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THE INTERWAR PERIOD AS A MACHINE AGE: MECHANICS, THE MACHINE, MECHANISMS AND THE MARKET IN DISCOURSE

Argument

This paper examines some of the ways that machines, mechanisms and the new mechanics were treated in post World War I discourse. Spengler's 1919 *Decline of the West* and Hessen's 1931 study of Newton have usually been tied closely to Weimar culture in Germany, and Soviet politics. Linking them also to the writings of Rathenau, Simmel, Chase, Mumford, Hayek and others, as well as to Dada and film studies of the city will indicate central features of a wide-ranging, international discourse on the machine and mechanisation. I argue that machines were so thoroughly integrated into social and economic experience that we can treat this as a distinctive new phase in the cultural history of mechanics, what some contemporaries called the "machine age": a period in which rather than the hand mill or steam engine, the city stands as an appropriate realisation (and sometimes symbol) of the significance but also ambiguities and tensions of mechanical life; and concepts of mechanisation were extended to encompass the economy and market mechanisms.

Two major events in the interwar period have strongly shaped our understandings of the social history of physics in particular and science and technology in general, while also playing signal roles in the development of the historiography of science and technology: Oswald Spengler's publication

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of *Der Untergang des Abendlandes* in 1918 and Soviet participation in the 1931 Second International Congress of the History of Science in London. Each offers an instance in which accounts of physics were engaged in much broader understandings of the character of science. Spengler had challenged the role of mechanistic, causal physics in a declining western culture, while Soviet scientists and historians insisted on the mutual interrelations between technology and science, arguing that social and economic history determined the direction of science in trenchant discussions of both the current five-year plan and the roots of Isaac Newton's work. Although these events have attracted diverse historiographical responses, prominent accounts have notably tied each to the specificities of time and place. Paul Forman's influential if problematic argument that German physicists and mathematicians bowed to social pressure, not empirical demonstration, in accepting acausal physics depended critically on the view that the loss of the Great War rendered German scientists in the Weimar Republic uniquely vulnerable to such pressure (Forman 1971, Carson, et al. 2011). Similarly, in explaining the nature of modernisation in Germany, Jeffrey Herf has emphasised the peculiarity of what appear to be nearly paradoxical conservative, reactionary engagements with technology such as Spengler's (Herf 1984). Likewise, while Gary Werskey's studies of the Soviet Congress explored its importance in drawing a nascent group of British socialists into a collective biography, Loren Graham's account of Boris Hessen's notorious paper on Newton has emphasised its immediate social and political context, showing how Hessen's argument about Newton could offer a defence against attacks on the bourgeois roots of Einstein's relativity, and help protect his

own position in the strongly ideological environment of the Stalinist state (Werskey 1988, Graham 1985).

This paper will link these two episodes, usually discussed in isolation, through their common engagement in issues surrounding mechanics and concepts of mechanisation. One way of reaching beyond the ineluctable specificities of case studies is to examine what contemporaries themselves regarded as general, and I shall here argue for the value of following many interwar commentators in considering the interwar period as a new age of the machine. Although historians have sometimes drawn attention to this term, it has most often functioned somewhat loosely as a descriptive label for the flowering of technologies and mass consumption in the period, pointing to the diverse ideological stances engaged and discerning a “machine-age modernism,” in the ways that Europeans combined Fordism with social-democratic politics and Americans developed revolutionary modernism and skyscraper commerce (Jordan 1994, Rodgers 1998, ch. 9 on 407). I will instead focus more closely on the terms in which the machine, mechanics and mechanism were themselves discussed, in order to draw out several significant features of an inevitably profuse and tangled discourse on modernity.

It is especially important to recognise the material and metaphorical breadth of concepts of mechanisation in this period. Materially, machines had long driven trains and powered factories but now also delivered electricity into both homes and factories, and the production of an increasing number of goods had been mechanised: glass-bottle and bulb blowing, bread baking and milk production, for example. I will argue that a new pervasiveness subtly

changed the social and conceptual significance of mechanism. Metaphorically the machine could symbolise both the progress and the dread of modern life and its warfare. In addition to engineering mechanisms and the mechanical theories of physics, natural selection counted as a biological mechanism and artists spoke of mechanical art while prices and markets were accorded new generality as economic mechanisms. A second distinctive feature is the explicitly international terms in which discourse on the machine was pursued, as I will document by linking debates in Germany with perspectives on industrial health offered in the U.S. and Britain as well as the Soviet Union. A final major concern is to show significant respects in which discussions of the machine age were framed historically, consistently looking back both to benchmark achievements like the scientific and industrial revolutions or the rise of the bourgeoisie – and also to significant authorities like John Stuart Mill and Karl Marx – in ways that strongly emphasise the longevity of the terms of reference invoked in discourse on mechanisation. But if the terms of reference remained similar, the profusion of kinds of mechanism was distinctive. While contemporaries often pointed to the significance of Ford and Fordism, and historians of science have typically focused on the rise of automata and robots in considering mechanical man, I will argue that the possibility of seeing the city as a machine (and organism) is a still more revealing feature of mechanism in the interwar period – as long as we recognise both the ambiguities that attended the sometimes surprising conjunctions of social settings and material systems that met on city streets, and the tensions between analytic and projective perspectives that were sustained in some of the most fruitful and critical invocations of the city as machine.

I will develop my account in three stages, first drawing out several revealing invocations of mechanisms and the machine in Germany and the United States, in order to establish the range of references engaged, the changing valence accorded machines, and the terms in which contemporaries described what they saw as the emergence of a new and international discourse, in which the figure of the engineer was especially important as the potential master of modern society. I will then explore a number of artistic and film renderings of mechanical life in the interwar period in order to build an understanding of the complex senses in which the city was beginning to be described as a machine. My final section turns to the tensions between ideal and generality engaged in discussions of mechanisms and the economy.

