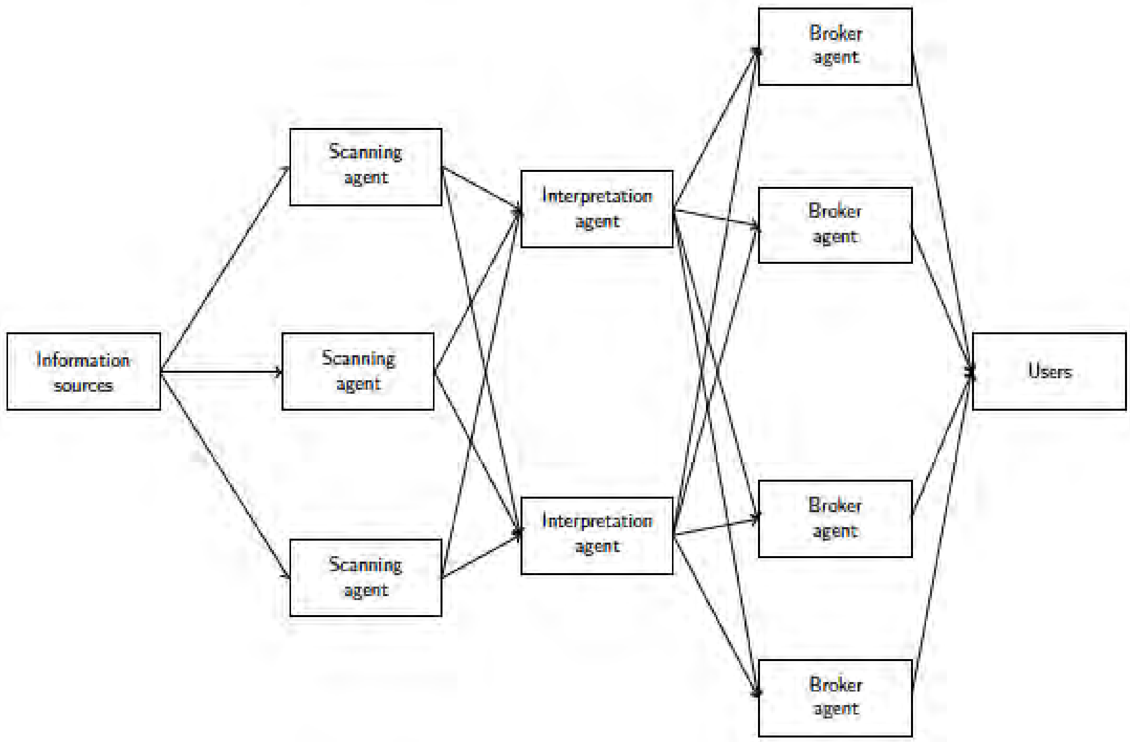

Figure 1: An information supply chain (adapted from Sun & Yen, 2005, p. 423)

The particular focus of their work is on information sharing. They point out differences between material supply chains and information supply chains in particular. Building on their ideas it is clear that it is difficult to establish property rights to information. Some information is public and with some there is a clear need and concern for privacy.

The difficulties arise in the latter case because while information can be secured, thereby establishing property rights over it, it is non-rivalrous in consumption, which erodes the ability to enforce property rights (Buchanan, 1965). Information therefore essentially has the characteristics of a club good. In managing flows of club goods different problems arise compared with the management of flows of private goods.

Justified True Beliefs and Information

The conception of knowledge as justified true belief can be traced to Plato in the Thetaetetus. This view of knowledge has largely been the benchmark view of knowledge in serious philosophy until 1963 when it was challenged by Gettier (Gettier, 1963). Much of the philosophical debate since then has concerned how to reconcile Gettier's challenge with the Platonic account of justified true beliefs as knowledge. Both the accounts of Ryle and Polanyi of knowledge fail to satisfy even the Platonic account. Polanyi's view could be perhaps be conceived as arguing that there are things we can know which cannot be rationally explained or justified. However, even Gettier accepts the rational justification postulate. Both Ryle and Polanyi and consequently Nonaka in following this path are at odds with both the standard account of knowledge as justified true belief and the subsequent discussion in the literature following from Gettier's challenge. This is not to argue that the justified true belief conception of knowledge is the last word on the matter. There is an ongoing debate in philosophy that attempts to deal with the challenges raised by Gettier.

