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ARTICLE

Knowledge Flows and Industrial Clusters: Assessing the Sources of Competitive Advantage in Two English Regions

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How knowledge is created, accessed, stored and disseminated has become a major focus of study when assessing the success or failure of industrial clusters. Marshall (1890; 225) initiated this debate when he noted: 'The mysteries of the trade become no mysteries; but are as it were in the air'. In the edited collection by Wilson, Corker and Lane (2022), emphasis has been placed on the links between knowledge, knowledge flows and how innovation systems evolve and adapt. This paper builds on their work examining how tacit and codified knowledge is created and disseminated across a cluster. Bathelt et al (2004) have demonstrated how successful clusters build effective 'global pipelines' to access knowledge generated elsewhere, prompting us to think how a business history analysis can incorporate these concepts and how these processes have worked in practice. The paper analyses two English clusters and the processes involved in the formation of a common body of knowledge, a 'knowledge-cum-industrial zeitgeist' which explains the cluster's performance. Specifically, it proposes a model that links internally-generated knowledge and 'global pipelines' that clusters develop to tap into externally-generated knowledge, which through effective feedback into the 'local buzz' results in further innovation and strengthens the cluster's competitive advantage.

Keywords: industrial districts; steel; pottery; competitive advantage

Among the many aspects of a voluminous literature on industrial clusters, it is a well-established view that the ways in which knowledge is created, accessed, stored, and disseminated is a major focus of study when assessing the success or failure of this form of economic activity. Curado even claimed that, in the twentieth-first century, instead of the classical production factors of land, labor, and capital, knowledge is the key driver of economic behavior that has become "the critical dimension in the sustainability of competitive

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advantage."[1] Drucker earlier wrote authoritatively about the emergence of a "knowledge society," arguing that knowledge was becoming such an increasingly important feature of society that businesses needed to adapt their innovation processes.[2] At the same time, although these views might well be regarded as highly credible, in downplaying the role of knowledge in earlier eras they fail to accommodate what was clearly a key factor in the development of industrial clusters since the mid-eighteenth century. As Jacob noted of the late eighteenth and early nineteenth centuries, the interaction of both local and foreign knowledge in innovative activities was a key feature of the way in which competitive advantage was achieved.[3] This paper builds on the collection edited by Wilson, Corker, and Lane, which established through close studies of ten historical clusters in the United Kingdom the relationship between knowledge generation, dissemination, innovation, and sustainability over the long run.[4] By further developing these themes, the paper provides a historical perspective to the debate about the role of knowledge, utilizing two case studies to demonstrate that its importance is not necessarily just a contemporary phenomenon.

In demonstrating this important point, we will delve deeper into Marshall's famous dictum that: "The mysteries of the trade become no mysteries; but are as it were in the air,"[5] This analysis will draw on the well-trodden debate concerning the differences between tacit and codified knowledge, highlighting in particular Gourlay's insights into the links between knowledge and behavior.[6] In addition, we will incorporate the work of economic geographers on what has been termed "buzz" to denote how knowledge is created and disseminated across a cluster.[7] Bathelt et al. have demonstrated how the most successful clusters built effective "global pipelines" to access knowledge generated elsewhere, prompting us to think how a business history approach can incorporate such concepts into a detailed analysis of how those processes worked in practice.[8] This will provide us with a more appropriate understanding of how the creation and transmission of knowledge in a cluster can act as a source of competitive advantage and lead to improved performance of both individual firms and the cluster as a whole.

Linked with this issue, we shall examine the processes at play in the formation of a common body of knowledge, resulting in what can be termed a "knowledge-cum-industrial zeitgeist" that explains the cluster's performance.[9] We use this term to represent two aspects of knowledge in a cluster: firstly, to represent the common knowledge at any moment in time held by actors in a cluster and, secondly, to represent how this knowledge is changing, evolving, and being transmitted between actors on a continuous basis. As new knowledge about production, technology, market trends, and so forth is brought into a cluster, knowledge deemed obsolete and outdated is removed in a constant process of renewal related to the decisions regarding what knowledge is important to a cluster, its industries, its firms, and all its associated actors.

1. Curado, *Knowledge.*
2. Drucker, *Age of Discontinuity.*
3. Jacob, *The First Knowledge Economy.*
4. Wilson et. al. (eds), *Industrial Clusters.*
5. Marshall, *Principles of Economics,* 225.
6. Gourlay, "Conceptualizing Knowledge Creation."
7. Storper and Venables, "Buzz."
8. Bathelt, Malmberg, and Maskell, "Clusters and Knowledge."
9. Wilson et. al. (eds), *Industrial Clusters,* 267.

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To achieve these aims, two English case studies will be analyzed, the North Staffordshire Potteries and Sheffield steel. Although each is set in different time periods, it is possible to derive generalizations from the source material available. We acknowledge that undertaking research on industrial clusters is often a lengthy process, requiring the integration of a diverse range of sources from surviving business records of firms, individuals, records of other actors in a cluster such as educational or inter-business institutions, and official documents such as patent records. Each case study presented here represents as immersive exploration of sources and material on both Staffordshire and Sheffield that allows researchers to read with and against the documents utilized to highlight connections between people, places, and events that may be missed or underrepresented by looking at case studies of individual firms or business leaders. The scope of the empirical material we present is the result of our archival explorations, the outcome of which is an ability to highlight not only firms, institutions, and other actors in clusters but the spaces between them and beyond the cluster where knowledge exchange can take place.

The cases represent two examples of industries that not only clustered within geographically bound areas, thus generating spatial proximity between actors, but also exhibit, as we will demonstrate, many of the features associated with relational proximity that facilitated the transfer of information between those actors.[10] Specifically, we have illustrated how knowledge generated within a cluster that is mostly regarded as tacit is linked with exogenous sources in order to achieve and sustain competitive advantage, with the knowledge-cum-industrial zeitgeist operating through a continuous feedback loop (see Figure 1). In addition to creating Figure 1, we have created Figure 2 by adapting Casson's depiction of the flow of information from a cluster to the metropolis and the rest of the world.[11] From these new diagrams, we can further demonstrate the ways that knowledge can be disseminated. As the discussion below will highlight, our conceptualization of knowledge, whether tacit or codified, is focused on scientific and technical knowledge, rather than market or commercial information as favored by Casson. By considering the case studies here through the lens of Figures 1 and 2, we hope to expand our understanding of how clusters gain competitive advantage. In our work, we are building on recent scholarship on industrial clusters that highlights the role global pipelines play in the transmission of knowledge into and across clusters,[12] the local and global connections that industrial clusters can form,[13] the positive role of local trade associations in industrial clusters,[14] and the role that national institutions can play in their development.[15] We are also focused here on the reasons behind the growth and development of clusters and the sources of competitive advantage, rather than the lifecycle of clusters over the very long run.[16]

10. Bathelt, "Buzz-and-Pipeline-Dynamics."

11. Casson, "Regional Business Networks," in *Industrial Clusters,* ed. Wilson and Popp, 38.

12. Fernández-Moya, "Creating Knowledge Networks"; Ville and Wright, "Buzz and Pipelines"; Bathelt, Malmberg, and Maskell, "Clusters and Knowledge."