The machine age

In *Seeing Like A State*, James C. Scott has written that if you were to look for a moment and a man to mark the “birth” of high modernism in the twentieth century, it would be German mobilisation in World War I and the person most responsible for it, the German-Jewish industrialist Walther Rathenau (Scott 1998, 97-98). As we shall see, Rathenau also offers a suggestive key to conceptual perspectives on mechanism. Trained in physics, philosophy and chemistry in Berlin and Strassburg, as well as in machine construction in the *Technische Hochschule* in Munich, from the 1890s Rathenau accepted increasing responsibility in AEG, the electrotechnical firm that his father Emil had founded. Walther helped pioneer the formation of cartels and syndicates to decrease competition amidst economic difficulties, and while AEG collaborated with Peter Behrens to develop industrial design in the early 1900s, Rathenau’s pen brought him widespread notice. His 1912 book *Zur Kritik der Zeit* met the promise of its title with a diagnosis of the present that

was comprehensive and capacious, yet discriminating (Rathenau 1925 [1912], Volkov 2012). Joining a long tradition, Rathenau pointed to a pervasive condition or form of expression that he described as “mechanisation.” Having noted that mechanisation had first been felt in the production of goods, but had necessarily ramified dramatically given the centrality of production to all material life, Rathenau carefully picked out a long series of its present characteristics:

To the economist it appears as mass production and distribution of goods; to the industrialist as division of labour, accumulation of labour, and manufacture; to the geographer as the development of means of transportation and communication, and colonisation; to the technician as the control of natural forces; to the scientist as the application of the results of research; to the sociologist as the organisation of labour; to the business man as enterprise and capitalism; to the politician as realistic economic and political statecraft. (Rathenau 1925 [1912], 48)

Yet Rathenau went on to point to a singular spirit that he thought was common to all these diverse characterisations, distinguishing them from earlier forms of life. They betrayed, he wrote,

an impulse of specialisation and abstraction, of standardised thinking devoid of surprise and humour, of complicated uniformity; a spirit which seems to justify the name mechanisation even when applied to the sphere of emotion. (Rathenau 1925 [1912], 48)

Of course machines and mechanisation have long and vital histories, with historians of science tracing their investigations of mechanical philosophies at least as far back as the early modern period (Bertoloni Meli 2006, Riskin 2015). Recently, historians of literature and science have argued that we should recognise important precedents to post World War II treatments of cybernetics and cyborgs in the prosthetic engagement of Victorians with machines as living forces, diverse treatments of mechanism in biological thought in the late nineteenth and early twentieth century, and new forms of automata such as the robots that Karel Čapek introduced to the stage in 1920 (Ketabgian 2011, 1-6, McLaren 2012, Riskin 2015, see also Ruse 2005) The varied and above all practically realised forms of mechanisation that Rathenau identifies usefully complement this focus on biological mechanism and bodily hybridity. Note in particular that Rathenau links the physical machines of industrialisation and its products to a diverse array of social practices and disciplinary engagements, each approached somewhat differently, yet complexly uniform. We might think of these as the sinews of a new material and social hybridity. The capaciousness of this list, its careful distinctions between interrelated facets and Rathenau's critical perspective all point to significant features of what mechanisation was beginning to mean in Germany. His list also reflects the organisational qualities Rathenau brought first to his firm and industry, and later to Germany through his role in the War Raw Materials Department, and subsequent ministerial appointments.

That along with industrialists Rathenau could include academic roles such as geographers and sociologists and point to so many different perspectives surely reflects the *Streit über Technik* that had emerged around the claim of engineers for cultural and professional recognition, formalised in the right

that *Technische Hochschulen* gained in 1899 to award doctorates. Along with measures to reform secondary schooling and mathematics teaching, the Kaiser's decree opened debate on the role of technology to diverse scholarly audiences, with a flurry of contributions from historians, engineers, scientists, and sociologists, and repeated recourse to the title that put everything on the line: "Technik und Kultur" (which the elite association of academically trained engineers adopted when renaming their journal in 1922). Together with Rathenau's colleague the engineer Wichard von Moellendorf (who drew on the work of the historian Karl Lamprecht and the sociologist Georg Simmel to discuss the economic role of the engineer), such culturally renowned and academically powerful figures as the economic historian Werner Sombart, the physical chemist Wilhelm Ostwald and the historical sociologist Max Weber took part. Their contributions explored long-term historical origins for the central roles at issue – such as capitalist and entrepreneur – as often as they set out critical relationships between different disciplines and sectors of society (Mayer 1906, Sombart 1911, Ostwald 1909, Moellendorff 1912, 1913). Sombart provides an important example. In *Der moderne Kapitalismus* (1902) and *Der Bourgeois; zur Geistesgeschichte des modernen Wirtschaftsmenschen* (Sombart 1913, 426-27) he offers an account of the importance of technical inventions and all the industries involved in machine manufacture as a nursery of the capitalist spirit; Karl Hall has argued that he wrapped a stereotypical image in the individuality of the master artisan (Hall Forthcoming 2017?). In this context Rathenau's discussions represent something of a literary flowering with a distinctly emotive and affective cast, but the call he uttered for a new birth of the soul was far from rare. Historians have most often been concerned with the changing

understandings of technology at issue, and with discussions of the cultural role and social identity of engineers; see for example the fine comparative studies presented in (Hård and Jamison 1998, Hård 1998). Rathenau was perhaps the most prominent example of the increasing extent to which engineers, technical physicists and industrialists now claimed cultural significance with a place interpreting the tenor of the times (as well as making it).

For many World War I came to represent a particularly strong example of the characteristics that Rathenau had discerned, especially as its conflicts extended from weeks to months to years – and this decisively changed the valence of mechanism as a metaphorical diagnosis of the system or the spirit of the age. If Rathenau had sold thousands of copies of *Zur Kritik der Zeit*, Oswald Spengler's 1918 *Der Untergang des Abendlandes* created a sensation and was still more enveloping in its often bitter discussion of the ills of mechanisation. Drawing out the peculiar role of physics in Spengler's thought will show how his commentary shifted between physics and mechanics as an image of the intellectual world and source of social analogies, to the machine and the engineer (not entrepreneur) as key to the future of technology. Spengler thought he could pick out an understanding of the world as history from the world of nature in a way that others had only been able to glimpse dimly; and he described himself as separating the two possible ways of possessing and experiencing the environment: "the organic from the mechanistic world impression." Spengler's study of world history would distinguish:

the inner concept of form from that of the law, the image and symbol from the formula and system, the singular reality from the permanently possible, the goal of the tactically ordered imagination from that of the purposely decomposed experience, or, to identify here an unprecedented, highly important antithesis, the region of validity of the chronological from that of mathematical number. (Spengler 1919 [1918], 7)

Thus Spengler offered a new, morphological kind of history built on analogy and symbol, arguing that until now history had taken its model from the physical sciences.