Information can be thought of as that which makes you able to make predictions better than chance (Adami, 2016). A precise definition of information may be made in terms of entropy, a measure of uncertainty. Abstracting somewhat from Adami's account information is the difference between the maximal uncertainty (entropy) and the actual uncertainty concerning something (X). Information therefore is defined as that which reduces uncertainty. Adami's account differs a little from the usual story told of information and uncertainty. There are two alternative but equivalent definitions used (Gray, 2013).

Knowledge Creation and Unstructured Data

Polanyi argued that face recognition is an example of tacit knowledge; one may recognize a face without being to articulate who it is. Yet face recognition software is making rapid progress, and the development of biometric methods based on machine learning is making tacit knowledge amenable to computational analysis. When this happens such knowledge is simply a problem in the analysis of unstructured data. The facial images then become information, so that tacit knowledge becomes an element of latent information within it. The written program becomes an expression of what we know about face recognition. Numerous other examples held up as representative of tacit knowledge fall into the same category and with further analysis can be seen to be little more than examples of unstructured information. Earlier writers in the Ryle-Polanyi tradition perhaps could not have foreseen the rise of machine learning that eliminates the distinction between tacit and explicit knowledge. Is this technology being used in firms, and does it have management implications?

Most certainly. Face recognition software is being used from everything from biometric security through to e-learning research into emotions, another supposed example of tacit knowledge, that has progressed to the point where analysis of facial micro-expressions that reveal emotional responses using machine learning is possible (Pfister, 2011). A written computer program for face recognition is a set of instruction that tells us how to recognize faces. As such the existence of such programs implies that we can tell how to recognize faces and that the face recognition problem is no longer an example of "knowing more than we can tell".

Today many problems involving unstructured data that would once have been considered examples of tacit knowledge are being analyzed by writing down sequences of instructions for acquiring such knowledge (programs). These programs are for the most part written by people who are in fact able to say "how we can tell". In fact, they say this by writing a face recognition program. Machine learning has narrowed the gulf between Ryle's knowing how and knowing what. Programmers have learned to narrow this gap incrementally through observation and technology capture of the information and applied it through technology such as algorithms and hardware.

Returning to the Knowledge-Creating Company

If we grant that explicit knowledge largely has to do with what we glean from structured data and tacit knowledge is concerned largely with the same sorts of problems as those involved with the analysis of unstructured data and furthermore, following Nonaka we concede that it is the act of combining these two types of knowledge that generates new knowledge. We would then expect that the combined analysis of structured and unstructured data (Koenker &

Zeileis, 2009) is likely to generate new knowledge. This is precisely what data science and machine learning do that is new.

Workflow Automation

Workflow automation has a long tradition. Since the introduction of the production line, increases in production efficiency have largely been due to increased automation of workflows (the other main source of efficiency gains is in regard to energy inefficiency). In the IT sector scripting languages have long played a role in automating workflow on a user's machine. The use of VBA (Visual Basic for Applications), for example in automating a series of steps or sequences of commands in Microsoft-Excel, should be familiar to many. To users of the various flavors of UNIX including Darwin-OS/X shell scripting via the bash shell enables automated copying of files; the "make" program, for example, allows for the automation of installation and updating of files without the user having to go through each step of the process. However, make scripting and even VBA have for many years remained for many users of information technology rather esoteric tools. Despite having been in widespread use for many years, workflow automation has for the most part remained limited to the programming community. There is increasing evidence that this is about to change.