13. Amdam and Bjarnar, "Globalization and the Development of Industrial Clusters."

14. Hashino and Kurosawa, "Beyond Marshallian Agglomeration Economies."

15. Spadavecchia, "Building Industrial Districts."

16. For a discussion of cluster lifecycles, see, for instance: Popp and Wilson, "Life Cycles"; Martin and Sunley, "Conceptualizing Cluster Evolution"; Charles, "The Evolution of Business Networks and Clusters," in *Industrial Clusters*, ed. Wilson et. al.

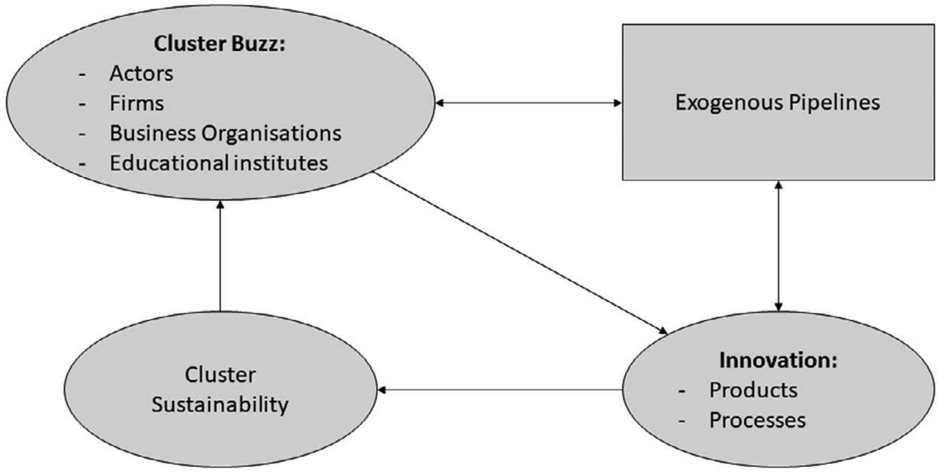

Figure 1. Knowledge flow and cluster sustainability.

From our historical perspective, this work can be reframed by highlighting the links between local buzz, global pipelines, and the processes of innovation within clusters, resulting in sustainable competitive advantage (see Figure 1). Although it might be obvious to note that the most successful clusters are clearly those that develop the ability to fashion these channels, while cluster failure can often be attributed to the neglect of these mechanisms, it is essential to analyze the patterns of causation to explain these developments. In developing a feedback model and presenting our case studies, we will contribute to this debate, extending the concepts used in economic geography to improve the ways in which business historians can approach the issues. The paper will start with a literature review focusing on the development of work on clusters and, in particular, that which prompts a focus on the agency of actors and their role in creating and disseminating knowledge across and between clusters. Although the literature on clusters is, of course, broad in both temporal and geographical coverage, this discussion will help to generate appropriate "scaffolding" to highlight the contribution of our case studies. By using historical cases, we can enhance our understanding of both the buzz and pipeline concepts beyond their origins in the economic geography field. This will be followed by an analysis of how this scaffolding can be applied to the two case studies, linking them as closely as possible to Figures 1 and 2. We will then provide some concluding thoughts aimed at sparking further debate about these issues, and demonstrating the synergies between contemporary and historical approaches to studying industrial clusters.

Literature Review and Scaffolding

We acknowledge there is body of literature on industrial clusters, which is broad both geographically and temporally, providing a wide range of possible avenues from which to begin to

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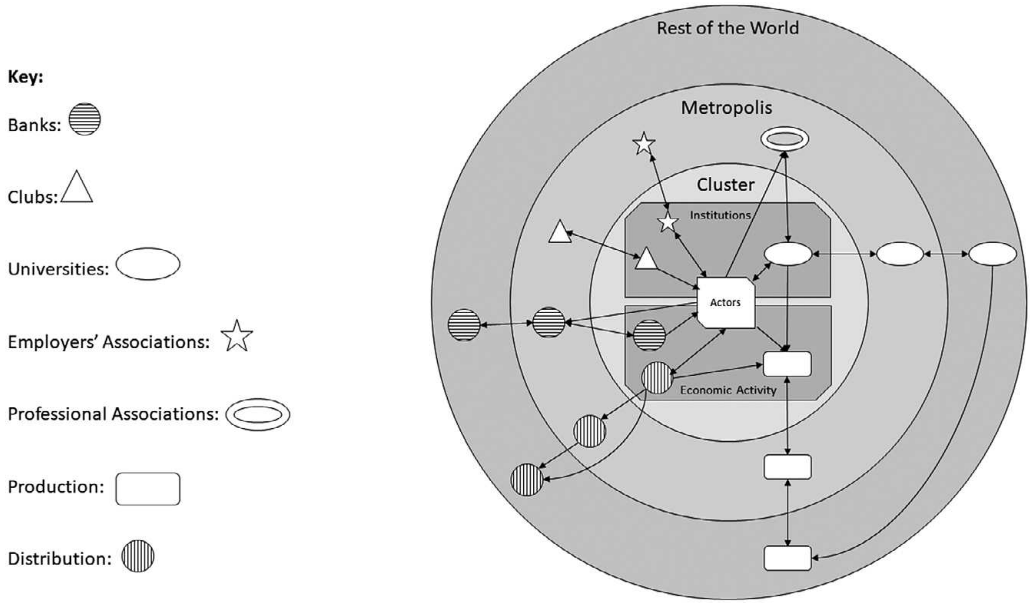

Figure 2. Cluster, national, and international links.

develop research and conceptualization in this area. The work of Charles[17] synthesized this to highlight issues related to economic agglomeration theory,[18] growth pole theory,[19] flexible specializations,[20] the California School with transactions costs theory,[21] the French led development of the innovative milieu,[22] innovation systems and learning regions,[23] and strategic management.[24] Given our historical focus on knowledge, we believe that a suitable starting point for our literature exploration is the work of Marshall. His work on conceptualizing industrial districts has proven remarkably persistent in conceptualizing clusters both historically and contemporaneously.[25] His original ideas have been adapted and applied in myriad ways, and so it is to his work that we turn first.

To explore the role of knowledge in the development of clusters, it is worthwhile extending the quotation from Marshall used earlier, which provides the basis for beginning to think about knowledge within the context of our case studies.

> When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from the near

17. Charles, "Evolution."
18. Marshall, *Principles.*
19. Peroux, "Note."
20. Piore and Sabel, *Second.*
21. Storper and Christopherson, "Flexible"; Scott, *Industrial.*
22. Aydalot and Keeble, *High Technology.*
23. Cooke, "Regional"; Rutten and Boekema, *Learning.*
24. Porter, *Competitive.*
25. Belussi and Caldari, "Origin."