Spengler's understanding of the physical sciences was idiosyncratic, but based on the 1904 doctoral dissertation he wrote on Heraclitus under the neo-Kantian philosopher Alois Riehl. Spengler offered parallels between Heraclitus's views and the energetics of Ostwald and Mach, celebrating what he saw as Heraclitus's rare insight into the inner relationship between culture and nature, with all cultural forms – the state, society, customs, intuitions – depending on nature. As a product of nature, they too were subject to the necessity of change. Spengler regarded the role of resistance and the equilibrium of opposing tensions in energetic considerations as analogous to the significance of war in man's existence (Spengler 1904, 30). He also articulated a concept of form based on the mathematical laws of nature, writing of the possibility of determining natural phenomena purely numerically without postulating an "essence," using Hertz's electromagnetic theory of light as an example; and distinguishing between the way that materialistic science treated matter and energy and the rather different distinction between substance and form that Heraclitus and the energeticists

drew (Spengler 1904, 39-40). Spengler's early work thus indicates close familiarity with significant aspects of the physics of his period. One corollary is that Spengler's concepts of science and society drew on a heritage that he shared with many of the scientists who commented on his later work. In turn, their complex responses to Spengler's writings reflected this common ground in what John Heilbron has described as *Fin de Siècle* descriptionism, as much as it does any capitulation to external social forces, in the way that Forman depicted the phenomena in the 1970s (Staley 2008, Carson, et al. 2011, Wise 2011).

By 1918, Spengler offered a symbolic understanding of form and had inverted his perspective on nature and culture to present a determinedly historical understanding of both, while offering a stark portrait of the Faustian power expressed in what he called "the machine." Now Spengler argued "no science is only system, only law, number and order." Rather the science of each era, the Greek period or his own, was a historical phenomenon, an organism determined by fate and culture: "In modern physics there lies not only a logical but also a historical necessity. It is not only a matter of intelligence but also of race" (Spengler 1919 [1918], 531).

Spengler began his discussion of physics by recalling Helmholtz's famous 1869 account of the mechanical goals of science, and then contrasting the perspective that a physicist would take on mechanics with that of a sceptic aware of the psychology of the scientific conviction in mechanical explanation, writing "To the one, present-day mechanics is a logical system of clear, unambiguous concepts and of relations as simple as they are necessary; while to the other it is an illusion characteristic of the structure of the

Western-European spirit" (Spengler 1919 [1918], 528). If Spengler thought the physicists' view of mechanics was illusory, Jeffrey Herf has shown that in 1922 Spengler pronounced the machine to be the devil – but also argued that technology expressed the Faustian will to power over nature. Exuding a primordial violence and steely energy, Spengler thought western technology was much more active than previously – the machine had now taken on a life of its own (Spengler 1923 [1922], 1,187, as cited in Herf 1984, 60-61 on 61). Herf argues persuasively that nevertheless Spengler was much more worried by finance and the role of the merchant than machine technology itself. For Spengler, both industry and agriculture were rooted in the soil and blood and involved in a pitched battle with finance and the money thinking of banks and the stock exchange, which reflected the primordial struggle between creative production and economic plunder. Thus for Spengler both the entrepreneur and the industrial proletariat were enslaved to technology, and hopes for technology must instead rest in the guidance that could be provided by the engineer, "the erudite priest of the machine." (Spengler 1923 [1922], 1,191, as cited in Herf 1984, 62).

Both Rathenau and Spengler focused on Germanic culture and the German state in their descriptions of the cast of characters involved in the industrial life of the present. They were in part engaged in showing how despite the war and the recognised economic strengths of the "American system of manufacture," the German state was uniquely fit to create the conditions for a true industrial life (Hård 1998, see also Jakobsen, et al. 1998). Rathenau reassessed his earlier emphasis on industry groups and disdain of the cultural impact of excessive production; the war showed him the need for increased production but also rationalisation and national endeavour. As it concluded

he first embarked on a writing programme, arguing in a pamphlet on the Kaiser that long before war broke out the conditions for it had been created by a “dehumanised, overmechanised” and selfish Europe, carving up the map with cynical economic and armament policies (Rathenau 1919, 47, Volkov 2012, 181-82). Despite the contradictions inherent in his position he moved into the Weimar government. As Foreign Minister negotiating to manage Versailles reparations with Western powers and, controversially, the Soviets, in 1922 he was murdered by members of the ultra-right nationalist Organisation Consul, who hoped to incite a civil war; Falk Müller’s contribution to this issue explores the further development of his company (Müller 2018?).

The academic culture of Germany had clearly devoted unusually sharp attention to questions surrounding technology, and the costs of controversial stances could be especially extreme when coming up against diverse assessments of national needs in the political and economic crisis of the early Weimar republic. But similar issues were faced in many different countries and the work of a group of American social theorists, writers and commentators will demonstrate an increasingly international discourse. Most prominent amongst them were the economist and sociologist Thorstein Veblen, the economist Stuart Chase and the literary critic and historian Lewis Mumford. Veblen and Mumford have attracted far more attention than Chase, largely because of the importance of Veblen’s 1921 book *The Engineers and the Price System* for the technocracy movement and the reputation Mumford’s monumental 1934 *Technics and Civilisation* won, often described as the most influential twentieth century history of technology (Veblen 1963 [1921], Chase 1929, Mumford 2011 [1934]). Most commentary has explored

these figures' understandings of technology, but as we shall see their thoughts were often framed in the language of the machine and Chase's 1929 book *Men and Machine* did more than any other to make this explicit.