The Emergence of Cloud Computing and the Software as a Service (SaaS) Paradigm[1]

SaaS has now evolved further and led to a number of new acronyms IaaS (Infrastructure as a Service),[2] Platforms as a Service (PaaS), XaaS (Anything as a Service) and iPaaS (integration Platforms as a Service). The latter involves connecting SaaS applications together, thereby eliminating the need for the user to interact with each application in separate instances. This essentially enables the automation of workflows via cloud applications. A number of iPaaS providers have now emerged, with companies like Blockspring, IFTT, Cloudpipes, Zapier among the better-known names. However, new challengers are entering the market with products such as Microsoft Flow. All of the above platforms fall into the category of integration platforms.

Other examples of workflow automation software include Automated Insights' Wordsmith software that employs natural language processing technology to automatically generate written reports from data. Such software when integrated with web-scraping technology and iPaaS will allow complete automation of the data collection, analysis and reporting cycle. This has the potential to radically change the nature of information production in the workplace.

In the next section I will consider the iPaaS market in detail and discuss current development and trends in competition between platforms in terms of how they may impact the information supply chain.

Integration Platforms as a Service

The introduction of containers and the rise of DevOps has also contributed considerably to increased automation of software development and particularly web development. New

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[1] SaaS or software as a service refers to software applications that are cloud based and accessible via the internet (Turner, Budgen, & Brereton, 2003).

[2] Examples of Infrastructure as a Service include Amazon Web Services (AWS), Microsoft Azure, Google Cloud, Digital Ocean, Rackspace and similar cloud service providers.

innovations in this area are making it easier to deploy new software in the cloud. The key to this is automation of workflows. DevOps enables the integration of software development, deployment and maintenance during production and automates the development, deployment and production workflow using approaches based on software containers (examples of this technology include Docker).

Given the appearance of so many new startups and the presence of old established IT players competing with new products based on the iPaaS model, we should expect to see considerable future competition in this market. The analysis of platform competition has been developed by Rochet and Tirole (2003). Competition between integration platforms is increasing and thorough analyses of this new technology are lacking. The theoretical bases for understanding pricing in such markets exist but there is a lack of case studies.

The rise of IPaaS has changed the nature of the information supply chain in a number of ways. If we examine the model depicted in Figure 1 (Sun & Yen, 2005), then there are information sources, three types of agents (scanning, interpretation, and information brokers), and finally users. A stylized model is depicted in Figure 1 and the impact of the introduction of iPaaS is depicted in Figure 2.