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> neighbourhood to one another. The mysteries of the trade become no mysteries; but are as it were in the air and children learn many of them unconsciously. Good work is rightly appreciated, inventions and improvements in machinery, in processes and the general organisation of the business have their merits promptly discussed: if one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus becomes the source of further new ideas.[26]

Marshall here is describing the process of cluster formation: the activities that actors undertake in the pursuit of competitive advantage, which together create an environment that is worth more than the sum of its parts (the well-known Marshallian externalities). At its core, alongside these externalities is the cluster environment that will later be advanced in a variety of ways by scholars of industrial clusters over the twentieth and twenty-first centuries. As with our study, Marshall has remained influential and as the starting point for theorizing about (and critiquing) cluster dynamics. The 1980s saw a distinctly Italian perspective on clusters develop through the work of Brusco, Bagnasco and the concepts of the "Third Italy" or "Emilian model" used to describe the industrial environment in craft-based clusters of Northern Italy in the 1970s and 1980s.[27] These ideas built on Marshall's work and advanced a more dynamic theory of clusters pushing perspectives toward the agency of individuals and their social interactions alongside their economic activity. In more recent years Becattini pushed for a renewed focus on industrial districts and clusters, in what might be termed a neo-Marshallian model—again based on empirical observations of Northern Italy and emphasizing not only the original Marshallian covering not only externalities of economies of scale, knowledge spillovers, a thick market for specialized inputs, and the all-important industrial atmosphere but also the shared values, identity, and cooperative competition exhibited by actors in these regions.[28] Again, the development of scholarly approaches to clusters pushes our focus toward the agency of actors within them, their behavior, decision making, and dynamism.

For Marshall, knowledge was something that existed around and between actors in industrial clusters—it was the context in which business activity was undertaken and it was something that became embedded in the environment. To fully understand these processes and to further develop the ways in which knowledge specifically can act as a source of competitive advantage within historical clusters, we must therefore first consider knowledge itself because this too is subject to different interpretations and applications.

The eminent philosopher Polanyi[29] was the first to note that differences existed between tacit and codified knowledge, providing Nonaka and Takeuchi with a terminology to explain innovation processes in Japanese firms and thus pioneering the application of knowledge studies to the business context.[30] Gourlay, on the other hand, not only offered a detailed critique of the terminology used by Nonaka and Takeuchi, accusing them of misinterpreting Polanyi's definition of tacit knowledge, but also offers fresh insights into the process of

26. Marshall, *Principles*, 225.
27. Bianchini, "The Third Italy"; Brusco, "The Emilian Model"; "The Idea of the Industrial District," in *Industrial Districts*, ed. Pyke, Becattini, and Sengenberger.
28. Becattini, *Industrial Districts*; Zeitlin, "Industrial Districts and Local Economic Regeneration."
29. Polanyi, *Personal Knowledge*; *Tacit Dimension.*
30. Nonaka and Takeuchi, *Knowledge Creating.*

knowledge management.[31] Specifically, while acknowledging that Polanyi's "phrasing is sometimes ambiguous," Gourlay emphasizes that, to the philosopher knowledge is "a process, 'knowing,' not an object."[32] This highlights for us the importance of behavior alongside a body of knowledge and the ways in which actors in a cluster link tacit and codified knowledge to generate competitive advantage. As Evers noted, facilitating the transfer of tacit knowledge is consequently one of the most difficult aspects of knowledge management, given that this type of knowledge is inherently personal, being very much a feature of an individual's skillset.[33]

The definitions explored so far are important, whether based on binary interpretations in the familiar tacit/codified sense or typologies of knowledge that encompass a broader spectrum of "types," dependent on their context and use.[34] Crucially, we acknowledge what Gourlay claims when concluding a survey of this literature, in that "it seems useful to regard the two forms of knowledge as consequences (and also, to a degree, components) of two general modes of behavior. Knowledge, on this account, is, and can perhaps only be, managed indirectly, through managing behavior."[35] These distinctions are important because they influence how we perceive knowledge creation and dissemination in the past between and across time and space. For instance, at one end of the spectrum, knowledge is learned and understood by means of acquiring and absorbing new information, either consciously through didactic instruction or informally through contextual and experiential learning mechanisms. At the other end are those channels, institutions, and organizations that provide both the scaffolding for this transfer into and across a cluster for instance and creating new knowledge themselves within the cluster.

Building on these useful insights, it is consequently clear that, as Schoonmaker and Carayannis note, the growth of a cluster will be contingent on its access to intellectual property and effectively managing the behavior of key actors.[36] Storper and Venables refer to this as the "buzz" in a local environment, highlighting how: "Individuals in a buzz environment interact and cooperate with other high ability people, are well placed to communicate complex ideas with them, and are highly motivated…It is unsurprising that people in a buzz environment should be highly productive."[37] At the same time, while accepting the vital importance of buzz, Bathelt et al. argue that to be consistently successful a cluster needs to be linked to "pipelines between the cluster and distant sites of knowledge."[38] There exists, then, a symbiotic relationship between knowledge exchange within a cluster (buzz), and knowledge flows into the cluster (pipelines): The more pipelines are pursued by firms and actors within a cluster, the richer and more dynamic the buzz becomes. This extends what we noted earlier as the scaffolding that facilitates the movement of knowledge from being an internalized structure to one that requires extensive links to those institutions and firms that possess knowledge that is complementary to that which exists in the cluster. As Bathelt et al. imply, clusters cannot operate over the long term in isolation from what is happening technologically

31. Gourlay, "Conceptualizing."
32. Ibid., 1422.
33. Evers, *Knowledge Hubs.*
34. Gourlay, "Conceptualizing," 1426.
35. Ibid., 1431.
36. Schoonmaker and Carayannis, "Regional Innovation Networks."
37. Storper and Venables, "Buzz," 24.
38. Bathelt, Malmberg, and Maskell, "Clusters and Knowledge."

in other parts of the world. Importantly, they argue that, where buzz and pipelines reinforce one another, both tacit and codified knowledge can more readily be exchanged.[39] This is particularly pertinent to our case studies where knowledge of both types at the cutting edge of the respective industries was being developed and applied and where new and improved products and processes were continually evolving.

Our first contribution to approaches to cluster studies is to incorporate the ideas of both Storper and Venables and Bathelt et al. and to create Figure 1 to visualize the links between the buzz in a cluster, innovation, and cluster sustainability. Because we are analyzing historical clusters, rather than the terminology "global pipelines" drawn from contemporary cluster studies, we refer simply to "pipelines" that clusters and the actors within them built and exploited. We define pipelines as communication channels, formal or informal, that extend beyond the boundaries of the cluster to reach bodies of potentially useful knowledge existing elsewhere.[40] These act as channels for information and knowledge to flow directly into and out of the buzz and innovation activities of a cluster. Our model as shown in Figure 1 presents this as a continuous process that feeds into the cluster's sustainability and innovation processes, adding to the dynamism inherent in this form of economic organization. This highlights the vital importance for entrepreneurs and firms within clusters to ensure that they integrate effectively into this flow of knowledge as they develop both new products and appropriate production processes. It is also clear that sustainability is dependent on this process because without innovation it is difficult to see how the cluster can continue to flourish. Overall, Figure 1 incorporates Marshall's original emphasis on knowledge as something that is "in the air" and extends this to highlight the relevance of contemporary economic geography insights for historical study: namely, the importance of the behavior of actors within the cluster in managing knowledge through, for example, the creation of pipelines that connect both to the buzz and to the knowledge-cum-industrial zeitgeist of that cluster. Our cases allow us to explore this empirically as well as conceptually.