In her study of changing perspectives on technology in the U.S., Ruth Oldenziel shows that the rather mixed and inclusive nineteenth century understandings of the nature of the industrial arts and participation in them were narrowed significantly in Veblen's 1921 treatment of technology as the preserve of engineers. Veblen gendered machines male while offering an encompassing metaphorical understanding of the industrial system as a self-generative, self-contained machine, writing "The industrial system is notably different from anything that has gone before. It is eminently a system, self-balanced and comprehensive, and it is a system of interlocking mechanical processes, rather than of skilful manipulation. It is mechanical, rather than manual." (Veblen 1963 [1921], as cited in Oldenziel 1999, 45-46). More recently, Eric Schatzberg has explored Veblen's reading of Sombart, Simmel and others, and charted the subtle transformation of understandings of technology reflected in Veblen's use of specific concepts of "technology" as a translation of the German term "Technik." Schatzberg notes Veblen's sophisticated discussion of social dimensions of technology and subtle account of the relations between science and technology, arguing that few could follow the latter. Veblen thought industrial operations had to be understood as a "machine process" that interrelated multiple mechanical operations in one whole. Technology was not the system itself but its physical principles understood as the collective and cumulative knowledge of the industrial arts. That it could effectively be monopolised when ownership controlled the material means of utilising this knowledge was central to a

critique of capitalism. First articulated in articles published in 1906, by 1921 Veblen had conjoined his critique with an argument for a new “Soviet of technicians” or “production engineers.” By being free of pecuniary interest, Veblen argued they could direct industrial development appropriately, a stance that proved controversial and might have seemed particularly utopian in post-war America. Schatzberg laments the conceptual elisions that occurred when later authors conflated the sense of technology as the study of a field, with technology as the object of study. Having limited his focus to the scholarly uses of “technology,” primarily in the social sciences, Schatzberg notes that a more complete account of the cultural dimensions of technology would have to follow Oldenziel’s lead in examining “the full range of terms – such as *the machine* and *science* – that were used to discuss the material culture of modernity” (Schatzberg 2006, 488, 2012, see also Jamison 1998).

Chase was an associate of Veblen’s who joined him as a member of the Technical Alliance from 1919 to 1921. In 1927 he published on money and advertising, before visiting Soviet Russia as a member of the First American Trade Union Delegation and co-authoring a report on the nation’s second decade. This experience gave him the trope of imagining what it would be like to transpose a Russian urchin to New York, supposing for a moment he became a talented scientist, “a generic figure for the scientist and engineer, familiar with the main aspects of modern technology and capable of operating its mechanical devices.” This was how the opening chapter of *Men and Machines* framed its study of the way machines had banished past biological limitations. Chase described the great extension of physical and mental capacities in telescope, microphone, radio, the electron tube micrometer and the MIT integrating machine, and contrasted what a man’s

back could carry with the power of a crane and steam hammer; yet also noted that one “would take no peasant from his village in the certainty of making him happier in New York” (Chase 1929, 7 and 9).

Raising the question whether we are enslaved by our machines, Chase ran through representative groups of writers who railed against machines, celebrated them, or sat on the fence, helpfully giving some measure of the field of discourse. As well as Spengler, amongst those indicting the machine Chase described the views of a group of American and British authors with several scientists amongst them: Samuel Butler, Austin Freeman, Henry P. Frost, Frederick Soddy, J.B.S. Haldane, Bertrand Russell, Philip Gibbs, Benjamin Disraeli and H.G. Wells. That group was larger than those he listed in favour or undecided combined. Although Chase thought he could have multiplied each list endlessly (in the same proportions), he also commented that all of these views had been given in summary form, with the possible exception of Freeman’s (Chase 1929, 9-19). Indeed Freeman’s 1921 book *Social Decay and Regeneration* had offered lengthy descriptions and detailed analysis. He regarded machines as concrete expressions of knowledge and thought their evolution showed mechanism had a life of its own, “as an independent entity governed by its own laws and having no necessary connection with human needs or human welfare” (Freeman 1921, 84). Freeman characterised the effects of mechanism on itself, on the human environment, the social organism collectively, and on the individual, before outlining a set of consequent social anti-bodies and offering a eugenic solution. But his analytic care was exceptional: few had written fully enough to give Chase a satisfactory understanding of why they thought as they did.

So Chase offered an anatomy of machines as well as a historical perspective on their development. Drawing on the international success of Karel Čapek's 1920 play depicting synthetic organic automatons rebelling against humanity (discussed in (Riskin 2015, ch. 9)), Chase wrote on robots, but also on skills, saving labour, the flood of goods, skyscrapers, and playgrounds, to list just some of his chapters. He thought power machinery belonged in making other machines and glass and bottle making, for example, but not in fine bread making or ornamental metal work. A judicious recognition of the limitations of technology was necessary and machines should not be blamed for the cheap and nasty stuff they were used to produce (Chase 1929, 238-39). As the U.S. moved into depression, Chase brought his analysis to bear on public policy, noting in the preface to his 1932 book *A New Deal* that progressively advancing towards "an all-inclusive mechanical balance," the industrial system was approaching a critical tipping point, and the "mechanical state of the industrial arts" could no longer be served by the control of production in the hands of vested interests. Like Veblen before him, Chase's solution was technocratic: to entrust control to production engineers without commercial interests. Linking a sharp analysis of industrial and economic problems to such general ideas as the machine and technology in addressing critical unemployment issues won him favour, but also proved problematic. While Franklin D. Roosevelt adopted Chase's title in his acceptance of the Democratic nomination for president in the summer of 1932 and Chase became part of his inner circle, the technocracy movement that Chase represented was attacked by physicists, engineers and business leaders like Karl T. Compton, Arthur Sheridan and Arthur D. Little, who belittled the novelty of the analysis and sought to break the links that Veblen and Chase

had made between technocracy and engineering as a profession and between technocracy and technology (or machines) as the product of engineers' work (Oldenziel 1999, 47-48, see also Bix 2000). Yet David Hart's account of the varieties of liberalism in play in U.S. science and technology policy highlights the role of metaphors of the machine and the ideal of developing an administrative state "as precise and powerful as an automobile engine," in the words of Roosevelt's Secretary of Agriculture, Henry Wallace (Hart 1998, 62-71 and 78, quote on 62). Thus many shared language of this kind while disagreeing on where control should be vested; notably in the early phases of Roosevelt's administration the MIT president Compton sought to enlarge the understanding of "public works" to include science even if he resisted ceding control to engineers.

Soon the encompassing nature of Chase's concern with the machine had been matched and then exceeded by Lewis Mumford, who toured American and European museums of science and industry and wrote drafts of what would later be published as *Technics and Civilization* in 1930 and 1931. Mumford saw the key to an ability to "transvalue" the machine to lie in the observation that many of the most important new developments in the late nineteenth and early twentieth century had come in part from the study of physiology and anatomy and intimate work with the human voice, eye and ear. The telephone, phonograph and motion picture represented machine technique approaching the organic, and indeed recovering elements that Mumford thought had been repressed in earlier phases of the development of the machine, which had failed to recognise or turned away from the moral and social problems involved in their development. Thus Mumford set the

machine in a matrix in which understanding it was a critical means to understanding both society and self (Mumford 1934, 4-7).