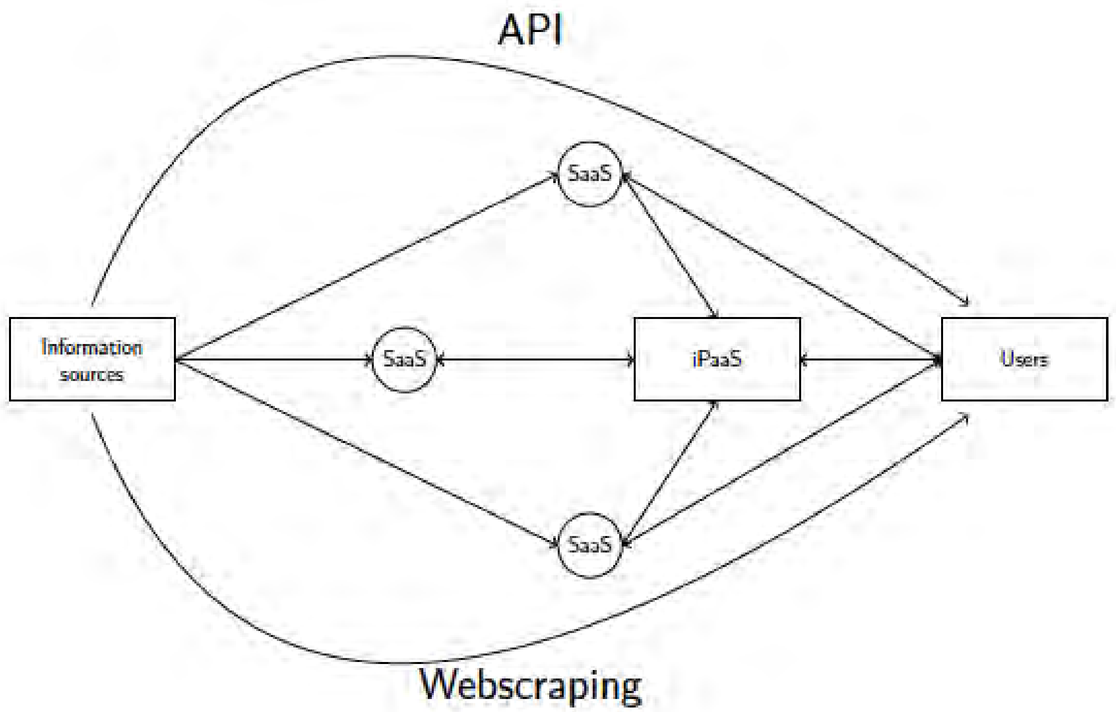

Figure 2: Where iPaas fits in the information supply chain

In Figure 1 it can be seen that end-users acquire information through brokers who obtain this information from interpreters, who obtain it from scanners who have scanned the information directly from sources. This is the traditional, relatively linear model of the infromation supply chain as described (Sun & Yen, 2005). Scanners for example might be statistical agencies or other sources of information in collated form, interpreters could be research organisations and media suchas newspaper, television, etc. Brokers form part of the distribution function that distributes processed and interpreted information to customers.

Today, with the help of API's and iPaaS end-users can directly access information from the scanning level, without making use of brokers or interpreters. For example, to obtain data from, say, the World Bank, I might once have gone to their website and downloaded an Excel file, then opened it and begun analysing the data, or I might have purchased data from a third party data vendor (a broker). Today, I am able to use the World Bank's API and, with a single line of computer code, import the data directly into R or Python and begin processing and displaying it. The manual search and downloading steps are removed from the process. It also does not matter whether the data is in structured or unstructured form, because webscraping utilities allow one to directly access embedded information in webpages without downloading and processing files, and the same can be done with sound and images. The programs used to write these commands provide a permanent record of the steps involved in enhancing reproducibility and automation. The user no longer has to remember what they did to acquire the data. Figure 2 depicts how iPaas modifies the information supply chain. It also incorporates how users are able to directly access information (data) using API's (Application Programming Interfaces) or by directly scraping webpages.

iPaas provides a different level of functionality in that it allows the customer to directly link local and cloud based applications in customizable and modular ways. So, for example, the end user can use an iPaaS to reconfigure different SaaS applications to customize their own personal information supply chain (essentially this is what services like Blockspring, Cloudpipes and Zapier do). SaaS applications my be linked together in series or in parallel to automate workflows for acquiring and processing information and for enabling routine actions.

Some SaaS applications – for example, Slack – have iPaas functionality built-in, and it enables integrations in the form of Apps (Slack Apps). For example, it is possible to integrate Slack with Blockspring and then a Webscraping App, to directly import web data to the Slack command line or to a file. This allows the rapid acquisition of web content that can then be be passed to collaborators mid-chat without having to access a web browser. iPaaS essentially provides end users with endless possibilities for experimenting and reconfiguring cloud-based workflows without requiring any formal programming experience.

At the same time this has consequences for cybersecurity, because the ability for the user to reconfigure different pathways in the cloud means that websites and services that may have been blocked from the end user's perspective are now accessible through reconfiguring of the path by which information flows, and this is largely in the end user's control.

The use of API's and web-scraping essentially allows the end user to automate direct access to the information source thereby bypassing the whole supply chain. This is like consumers purchasing products directly at the factory, rather than through retailers but then arranging direct delivery, rather than having to pick their goods up at the factory. It is a fundamental part of the reproducibility drive within the sciences discussed in the next section.