Having created this diagram, we also recognize that it provides only limited insights into the scaffolding that represents the different organizations and actors that contributed to the flow of knowledge. Our second contribution, therefore, is to complement Figure 1 by creating Figure 2, adapting a diagram devised by Casson in which he represents the flow of information across and between a cluster, the wider "metropolis" and the "rest of the world."[41] We have placed actors at the center of our diagram to represent both the role they play in the continued development of buzz and a knowledge-cum-industrial zeitgeist in a cluster and their role in building and maintaining pipelines into and out of the cluster. The outer layers of the diagram also demonstrate that pipelines develop not only between firms but also between other institutions connected with the cluster.

Figure 2 consequently presents a fuller picture of the key components of a cluster, as well as how they develop external relationships that add to the buzz and contribute to innovation and sustainability and the competitive advantage of a cluster. It serves, then, as a useful framework

39. Ibid.
40. Ibid.
41. Casson, "Regional Business Networks," 38.

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for synthesizing contemporary and historical approaches to clusters, bringing the concerns of business history and economic geography together.

Before moving onto providing empirical evidence to demonstrate how Figures 1 and 2 work in practice, a final issue relating to the cluster is the manner in which these processes are managed and controlled. As Popp, Toms, and Wilson note: "The importance of the interaction of governance arrangements and resource distribution might be most acute in relation to intangible assets, particularly those 'untraded interdependencies' described as attaching to 'the process of economic and organizational learning and coordination.'"[42] These insights were based on applying the resource-based view of the firm to cluster dynamics in which firm-specific factors are traditionally considered as the major drivers of strategic change. At the same time, they also recognized that social scientists have developed a knowledge-based view (KBV) of the firm, giving knowledge a prime position as a firm's most important strategic resource.[43] This returns us to the earlier point that as knowledge is inherently the property of an individual, firms need to develop ways of effectively building processes that allow it to flow into the firm and generate improvements to either products or processes. As Lindsay notes, it is consequently essential to study the dynamic interplay between individuals, communities of practice, and firms (or even whole industries) to understand the reasons for success or failure.[44] Marshall's "mysteries of the trade" cannot be left to rhetorical expositions; it is vital to examine the empirical data and operationalize Figures 1 and 2.

Pipelines to Knowledge in an Early Cluster: The Potteries

The North Staffordshire Potteries is a case in which knowledge flows and transfer operated in a different institutional and historical context. This context is important for the study of clusters because the densely populated earthenware cluster was one of the earliest and longest lasting industrial clusters in the United Kingdom, having emerged as the center for national production by the mid-to-late eighteenth century and retaining this dominance until the late twentieth century.[45] Textile production in one of the most well-known industrial clusters in Lancashire experienced industrialization proper during the late eighteenth century with the introduction of machinery and engineering prowess.[46] Production of pottery, however, remained a craft-based and knowledge-intensive industry until the late nineteenth century, when mechanization proper arrived in the production stage after decades of experimentation.[47] Knowledge, experimentation, and practical expertise in the hands and minds of potters remained crucial to competitive advantage in a cluster that experienced substantial turnover of partnerships and producers.[48] In contrast to Sheffield and its long history of the cutler's

42. Popp et. al., "Industrial Districts as Organizational Environments," 357.

43. Grant, "Knowledge-Based Theory."

44. Lindsay, "Development."

45. Weatherill, *The Growth of the Pottery Industry in England 1660–1815*, 440–453; Lane, "Secrets for Sale?" 862.

46. Cookson, *The Age of Machinery.*

47. Lamb, "The Press and Labour Response"; Lane, "Secrets."

48. Lane, "The Trees of the Forest."

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guild, the industry developed without such a formal institution or codified trade rules governing access, training, and skill development in the workforce. The cluster witnessed few attempts to organize formal training, skill development, or R&D during the eighteenth and nineteenth centuries, some of which were extremely short-lived or failed to even come to fruition: The Pottery Philosophical Society, for example, was launched in 1819 but only lasted until 1835, with questions remaining over its performance or utility after the first six or seven years of its existence.[49] A group of potters also tried to form a collective R&D company in 1775, but this failed to materialize.[50] Indeed, Casson and Dodgson highlight the difficulty within the region of collaborative training and knowledge production.[51] We know from surviving business records of larger companies that there were large numbers of apprentices living and working in the region, but we know little about how these apprenticeships worked in practice.[52] Despite the importance of apprenticeship for acquiring and transferring tacit and explicit knowledge in the industry, documentary evidence is scant in official records, given the informal approach taken by the industry at large. This issue continued well into the middle of the nineteenth century and was exacerbated by a reluctance on the part of potters to indenture formally their apprentices (who numbered some 5,000 in 1853, according to Chamber of Commerce estimates) due to the stamp duty costs.[53]

Viewing the cluster through the lenses of Figures 1 and 2, however, allows us to illuminate a cluster that was influenced by some of the tensions and phenomena highlighted in the literature review and shown in the diagrams. In this case, the letters of Josiah Wedgwood I (1730–1795) and business records held by the Wedgwood Museum archives allow us to examine closely specific knowledge flows through pipelines into the potter's company and beyond through the buzz of the cluster. The business communications and records reveal his position along several pipelines (see Figure 1), as well as the importance for the industry-at-large of his well-known membership of the Lunar Society—a "club" in Figure 2. This membership also reveals the fragility of the feedback model and highlights the need for constant management and reciprocity along the pipeline for potential knowledge transfer to be converted into realized transfer.

The Wedgwood family is undoubtedly one of the most famous names associated with pottery production in England from the eighteenth century to the present day: The company founded by Josiah Wedgwood I in 1759 still operates as a producer of luxury and prestige earthenware based on traditions of artisanship and skill, the numerous ownership changes of the last few decades notwithstanding.[54] The Master Potter's rise to prominence is well-known in terms of his business acumen, partnership with Thomas Bentley, skill at the potter's wheel,

49. Shapin, "The Pottery Philosophical Society."

50. Lane, "Knowledge."

51. Casson and Dodgson, "Designing," 270.

52. For example: see Josiah Wedgwood's "Common Place Book" for June 1790 where a figure of sixty apprentices across various production processes is listed. This is considerable; they formed part of a workforce of 306 across both useful and ornamental ware factories. British Library Manuscripts, *Add MS 71093 ff 50.*

53. An example of discussions concerning the informal approach to apprenticeship taken in the industry given the lack of formal guild legacy can be found in: *Staffordshire Advertiser*, 9 January 1847, 5.

54. For two of the most recent ownership transitions of "Waterford Wedgwood," in the wake of their collapse into administration in 2009, see Arnold, "Waterford Wedgwood to Hasten Overseas Production"; Brown, "Waterford Wedgwood Royal Doulton Sold to Finnish Group for $437m."

and his position as a key influence on the social and economic developments of eighteenth-century society.[55] He is also known as an incredibly well-connected inventor and innovator, writing thousands of letters to business partners, merchants in England, Europe, and North America, influencing and drawing influence from aristocracy, socialites, and contemporary thinkers alike. His social and business networks extended far beyond the concentrated industrial cluster of North Staffordshire and served as conduits of knowledge transfer, as well as trade routes and sources of access to specific raw materials required to produce the high-quality wares that quickly became associated with the region in the second half of the eighteenth century. The pipelines extending to and from the potter varied in their utility and function, but all were actively managed, maintained, and served the purpose of bringing new and useful information closer to the immediate realm of production (the cluster). Some of these pipelines served the individual more than the cluster at large, but others, as the discussion will show, fed into and spread across the buzz of the cluster, contributing to the innovative prowess and success of the industry over the long term.