Mumford linked science and technics closely, writing that the concept of a neutral world, a new objectivity, had relied upon the combination of the scientific method and the machine technique, emerging only in the nineteenth century, and he was particularly interested in what this meant for man's character. In this respect, Mumford argued:

In the development of the human character we have reached a point similar to that we have attained in technics itself: the point at which we utilise the completest developments in science and technics to approach once more the organic. But here again: *our capacity to go beyond the machine rests in our power to assimilate the machine. Until we have absorbed the lessons of objectivity, impersonality, neutrality, the lessons of the mechanical realm, we cannot go further in our development toward the more richly organic, the more profoundly human.* (Mumford 1934, 363)

Historians discussing these authors have commonly picked out a handful of their contributions for closer analysis. On the one hand these have often been pursued with an overarching concern for two rather general themes. They have been linked to modernity (and anti-, reactionary- or more recently post-modernity); or they have been pursued with the boundary work of science studies in mind, considering the relations or distinctions between "science" and "technology" and between "pure" and "applied" endeavours, chasing terms still at work in our analysis today (Herf 1984, Hård and Jamison 1998, Schatzberg 2006, 2012, Forman 2007). And on the other hand historians have

often resolved the work of these authors into quite local cultural environments, with Jeffrey Herf tying his account of reactionary modernism strongly to the specificities of the political and cultural situation of the Weimar Republic, for example.

Taking them up in this paper with the explicitly comparative perspectives explored fruitfully by the contributions to Hård and Jamison's edited volume on the appropriation of technology – but approaching them instead through the differently resonant concept of the machine – has shown that this term changed valence in the period before and after World War I, but also that for several thinkers in the interwar period “the machine” became an overarching concept encompassing significantly interrelated elements of the technical and social dimensions of the industrial economy. As Rathenau's comments suggest, it was multiply realised in a rich range of different forms of “mechanisation.” The machines and industries concerned were often electromechanical, reflecting the increasingly wide reach of electricity, and distinctions in types of power or locomotion were rarely emphasised. The boundary between the organic and the mechanical was often crossed – and sometimes this was regarded as critical to the proper rapprochement with the machine.

Considering even this relatively small group of German and American authors we have also seen the possibility of tracing concepts of the machine and mechanisation across diverse international contexts. Both the bibliographies and many of the central historical arguments of books like Rathenau's, Spengler's and Mumford's aimed at characterisations of the centrality of machines to western culture. In taking up the relations between

technical and cultural achievement, the role of engineers and the state, and the possibility of the machine taking jobs, they addressed current political needs and also raised questions of vital interest in many other nations – which in turn often engaged them by drawing on their writings. A brief discussion of British and Soviet treatments of mechanisation will demonstrate this point, while also preparing ground for my analysis of artistic and economic work with the concept of mechanism in following sections. Daniel Wilson has recently traced a similar discursive context in Britain to J.A. Hobson’s groundbreaking discussions of industrialisation in the late nineteenth century (Wilson 2015). In the 1920s, just as Chase noted the writings of many British commentators, the literary scholar F.R. Leavis and his colleagues in the *Scrutiny* movement drew on Chase when articulating an account of the changing nature of work. Hilliard describes them as using the machine as “a governing metaphor for modernity,” and Ketabgian has suggested that Leavis’s anti-industrialism has strongly shaped received views of the industrial psyche as stunted and dehumanised (Hilliard 2012, 57, 61-66 on 61, Ketabgian 2011, 7). Addressing the bureaucratic roots of computing in Britain, Jon Agar has shown that the governing metaphor for government was likewise mechanisation. In the 1920s and 30s in particular, Agar argues an “expert movement of mechanisers” helped secure Treasury control over the Civil Service through an Investigating section that promoted mechanisation in the treatment of records, tasks and files. Their aims were articulated in a memorandum that Major Sydney George Partridge sent to the Adjutant General in 1916, arguing “It is the aim of every alert organisation seeking efficiency and economy in office administration to strike the balance between the ‘human’ and the ‘mechanical,’ and the more efficiently a Department is

organised the greater will be the tendency for the 'mechanical' to encroach on 'human' territory" (Agar 2003, ch. 6, on 162). Vladimir Lenin's organisational aims were still broader, while his methods were sharper. James C. Scott describes how his understanding of the vanguard party as the "machinery of revolution" went together with Lenin's readiness to see the template for social change in electrification. Stephen Kotkin has developed a similar approach more comprehensively. In a brilliant comparative study of Soviet forms of modernity he argues that distinctive engagements with mass production, mass culture, mass politics – even mass consumption – served as integrating mechanisms in the Soviet Union, as they did amongst western nations (Scott 1998, ch. 5, Kotkin 2001, 112-14) But closely engaged with important political aims as they were, such mechanisms – and even attitudes to the concepts of mechanics – were also advanced by contrast and threat as well as by persuasion and cooperation. Although celebrating the machine, like Spengler Lenin had engaged closely with physics in critiquing Mach for the supposed solipsism of his epistemology in 1909. This stance (and later Stalin's views) strongly shaped the direction of ideological and philosophical critiques of physics in the Soviet Union through the 1920s and 30s, where a prominent member of a "mechanist" faction claimed the imprimatur of reductionist science and dialectical materialism in arguing against Einstein's relativity for its idealism (Joravsky 1961, chs. 2, 10). This will help suggest the need to relate Soviet contributions to the International Congress in History of Science to international debates on mechanism and the machine question as well as to more immediate social and economic roots in factional Soviet politics. Boris Hessen and Nikolai Bukharin engaged Sombart, Spengler and Chase as well as Marx in developing their treatments of past and present relations between

machines and the social fabric of science and industrialisation, and they offered radically new accounts of scientific practice in doing so (Bukharin 1931, Hessen 1931, Joffe 1931, Zavadovsky 1931, Werskey 1971, Kojevnikov 2008).