The Scientific Supply Chain, Reproducibility and Workflow Automation in Science

The rise of workflow automation in the production of knowledge in industry and in particular in the IT industry is paralleled in the academic world by the reproducible research movement. That research be reproducible in order to stake a claim of being scientific has long been a tenet of scientific research. The rise of information technology has led to increased emphasis on the reproducibility/replicability of all steps of scientific supply chain from initial data collection, through analysis to report writing/generation and publication. This process has been termed reproducible research (Claerbout, 1992). Examples of software tools that support reproducible research include R packages, Sweave and KnitR, which allow the automatic generation of reports and documentation from statistical analyses conducted in the R package for statistical analyses.

The idea is to see data collection, analysis and report writing as an integrated whole based on principles of literate programming (Knuth, 1984). So, for example, KnitR allows one to export commented analyses from the R package directly to Microsoft Word and other word and document processing packages. In effect the idea is to automate the production of scientific reports by combining data and analyses with an automated workflow in something akin to a supply chain for information. Nor is package support for reproducible research confined to R. Python has a version of Sweave: PSweave and commercial vendors of academic software such as STATA have begun addressing the question of how to modify their software to enable and enhance reproducibility of research and the automation of the data analysis and report writing process.

Increasingly, data is collected through automated scraping or the use of API's (Application Programming Interfaces) directly from webpages without the need for entry by hand (see Figure 2), it is then collated and pre-processed (cleaned, munged, wrangled) before it is analyzed and then incorporated into a written report (Web Scraping, 2009). Multiple iterations of the process are frequently managed using version control systems that allow change tracking and in some cases, through integrations with communications packages such as Slack provide automated updates of changes to research team members. While reports are currently still hand written, the automated generation of written reports from data is now possible. See, for example, Automated Insights' Wordsmith software that has been used to analyze and generate reports for Associated Press (AP) among other clients. The automated collection, analysis and generation of written reports is therefore already feasible although not yet in widespread practice.

Workflow automation in the education and knowledge sector, at least in research and particularly in the sciences, is already well underway. Software-based lab management systems and electronic lab notebooks augment these systems and further contribute to the automation of the scientific enterprise of information production and dissemination. The automation of this part of the information supply chain, although characterized to some extent by different technology to that which is being used in industry, cannot be said to be either lagging or leading compared with similar developments in industry.

Academic research is yet to incorporate the iPaaS model to any great extent, and has for the most part not systematically developed cloud based technology, due, it would seem, to a desire by university and research administrations to retain control of information technology rather than outsourcing it. The reproducibility drive in science has also been criticized (Bissell, 2013). Potential downsides to reproducibility include too strict requirements leading to the possible stifling of innovation.

Bacon's vision in the Novum Organum of automatic science may not quite yet be here, but is at least a vision that in the light of recent technological advances today appears plausible.

Conclusion

In this paper I have addressed the changing nature of the firm from the perspective of recent developments in information technology. I have argued that the old distinctions between tacit and explicit knowledge due to Polanyi break down when confronted with recent developments in machine learning technology, which simply treat tacit knowledge sources as unstructured data. These methods, in conjunction with new technologies ranging from web-scraping through to cloud application integration (iPaaS) and the rise of the reproducibility movement in science, are leading to increased automation of information production that has and is continuing to change the nature of the information supply chain. Automation is unlikely to be confined to the shop floor but will increasingly impact managerial tasks in business and the research world. The implications of this development have yet to be considered in any detail but are likely to be profound. I have tried to outline the broad trend of this development and embed it within the literature on knowledge and information management. One caveat is that much of this technology is very new and is evolving rapidly, so predicting future trends is somewhat difficult. However, workflow automation is presenting a strong signal that it may be the next major trend in IT, which will impact business and academia in the same way that it has begun to impact some sectors of the research industry.

These developments suggest a number of future research directions. Firstly there is increasingly a need for operations managers to become aware of how automation of information workflows can enhance operational efficiency. There is a need for further research at the interface of operations management and information management with a focus on automation of information workflows; in both academia and business the importance of these new developments appears to be underappreciated. The buzzwords of today are concerned with big data, cloud computing, robotics and digital transformation, but none of these terms adequately cover the automation of information workflows that has been quietly occurring for a number of years but has largely gone unnoticed.

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