For instance, Wedgwood and his business partner, Thomas Bentley, built and maintained a substantial pipeline in the 1770s for commercially useful knowledge transfer between the pair's Greek Street showroom in Soho, London, and the manufactories of Burslem, Staffordshire. Through daily letters and communication, Bentley was able to keep Wedgwood alert to the changing fashions and demand of the high-profile visitors to the showroom, with Wedgwood adjusting production and design direction in response to this near-constant flow of information. Blaszczyk frames this relationship as part of a network of "fashion intermediaries," with key individuals forging connections between the spheres of producers and consumers (or supply and demand).[56] In this case, Bentley acts as the intermediary allowing Wedgwood to gain the upper hand over his competitors with as close to real-time market insight as eighteenth-century communication methods would allow. In the context of Figure 1, this pipeline brought innovation into the cluster that for a short period would render Wedgwood the first mover. As we will indicate with regard to the case of Jasperware discussed below, however, this position was later eroded by imitation.

Wedgwood also built knowledge pipelines between Staffordshire and the east coast of North America, for instance, to gain information about and access to new raw materials and clays found in Pensacola, modern day Florida. In November 1766, he wrote to Bentley:

> I am of opinion with you that the Pensacola Clay is better worth attention than the Cherokee, for the reasons you mention, & do not think the price extravagant, or too high to answer for manufacturing here[57]

Not only were his wares being sold across the globe, but he also utilized these commercial and personal connections to initiate the flow of market- and production-related knowledge into the

55. Blaszczyk, *Imagining Consumers*; McKendrick, "Josiah Wedgwood"; "Josiah Wedgwood and Thomas Bentley"; Reilly, *Josiah Wedgwood.*

56. Blaszczyk, *Imagining Consumers,* 12.

57. Josiah Wedgwood to Thomas Bentley, 17 November 1766, Wedgwood MS, 25/18133, Wedgwood Museum Archives.

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cluster. This was also not a unique activity, as other potters in England were searching further afield for raw materials for the purpose of innovation. Since the 1740s, English potters and porcelain makers had been experimenting with a clay known as unaker, or "Cherokee," clay (mentioned in the above letter), and in 1744 two potters at Bow porcelain factory—Edward Heylyn and Thomas Frye—filed a patent attempting to prevent others from using this material from North America.[58]

Wedgwood was unique, however, in the depth and sustained management of exogenous knowledge pipelines. His personal, commercial, and social network connections actively sought out knowledge derived and created in other regions and industries. Like other innovators of his time, he knew the importance of acquiring new knowledge and experience from external sources, in particular through connections to individuals who acted as bridges (or pipelines) between different industrial, regional, and knowledge contexts. Of particular importance were pipelines that allowed for access to deep experiential and tacit knowledge that Wedgwood himself could not develop yet could benefit from—the knowledge, for instance, both tacit and codified, of experimental chemistry that could be generated or acquired only through a career in the field. For instance, Alexander Chisholm served as the potter's experimental and technical assistant, as well as tutor to his children from 1781 until 1795, having previously worked as mechanical and scientific assistant to the experimental chemist William Lewis. Chisholm's impact on Wedgwood's development of new wares and colored glazes was substantive, not least because of the specific experience and knowledge of experimental chemistry he brought with him but also practically because many of the entries in Wedgwood's Commonplace Books were in Chisholm's hand.[59] To use Burt's terminology on structural holes between groups, Chisholm acted as a knowledge broker for Wedgwood (and by extension, the cluster) by bridging the structural gap between Lewis's experimental chemistry and Wedgwood's application of experimentation and scientific discovery to the production of earthenware.[60]

A similar pipeline extended out of the cluster from Wedgwood to a different knowledge base, that of chemist, geologist, and fellow member of the Lunar Society, James Keir (1735–1820). The pair were also contemporaneous members of the Chapter Coffee House Society and Royal Society.[61] These memberships can be viewed as "clubs" in Figure 2 and served to bring together two disparate yet connected fields of endeavor. Keir acted as the knowledge broker between Wedgwood and a specific set of relevant and useful scientific knowledge developed in the production of glass that proved instrumental in overcoming obstacles the potter encountered in developing his famous Jasperware—bold pieces composed of a body of one color, most commonly pale blue, green, and black, with scenes or portraits depicted in bas-relief.[62] The innovation of Jasperware was a major development in body composition of earthenware in the eighteenth century and was so successful that Wedgwood's Jasperware imitation of the cameo-glass "Portland Vase," thought to have been produced near Rome around AD 5–25, was

58. Woodcroft, *Patents for Inventions*, 6; Ramsay and Ramsay, "A Classification"; Lane, "Secrets."
59. Stewart, "Assistants to Enlightenment"; Reilly, *Josiah Wedgwood*, 315.
60. On structural holes and knowledge brokers see, Burt, "Structural Holes and Good Ideas."
61. Levere and L'e Turner, *Discussing Chemistry*; Schofield, "Industrial Orientation."
62. McConnell, *Survey.*

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advertised and displayed at ticketed events in London and across Europe in the 1790s.[63] Alongside other notable developments such as the hard-paste porcelain problem of the 1760s–1780s, finally cracked by the *New Hall Porcelain Company* (est. 1781), and the "majolica mania" that Minton & Co.'s prompted in 1851 with their invention of an elegant yet affordable earthenware, Jasperware remains one of the most recognizable and important ceramic innovations since 1750.[64]

The useful knowledge Wedgwood acquired lay in two areas. Firstly, there was Keir's understanding of flint glass, which could be used in place of ground down regular glass, as a raw material in the production of earthenware glazing frits. The use of this raw material helped reduce the presence of cracks and veinlike tensions in glazes, an imperfection known as "crazing." The second key insight brought into the cluster through this pipeline in 1776 was the process of annealing, a method of controlling the cooling of earthenware in a similar fashion to glass production. It was this latter process that helped Wedgwood develop his iconic Jasperware, the body of which required precise temperature control throughout the firing stages and proved a key innovation.[65] The pipeline of useful knowledge was intended to flow both ways, as Wedgwood endeavored to use his experimental facilities at his Etruria works to help Keir solve a similar type of problem, namely, the appearance of strata, or imperfections, in glass that made it unsuitable for use as an optical lens. After working for years on the problem (alongside perfecting Jasperware), by 1783 Wedgwood had produced a fourteen-page paper with his solution based on differences in the specific gravities of glass at different levels in the melting pot and their susceptibility to striation. The paper, held in fragments by the Wedgwood Archives and published in composite by Schofield in 1962, contains several passages demonstrating not only Wedgwood's understanding of his own abilities and role in driving innovation through experimentation but also his expectation that producing new knowledge in one field and applying it in another can not only help solve technical problems but also open the gates to transfer that knowledge beyond its original home context.

For instance, in relation to striation in glass Wedgwood is clear that "it is experiment alone which must determine by what process this can best be accomplished": experimentation that was both laborious and expensive but something he was uniquely placed to undertake with his knowledge of chemistry and glazes and the experimental resources available to him in his factories and workshops.[66] The potter's concluding remarks are also revealing because they highlight his awareness of the importance of not only solving a technological bottleneck but in also highlighting that the knowledge then spreads and is applied elsewhere.