Mechanical art and film: The city as machine

Having gained a detailed understanding of how mechanisation was discussed by those writers and commentators most directly responsible for depicting the interwar period as a machine age, we now turn to two different contexts in which highly creative treatments of mechanism were offered, considering mechanical art and film, and then economics. In both cases, I will argue, the profusion and pervasive nature of material mechanisms and forms of mechanisation helped promote the articulation of new and interrelated perspectives on the city and markets, in which forms of social mechanism were given new weight. The machine had long been the subject of artistic elaboration, and many amongst the avant-garde movements of the late nineteenth and early twentieth century worked with mechanomorphic images – Neue Sachlichkeit, Surrealism, Expressionism, Futurism – but they were taken up particularly strongly by those artists who joined the Dada Club in Berlin in the midst of World War I. Celebrating the language of their nation's enemy they followed the lead of Cabaret Voltaire in Zürich in producing vibrant, confrontational performances and artwork of ab/surd_!troubling juxtapositions to critique artistic and social assumptions (Kuenzli 2011). Helmut Herzfeld took the name John Heartfield and described himself as the "Monteur" or engineer of Dada. Adopting collage and montage to make art of current news and improve on old and new masters, as the war ended Berlin Dadaists strewed their images with machine fragments, wheels and gears,

and cast both political leaders and the age in mechanical terms – yet themselves embraced the possibilities of mechanical art and machine-life hybridity. In 1920 Raoul Hausmann alternately critiqued and claimed the mechanical in evocatively symbolic works. In “Der eiserne Hindenburg,” the military leader is drawn in ink with mechanical limbs and body – but a human face and hands – and with a megaphone hanging from his hairy buttocks. Yet in “Selbstporträt des Dadasophen,” the photo-montaged image of the suited Dada protagonist has a pressure gauge and film projector for its head, and a diagrammatic lung, while the polished wooden tailor’s head of “Mechanischer Kopf (Der Geist unsere Zeit),” incorporates measuring tape, watch gears and wallet. These hybrid human forms combine elements more often associated with the cybernetics and cyborgs of the post World War II era (Biro 2009, 117-20), but Dada images of the social are as revealing.

Consider the chaotic exuberance of George Grosz and Heartfield’s “Leben und Treiben in Universal-City, 12 Uhr 5 mittags,” which sets fragments of advertising and newsprint evoking American cinema into a tangled heap of drawing and caricature, together with a car wheel, a pocket watch, a strip of film, feet and faces: it is lunchtime in the film city (and Charlie Chaplin was a Dada hero). Hannah Höch rendered the social in more thoroughly political terms. Her monumental collage “Schnitt mit dem Küchenmesser, Dada durch die letzte Weimarer Bierbauchkulturepoche Deutschlands 1919/20,” offers deliberately profuse juxtapositions of politicians, soldiers, artists and others for and against Dada, with Einstein flanked by a gear and ball bearings, surmounted by an insect and train with the phrase “dada” (Henderson 2008, 106-08, Makela 1997). Einstein’s opponents such as Paul Weyland eagerly noted such references and were inclined to interpret his success as merely

popular mass suggestion, fuelled by newspapers (Wazeck 2009, 2014, 219-26, van Dongen 2007). Ironically, like Dada artists those arguing against Einstein often celebrated mechanics, but in a traditional understanding that could be held against Einstein's theory of relativity.

The theatre of war had given a sense of the vulnerability of the body and led to art re-appropriating media images to fracture a discredited leader and show the newly famous in the broken masses of a volatile Republic. Film likewise could build commentary from collation, and it too was used to offer distinctive interpretations of mechanisation and machines, especially in a number of highly suggestive accounts of the city from the late 1920s. Two decades earlier the sociologist Georg Simmel had closely tied the metropolis to money and a new form of mental life, as expressions of the peculiarly abstract relations occasioned by the division of labour – which also afforded unusual individual freedom. Yet for Spengler the inorganic city was a symbol of the desiccation of the modern era. Similarly, filmmakers offered both celebratory exploration and starkly difficult images of the metropolis. Because Simmel's perspective engages issues significant for later understandings of the economy and markets it will be helpful to outline it before considering several ground-breaking films. Bringing conceptual and artistic treatments of the city into contact can help us understand cultural grounds for newly general understandings of economic mechanisms.

In 1903, Simmel described the central problems of modern life to stem from the need of the individual to preserve autonomy in the face of now overwhelming social forces, heritage, culture and technology (which his 2007 translator rendered as "the technique of life"). If in the eighteenth century

freedom from the historical bonds of state, religion, morality and economic life had been highlighted, the nineteenth century had demanded a functional specialisation of life and work that made individuals incomparable, indispensable to one another, but also directly dependent on each other's activities. Nietzsche's response had emphasised individual struggle, while socialism sought to suppress competition; both responses pointed to the individual's need to resist being levelled and worn out by what Simmel called "a social-technological mechanism" (Simmel 2007 [1903], 182-83). Simmel associated this phenomenon most strongly with the city, and what he described as "a money economy," for the multiplicity and concentration of economic activity in the city had given the means of exchange an importance quite foreign to commerce in rural environments. Under primitive conditions production was bound in intimate personal relations. In contrast, the modern metropolis was largely supplied by production for the market, and Simmel thought this enhanced the abstract intellectualistic mentality that was the ideal of natural science. He also linked the distances and aversions, the rhythms of emergence and disappearance in city sociability with the extent to which the city granted individuals a kind and amount of personal freedom that had no analogy in other circumstances: the division of labour in this extended group both occasioned and necessitated a new, specific individuality (Simmel 2007 [1903], 184-85, 88-89).