> Many other, and probably much better methods, may hereafter be thought of by persons of greater leisure & more conversant in the art than I am. If I had the power of conveying to the practical glass-maker the same degree of conviction I am possessed of myself, that for attaining the desired end he has only this single object to pursue, lengthening the cords in his glass

63. Keynes, "The Portland Vase"; McKendrick, "Commercialization."
64. Holgate, *New Hall*; Weber et. al. (eds), *Majolica Mania.*
65. Schofield, "Josiah Wedgwood"; Casson and Dodgson, "Designing," 258.
66. Schofield, 294.

> as we do ours in clay; I should not have a doubt of seeing all apparent difficulties soon surmounted, and the important discovery happily accomplished in its full extent.[67]

Wedgwood was also acutely aware of the process of innovation in terms of what would now be considered sunk costs:

> for though the first discovery of a principle upon which this great work is to be completed may be attended with much expence & trouble, yet the principle being once ascertain'd there is great reason to hope that in this instance as in many others time & experience may point out the means of producing the desired effect upon easier terms.[68]

In the event, the paper was never publicly presented, and Keir himself "lost his direct interest" in glass production, selling his factory and thus shutting down the pipeline and the chance of the knowledge being transferred elsewhere.[69]

The pipeline between Wedgwood and Keir is important for several reasons. Firstly, it had a profound impact on the development of earthenware in North Staffordshire more broadly because potters in the cluster sought to imitate and replicate Wedgwood's Jasperware in the last quarter of the eighteenth century, thus prompting further innovation and experimentation. From the middle of the 1780s, James Neale & Co., Turner & Co., and William Adams & Sons Ltd. were all producing high-quality Jasperware pieces in the style of Wedgwood. By the first decade of the nineteenth century, after the death of Josiah Wedgwood I, potters such as Thomas and John Hollins of Hanley and David Wilson & Sons also of Hanley were experimenting with reversing the traditional white relief on a colored background to produce blue figures in relief on a white jasper background.[70] By the early nineteenth century, then, the skills and knowledge required to produce Jasperware became part of a common body of knowledge among many producers in the cluster, becoming elements of the evolving knowledge-cum-industrial zeitgeist that supported the cluster over the long term. In this sense, the codification of knowledge happened in one business and spread out across the cluster because of the tacit knowledge and understanding of competing potters pushing at the edges of innovation.

The pipeline is also important because the failure to transmit knowledge in both directions arguably retarded the growth and development of English glass production for over half a century. Wedgwood had discovered in 1783 that flint glass could be prepared for use as optical glass by agitating to produce a more homogenous product, thereby removing strata. This was also independently discovered in 1798 in Switzerland, for the benefit of the German optical industry, and did not make its way back to commercial use in England until 1848. Fiscal policies around glass production and excise duties complicated attempts to apply the knowledge by others, despite the domestic solution found by Wedgwood and recorded in detail in

67. Ibid., 295.
68. Ibid.
69. Ibid., 286.
70. Physical specimens of these imitation Jasperwares are held and cataloged in the V&A ceramics collection available through the museum website, "Ceramics," Victoria & Albert Museum, accessed August 9 2022, https://www.vam.ac.uk/collections/ceramics.

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his finished, yet unpresented, paper.[71] The feedback model built around a pipeline as shown in Figure 1, then, requires active management to retain its utility and function—the realization of the potential for subsequent innovation in glass production was delayed by decades in England once the pipeline was severed.

The episodes discussed above highlight the need for context in knowledge transfer both into and out of an industrial cluster. Certainly, the pipelines during the eighteenth century were not as "global" as those highlighted by Bathelt or indeed the other case in this paper. At the same time, it is clear that they extended beyond the boundaries of the Potteries region and served the purpose of connecting to knowledge generated elsewhere with the express purpose of bringing new knowledge into the cluster to stimulate or support product and process innovation, as shown in Figure 1.[72] This knowledge was then absorbed over time by the cluster. In these examples, it was done first within Josiah Wedgwood's factory and in the following years across the cluster to other firms. While it is, of course, difficult to demonstrate the flow of this knowledge across firms during the late eighteenth and early nineteenth century, we can turn to the physical artifacts left behind and preserved in museum collections or registered in collectors' encyclopedias and dictionaries of makers' marks. We must rely on the embodied knowledge within the products and firms of North Staffordshire, which by virtue of their existence demonstrate that this knowledge had traveled, albeit locally.[73] The critical element in its dissemination was the expertise and existing knowledge of those potters who, when faced with new information, were able either through experimentation or tacit understanding to apply it to a useful end. Thus, a key element in the evolution of an early cluster is the generation and acquisition of new knowledge from inside and outside the cluster. When this knowledge supports key innovations or first movers, as in the case of Josiah Wedgwood, we see how the buzz, or dynamic interplay between individuals, businesses, and the cluster in the creation and transmission of knowledge, can improve performance not only of the lead firms but also of the cluster as a whole.

Pipelines and Buzz in Nickel-Chromium Steels: Sheffield 1890s-1920s

Research on the Sheffield steel industry has highlighted both how the cluster was central to a transnational innovation system focused on armaments[74] and as a localized innovation and knowledge system with layers of both formal and informal networks that facilitated the transmission of new innovations such as stainless steel.[75] However, consideration needs to be given to how pipelines, the local knowledge-cum-industrial zeitgeist, and buzz interacted and provided benefits for the cluster, particularly when considering steel alloys containing nickel and chromium. From the 1890s through to the 1920s, progressive experimental work on nickel–chromium steels became the guiding force of the cluster, beginning with work in

71. Schofield, "Josiah Wedgwood," 295–296.
72. Bathelt, Malmberg, and Maskell, "Clusters and Knowledge."
73. Lane, "Secrets."
74. Corker, *Business and Technology.*
75. Corker, "Sheffield Innovation System," in *Industrial clusters*, ed. Wilson et. Al.

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research facilities, evolving to become core to the development of armaments in Sheffield, the invention of stainless steel, and ultimately the remaking of the cluster as stainless products took over from cutlery as the staple industry. Central to understanding this change in the cluster are two interrelated factors: the development of local knowledge related to metallurgy and Sheffield's important links to two other metalworking districts, Pittsburgh in the United States via the Firth-Sterling Steel Company and Essen in Germany with the Krupp company.

The prominent metallurgist and business leader, Robert Abbott Hadfield (1858–1940) pioneered the commercial production of alloy steels in the late-1880s and continued to work on the alloying of other elements into the 1890s. His investigations in 1892 into steels containing high proportions of chromium added to their metallurgical knowledge, the principles of which would later be applied to armaments. This research was often presented at societies for public consumption and protected by patents. By 1920, lists in the Hadfields company archives show 156 patents taken out by Hadfield and the records of over 100 speeches and addresses given by the metallurgist, including some in the United States.[76] Hadfield also had a vast network of metallurgical contacts across the world. In his 1925 book *Metallurgy and Its Influence on Modern Progress*, a section entitled "Illustrating the Ramifications of International Cooperation" revealed that that in the period 1878–1924 Hadfield supplied "specimens, particulars, and technical information relating to his various steels, also other metallurgical data of scientific and technical character" to 156 people in Great Britain (many beyond Sheffield), sixty-eight people in America (including Andrew Carnegie and Thomas Edison), thirty people in France, five in Sweden, eight in Germany, and a further seven across Italy, Russia, Spain, Japan, and Holland.[77] In addition to the commercial connections and pipelines Hadfield would later develop, he was also able to create his own pipelines across the globe for sharing knowledge and information, connecting himself with individuals at both the 'metropolis' and "rest of the world" levels of Figure 2, while contributing to the local metallurgical buzz of Sheffield as highlighted in Figure 1.

The use of nickel–chromium steel for armor production was introduced to Sheffield in 1894, via a license from Krupp of Essen for their Krupp Cemented armor, which contained 4 percent nickel and 2 percent chromium.[78] Quickly, the three Sheffield armor manufacturers, (Brown, Cammell, and Vickers) established production facilities, benefitting significantly from having access to technical advice from Krupp as required.[79] A clause in the Krupp license required any licensees to communicate any improvements they made in the manufacture of the armor back to the inventor.[80] These agreements highlight the connections between two "production" facilities in Figure 2, connecting the local to the rest of the world via a two-way knowledge exchange, ultimately to the benefit of both the Sheffield and Essen industrial clusters. The use of nickel–chromium steel for armaments soon spread further in Sheffield, and in 1897 Hadfield patented a nickel–chromium steel alloy for use with

76. Hadfield Presidential Addresses, MNHD/579 and Hadfield Patents 1881–1949, MNHD/747, Kelham Island Industrial Museum Archive.

77. Hadfield, *Metallurgy*, 361–364.

78. Stacey, *Naval Armour*.

79. Tweedale, *Steel City*, 102; Grant, *Steel and Ships*, 36.

80. *Vickers News*, 15 November 1919, 80–83; Scott, *Vickers*, 47–48.

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projectiles.[81] The alloy, containing 2 percent nickel and 2 percent chromium, was later marketed as Hadfields' special 2/2 nickel–chromium steel. Hadfield would license his "system" of manufacturing directly to Krupp in 1898 for a period of twelve years, a license that was renewed in 1912 for a further six years.[82] The license covered projectile manufacture and manganese steel production, including all associated patents, technological knowledge, and information.[83]

The pipeline between Sheffield and Essen demonstrated a reciprocal relationship regarding the use of nickel–chromium steels in armaments manufacture, further demonstrating how Figure 2 was operationalized. From 1900, Hadfield also licensed their method of projectile manufacture to Firth, another Sheffield projectile manufacturer, spreading knowledge of nickel–chromium steels across the cluster, and thereby enhancing cluster buzz as highlighted in Figure 1. In addition to their connection to the local knowledge-cum-industrial zeitgeist of metallurgical knowledge, Firth also had an established pipeline with the United States. In 1896, Firth obtained the controlling interest in the Wheeler Sterling Steel Company, based in Pittsburgh, Pennsylvania, to manufacture projectiles and tool steel in the United States, renaming it the Firth-Sterling Steel Company.[84] A key feature of the connection between Firth and Firth-Sterling was related to armor-piercing projectile technologies, the two companies exchanging technical details and patents in these areas prior to the Great War, replicating a connection between the local cluster and another part of the world, as demonstrated in Figure 2.[85]

Training and education in Sheffield continued a long tradition of passing knowledge to the next generation of workers and sustaining the local knowledge-cum-industrial zeitgeist. The surviving archival records and official history of the Company of Cutlers in Hallamshire, a guild established in 1624 for the regulation of local metal trades, recorded 28,500 apprenticeships and freedoms undertaken in Sheffield and the surrounding area from 1624 to 1814.[86] Toward the end of the nineteenth century, there also developed in-house provision for steel company workers to be trained in the methods of their employers.[87] Building on this tradition, during the Edwardian period university education emerged in Sheffield, principally in relation to metallurgy and further creating connections between actors in the cluster. This contributed to the buzz and enhanced the knowledge-cum-industrial zeitgeist of the Sheffield cluster (as highlighted in Figure 1), with an emphasis on education that added to cluster sustainability and cluster innovation. Central to the syllabus was a discussion of steel alloys containing nickel and chromium, contributing to the local networks of knowledge relating to the use of this material.[88] More focused research with alloys containing nickel and chromium continued in Sheffield for the armaments industry, in particular at the Brown-Firth Research Laboratory, where in 1913 Harry Brearley (1871–1948), engaged in research regarding the

81. British Patents 27,753/1897, 27,754/1897, and 27,755/1897.

82. For more information on the system, see *The Hadfield System.*

83. Hadfield–Krupp Agreements, 1898 and 1912, Hadfields Box 59, Sheffield Archives.

84. Tweedale, *Sheffield Steel and America.*

85. Corker, *Business and Technology.*

86. Hey and Unwin, "The Company," in *Mesters To Masters,* ed. Binfield & Hey, 33. See also Leader, *Company of Cutlers.*

87. Eason, *Business, Training and Education.*

88. Corker, "Sheffield Innovation System," in *Industrial Clusters,* ed. Wilson et. al.

erosion of the inner tubes of large caliber guns, made a breakthrough with experiments related to steel with a high proportion of chromium. The material, which contained 12.8 percent chromium and 0.24 percent carbon, was initially referred to as rustless steel; after further developments and refinements, the material gained its more commonly used name, stainless steel. Although never used for gun barrels, the commercial exploitation of the material was exceptionally rapid, with the Portland Works in Sheffield producing stainless steel cutlery under the guidance of Brearley in 1914.

This process demonstrates the connections between actors in the cluster and their contribution to innovative practice and sustainability, as revealed in Figure 1. Firth received their first orders for stainless steel in February 1915.[89] In the same year, Sheffield firms Brown, Hadfields, Vickers, Brown Bayley, and Sanderson Brothers all commenced stainless steel manufacture, making it impossible to patent the alloy in Britain.[90] Brearley subsequently patented stainless steel in the United States, the application for which was aided by advice from Robert Abbott Hadfield who had also been experimenting with chromium steels since 1892. As he revealed to Brearley in his letter to him, when examining samples from their experiments of two decades earlier Hadfield discovered that they had not rusted.[91] Here, we can demonstrate how two actors in the Sheffield cluster are both connecting to local innovation, as per Figure 1, and building new exogenous pipelines, as demonstrated in Figure 2, through codified knowledge regarding stainless steel recorded in U.S. patent records.

Firth's pipeline connection to Pittsburgh also proved useful in developing stainless steel manufacture in the United States, further reinforcing and developing the pipeline established in the Edwardian period for armaments. Firth's employee, George Ethelbert Wolstenholme (c. 1874–1940), oversaw the first casting of stainless steel in America at Firth-Sterling on 6 November 1917.[92] In the same year, a syndicate was formed to exploit the worldwide patents for stainless steel. Based in Sheffield, the Firth-Brearley Stainless Steel Syndicate ultimately patented stainless steel in twenty-one countries; sold the rights to patents exclusively to companies in Japan, France, and Sweden; established subsyndicates in the United States, Italy, Spain, and Switzerland; and licensed the manufacture of stainless steel to twenty-one steel companies in the United States and a further forty European steel companies.[93] These new commercial pipelines served to spread metallurgical knowledge from Sheffield, following years of focused research and extended pipelines that underpinned the development of stainless steel. The Firth-Brealey Syndicate's actions contributed to the spread of stainless steel knowledge to the rest of the world, as illustrated in Figure 2. The tacit, experimental research that laid the foundations for the development of the material became a key feature in the local knowledge-cum-industrial zeitgeist of Sheffield in the interwar period, as understanding of the gamut of processes and knowledge behind taking stainless steel from raw material to finished consumer product became the key to the evolution and sustainability of the Sheffield metalworking cluster.