In the late 1920s a range of extraordinary documentary and narrative films portrayed and examined many of these themes in ways that highlight the shifting scales on which the city could be imagined as a machine. Walther Ruttmann's documentary film of the course of a day in *Berlin: Die Sinfonie der Grosstadt* made art of the ordinary. Its opening scenes depict a steam train

and electrical power lines leading into/out of the city, and then near empty streets that gradually stir with people, before the factory machines start up, with glass, metal, milk and bread production all mechanised. The camera moves between diverse comings and goings on foot or by streetcar and bus, showing the factory at work, street scenes and construction sites, and cutting between fashionable Kurfürstendamm and the slum district. Ruttmann juxtaposes workers, horses, the wealthy, business men, and a lion all eating as if to emphasise a common need, without settling into a strong reading of their relations – and this is followed by images of mechanised washing up and a cat feeding on scraps. Newspapers are produced, wrapped, stacked, and sent to delivery with a series of words lifted from the rapid blur of newsprint pages: Krise (crisis), Mord (murder), Börse (stock-exchange), Heirat (marriage) and Geld (money, seven times) and then we are on a rollercoaster, in a revolving door, subject to vertiginous visual illusion amidst the solitude of a suicide attempt witnessed by masses. The film ends with Berlin's streets lit by electric light, fireworks and a searchlight. Ruttmann thought of his task as musical, but the way he writes about the problems of editing leaves unclear whether he is referring to his subject matter or the artistic medium: "While preoccupied with the cutting of the film, I realised how difficult it was to achieve a symphonic 'curve' or form in the film. Many beautiful individual scenes had to be cut out to avoid the effect of a series of static pictures. The structure of such a complicated machine, in creating the desired movement and to make the heterogeneous episodes an organic whole, had to consist of related incidents fitted to each other which would grip one by their intensity" (Ruttmann 1928). In contrast to the delicate realisation of Ruttmann's vision of the machine, the intense narrative drama of Fritz Lang's *Metropolis* rendered a

city doubly fantastic, both myth-infused and birthing the modern post-human – or rather revealing its caricature in the machined mimicry of the human. Yet in Lang’s expressionist idiom the city dwarfs its divided peoples and is clearly dominated by the machine wrought into its centre. Bitter struggles between the head and hand see the destruction of the heart-machine, which has feasted on the bodies of the labourers that served it, but the promise of mediating hearts at least halts the wreckage of the city torn apart by its people.

These 1927 films were followed in 1929 by Dziga Vertov’s brilliantly innovative documentary *Man with a Movie Camera*. This was shot for the Ukraine State Studio shortly after Vertov had finished *The Eleventh Year* (1928), a study of Soviet electrification that John Mackay describes as an “energetic montage” focused above all on process in “documenting humans and machines collectively overcoming nature’s stony inertia” (Mackay 2007, 41). In his 1922 “We: Variant on a Manifesto” Vertov had described his task:

Because people cannot control their movements, we will until
further notice not include them as subjects in our films.

Our way takes us through the poetic machine, from the
corpulent gentleman to the perfect electric man.

We reveal the soul of the machine, causing the worker to love
his workplace, the peasant his tractor, the engineer his engine—

We bring joy to mechanical labor,

We make peace between man and machine,

We train the new man. (Vertov, *Kino-Eye* 11 as cited in (Feldman
2013 [1998], 21)).

Using the mechanical eye and the machine art of film to depict the life of a city and its people, Vertov fought for the complete separation of film from literary and theatrical languages, developing a sharply edited study with rapid shifts of perspective and interwoven rhythms, that deliberately constructed a series of analogies between audience and subject, camera and eye, people waking and an awakening city. Vertov switches between city bench and home, motor and factory, transport and rest, and builds and dissolves a set of contrasts, layering human, animal and mechanical motion into the same screen. This was an experiment in new kinds of cinematic communication without the help of subtitles, scenario or theatre; and Vertov's radically reflexive authorial stance also dramatically highlighted the agency of the audience, left to experience a vision of the city without story. Later commentators have debated whether the city is portrayed as mechanical or organic, but the deep analogies that Vertov's film vision capture and illuminate so self-consciously are surely more important than resolving this tension. His medium itself provides a machined enhancement, revealing illusions like split scenes of passing trains that mechanically enhance on the speed and intervals of physiological vision – and can be trusted because the viewer is shown how they are made (Cook 2007, Feldman 2013 [1998], Turvey 2007).

In 1936, Charlie Chaplin's *Modern Times* joined the genre of film commentary on the city and factory machine with a clear political perspective rendered sharply comedic. Reportedly, the film owed its genesis and factory motif to the worldwide success of the lyrical *City Lights* in 1931, with its social inversions between the Millionaire and the Tramp (whose feet had briefly appeared on screen in Ruttmann's movie) and a set echoing London, Paris

and Naples as well as Los Angeles. Soon after its Los Angeles premiere (with Albert and Elsa Einstein guests of honour), Chaplin toured depressed European cities to promote *City Lights*; discussing Mahatma Gandhi's grim perspective on industrialisation prompted him to take on the machine. Fittingly, this backstory illustrates the international dimensions of the industrial modernism of Western cities.

The shifting analytic perspectives of the documentary films *Berlin: Die Sinfonie der Grosstadt* and *The Man with the Movie Camera* seem to highlight the scale and pervasiveness of different forms of mechanisation, while *Metropolis* and *Modern Times* emphasize the breath-taking dominance and relentlessness of the machine. Each delivers a strikingly innovative vision of the machine in the city, but it was the artist, architect and urban planner Le Corbusier who sought to offer the epitome of the machine age city. Indeed, in 1927 Le Corbusier titled an early article "Toward a Machine Age Paris," and he developed manifestos and plans dominated by the right angle, straight lines, and strict functional segregation to allow single purpose planning and standardisation in cities that might inspire the future. Scott's *Seeing Like a State* offers a brilliant exposition of the influential extreme that Le Corbusier presents, sketching visions of the same radiant city to thoroughly transcend present day Moscow, then Paris, noting that when Le Corbusier did get the chance to build Chandigarh from Jawaharlal Nehru, residents had to build an unplanned periphery on the outskirts of the austere and monumental centre he constructed (Scott 1998, ch. 4). Collectively the diverse renderings of the city we have considered echo the wide span and heterogeneity of Rathenau's diverse forms of mechanisation. But in suggesting that the city is an appropriate symbol of the machine age in the interwar period I do not mean

to argue that contemporaries took the city as a central metaphor for the machine, or that the period was defined by Le Corbusier's singular projective visions, though these were important. Rather it is the fact that some saw the city as already a machine, its life pervasively run through by heterogeneous forms of mechanisation that is most revealing, for this offers a new and importantly ambiguous image of the social life of the machine (and this is characteristic of the age).

The machine age in physics?