89. Firth's Report to Brown's Board, 23 February 1915, X308/1/2/1/4/10, Sheffield Archives.
90. Barraclough, "Sheffield and the Development of Stainless Steel."
91. R.A. Hadfield to H. Brearley, 10 May 1916, X318/1/6/4, Sheffield Archives.
92. G.E. Wolstenholm to F.C. Fairholme, 23 March 1927, X318/2, Sheffield Archives.
93. Notes on the Firth-Brearley Syndicate, 1951, X318/1/1/3, Sheffield Archives.

At the Brown-Firth Research Laboratory, work continued with stainless steel under the guidance of William Herbert Hatfield (1882–1943), who took over from Brearley during the Great War after a dispute with Firth over the commercial use of the material resulted in his resignation. A type of acid-resisting steel was patented by Hatfield in 1922 that contained 18–24 percent nickel and 2–5 percent chromium, resulting in the claim that it was "very suitable for use in the manufacture of pipes, vessels and other apparatus used in chemical and industrial engineering and parts of devices which are required to be non-corrodible."[94] In 1923, Firth and Krupp arranged an exchange of their stainless steel knowledge and expertise, resulting in Brearley's original martensitic version of the material being swapped for Eduard Maurer and Benno Strauss's austenitic stainless steel.[95] This exchange of knowledge between Sheffield and Essen highlights an evolution of prior connections between the two clusters, as knowledge central to the evolution and sustainability of metalworking districts was shared between the global centers of steel manufacture. Building on this new information, in 1924 Hatfield developed 18/8 stainless steel, using 18 percent chromium and 8 percent nickel, marketed as Staybrite.[96] By 1929, stainless steel was in production across Sheffield, with seventy-one leading cutlery firms using the material directly procured from Firth.[97]

It is clear from this brief survey that Sheffield's local knowledge-cum-industrial zeitgeist and buzz environment benefitted significantly not only from its localized inventors, research facilities, and the university but also from its connections to Pittsburgh and Essen. In these two instances, the pipelines worked in both directions, a two-way exchange of armaments processes and patents, and in turn contributing to nickel–chromium steels becoming core knowledge in the cluster. The commercial usage of stainless steel was first started in the United States under the guidance of the Firth-Sterling company, leading to a new wave of patents and pipelines across the world, spreading knowledge of stainless steel to most industrialized countries. Underpinning this were local inventors such as Hadfield, with their extensive network of contacts related exclusively to metallurgy. Above all, this demonstrates how focused pipelines at the inception stages of metallurgical development—to companies in similar industries with Krupp, or part of a firm's network like Firth-Sterling—assisted in nickel–chromium steel becoming core knowledge in the Sheffield cluster, embedded by institutions such as the university and firms' training schemes. As Hadfield's reputation as a world expert in metallurgy developed, his personal pipelines to the rest of the world also proliferated; as the commercial exploitation of stainless steel became a reality, so too did the pipelines of knowledge to other firms across the globe.

Conclusion

When one considers the fuller quotation from Marshall referred to earlier, and its implications for the development of a knowledge-cum-industrial zeitgeist in the two clusters studied here,

94. British Patent 208,803/1922, 2.
95. Tweedale, *Steel City*¸ 255.
96. Tweedale, *Steel City*¸ 255.
97. *The Ironmonger*, 7 December 1929, 36.

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it is clear that not only was there a highly dynamic local buzz in both Sheffield and the Potteries, but also key figures captured knowledge to improve competitive advantage. Indeed, the third sentence in that Marshall quotation is perhaps more revealing than the second, highlighting the ways in which knowledge was generated, disseminated, and utilized. Although Figure 1 offers a simplistic diagram representing the links between cluster buzz, innovation, and sustainability, it is in Figure 2 that we can detect the principal features of the scaffolding at both the heart of the cluster and its connectivity to parallel institutions and activities at the metropolis and rest of the world levels. It is this connectivity that creates the zeitgeist, with the actors at the core of the cluster accessing this expertise and applying it directly to production activities. Here, we are providing some insight to the processes discussed by Jacob regarding both local knowledge networks and the interactions between local and foreign knowledge.[98] The whole process is highly fluid, as our two case studies demonstrate, combining internal and exogenous knowledge flows to enhance and sustain the clusters' market positions. In effect, we can see how cluster buzz feeds off its interactions with internal and external activity, providing the basis for a highly sustainable industry that continues to compete effectively for several generations.

This latter point requires some further clarification concerning the scope of our observations. We provide scaffolding to demonstrate how knowledge flows contributed to the generation of competitive advantage in two historical clusters, both of which continued to grow and evolve for many decades. Our observations of the exchanges between the various actors and institutions that interacted with clusters are restricted to specific points in time for both Sheffield and the Potteries, respectively. The Potteries in particular is an example of such pipelines and buzz being generated very early in the life of the cluster, while Sheffield represents a cluster at the height of its influence and innovative prowess. This paper does not attempt to explain the longer lifecycle of a cluster or the mechanisms behind their collapse. A separate and growing body of literature exists that seeks to address tensions between lifecycles and path dependency in clusters, which may provide avenues for future investigation.[99] Although the failure or death of clusters is, of course, a crucial element of the long-term perspective, it is one that requires further research in light of the findings of this paper for the earlier growth phases.

Having analyzed the dynamics of cluster buzz, we are still left with the conundrum introduced by Gourlay, namely, how firms converted the tacit knowledge generated locally and externally into a productive force.[100] It is clear from our case studies that, as the leading figures in the respective clusters led the various technological developments, they were well placed to ensure that the conversion process was direct and enforced. Indeed, the actors analyzed earlier captured the behavior of both collaborators and others in the cluster to sustain and even enhance the cluster's competitive advantage. This also returns us to the vital role of cluster leadership, a theme developed by Popp, Toms, and Wilson in their multidisciplinary incorporation of RBV, RKV, and governance concepts.[101] The challenge for those who study cluster evolution is to test this claim further by analyzing other clusters that perhaps do not

98. Jacob, *The First Knowledge Economy*, 11, 97–98.
99. Belussi and Sedita, "Life Cycles"; Elola et. al., "Cluster Life Cycles."
100. Gourlay, "Conceputalizing."
101. Popp et al, "Industrial Districts."

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possess the same kind of characteristics as the Potteries or Sheffield. Given what we have revealed in this paper, however, it is clear that the flow of knowledge is a central factor in explaining the dynamism of successful clusters, with leadership playing the role of catalyst in combining internal and external links. Although we acknowledge that not every cluster will fit our models, they are an important tool for examining how an industrial cluster connects to the world. The diverse way this may manifest itself in clusters around the world requires further examination and research.

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