Before exploring a correlate to this social life in concepts of economic mechanisms I want to take up (if briefly) an important responsibility. To examine what machines and mechanics meant within the physics discipline in the interwar period we would have to note the juxtaposition of two new forms of mechanics in relativity and quantum mechanics with the proliferation of versions of mechanics produced for applied mathematicians, mechanical engineers, and also physicists. In other words, a kind of discursive breadth of reference was already fostered for mechanics by the tremendous disciplinary and institutional diversification of physics (also exemplified by the contributions to this special issue). Texts on practical mechanics on the one hand, and the physics of the factory on the other were all represented in the pages of disciplinary and general scientific journals like *Physikalische Zeitschrift* and *Nature*. Take the example of one of the leading German physics publishers, the Leipzig firm S. Hirzel, whose advertisements in the *Physikalische Zeitschrift* (which it published) show that shortly before the confirmation of Einstein's relativity Hirzel was offering for sale Philip Lenard's book *Über Relativitätsprinzip, Äther, Gravitation*, and set its two Nobel prize winners Max Planck and Johannes Stark side by side in a single

advertisement, with three titles from Max Planck on *Einführung in die Allgemeine Mechanik*, *Einführung in die Mechanik deformierbarer Körper*, and *Die Stellung der neueren Physik zur mechanischen Naturanschauung* (S. Hirzel Verlag 1919). Hirzel also offered Gustav Winter's book *Der Taylorismus* and published the journal *Praktische Psychologie* (or industrial psychotechnics), which Anson Rabinbach has shown expanded rapidly in the immediately post-war period (Rabinbach 1990). The vast majority of the firm's *Kollegien-Hefte* collection of textbooks and handbooks were devoted to machine elements, machine technology, technical mechanics, hydropower, light engines; that is, to mechanics in a great diversity of forms – which in many ways provides a disciplinary basis for, or at least a clear reflection of, the breadth of discourse that I have noted above (S. Hirzel Verlag 1920b).

Similarly, just as Max Planck couched his discussions of the new physics in terms of the development of mechanical views of nature, the first seven pages of Einstein's popular account of relativity deftly establish – with a rather light touch – a set of significant contexts in which to consider his work. The first is the school, with his discussion of Euclidean geometry and the open question of its empirical truth. The second is the city, with his reference to Potsdamer Platz in Berlin as an everyday example of how to specify an event in a system of reference. And the third is the railway, with his discussion of space and time in classical mechanics (Einstein 1917, 1-7). Thus Einstein's account meshed rather neatly with the practical and metaphorical understandings of mechanisation in the period – something that was heightened still further in the opening segments of the experimental documentary film on relativity for which Einstein was a consultant, released in 1922 (Wazeck 2010). Yet his opponents often insisted on a more traditionally practical understanding of

mechanics. In the 1920 advertisement for a new, expanded edition of Philipp Lenard's *Über Relativitätsprinzip, Äther, Gravitation*, it was noted that the author handled his subjects "from the standpoint of a natural scientist who feels themselves led more by the experience of the material world than by philosophical demands. He grounds his worldview not on mere mathematical equations, but on mechanisms. In this departure from the customary handling of the matter lies the high value of the book" (S. Hirzel Verlag 1920a, Hentschel 1990). As is well known, in the 1930s Lenard's account was expanded to the point of vicious caricature in his four volume depiction of *Deutsche Physik*, this time with a different publisher (Lenard 1936, Hentschel 1996, lxx-lxxviii).

Mechanisms and the economy

Having explored the development of a very general concept of "the machine" as a system in the previous sections, I wish to conclude by considering the origins of the sense in which we now speak of the economy in terms of market mechanisms. Recalling Rathenau's 1912 treatment of mechanisation, it is worth emphasising that he described "the economist" as seeing mechanisation in mass production and the distribution of goods, without referring to markets. So when did economists or others first start to write of markets, mechanisms and the economy in the same breath, and what does it mean to think of market prices as a mechanism? This section contributes towards answering these questions by first outlining the pertinence of discourse on machines to a general concept of the economy, and then showing that the wide scope of this discourse was important for the economist Friedrich Hayek's influential account of the roles of prices and

markets in the economy; but that he also undertook a deliberate attempt to reshape its metaphorical, connotative dimensions.

In his study of the practices and concepts of capitalism as these were engaged in Egypt, Timothy Mitchell develops a view not unlike the perspective that Oldenziel and Schatzberg have taken to subtly changing concepts of technology, arguing that the general concept “the economy” only emerged in the English language in the late 1930s, with the contraction of empires and increasing isolation of countries feeling the effects of the Great Depression. Before this period the term referred to household stewardship or, as “political economy,” to management or public administration. While Simmel’s analysis of the city points to historical factors that could be significant for the emergence of a general concept of economy, it is telling that there Simmel himself always refers specifically to a money economy (sometimes in contrast to barter), and is equally specific in referring to metropolitan markets. Yet, as Mitchell shows, it has been easy for later authors to read back into Simmel’s writing broader concepts that were actually developed only somewhat later. While Edward Shils’s 1936 translation of the essay followed Simmel in using the indefinite article to refer to *a* money economy, in 1950 Gerth and Miller inserted the definite article in their translation, writing “The metropolis has always been the seat of *the* money economy” (Mitchell 2002, 80-81).

Mitchell goes on to argue that a new, more general concept was developed by economists like John Maynard Keynes, in part as a result of their work managing the circulation of money in the enclosed geographical space of colonial India, which he writes led them to refer to the economy as “a self-contained mechanism whose internal parts are imagined to move in a

dynamic and regular interaction, separate from the irregular interaction of the mechanism as a whole with what could now be called its exterior” (Mitchell 2002, 82, 2005). If Mitchell is right about this, his argument points to a further significant dimension of the cultural history of concepts of mechanism I have been developing here. Mitchell never analyses mechanism in detail, but two revealing moments in his careful histories of colonization and economics underline this possibility. In *Colonizing Egypt*, Mitchell offers a telling account of the terms in which the Earl of Cromer described what he called the state machinery and political machinery of Egypt in the 1907 book *Modern Egypt*. There Mitchell argues that at the point at which Cromer described his own power as Consul General as mechanical, he resorted also to images of the body politic (Mitchell 1988, 159-60). Similarly, more recently Mitchell has shown that when supervising the cadastral survey of Egypt in the same period, Captain Henry Lyons described the survey as depending on “an almost mechanical system of work... carrying the principle of the division of labour to its extreme possible development” (Mitchell 2002, 89 and 119). After returning to Britain in 1907, Lyons served as director of the Science Museum in the period from 1920 to 1933 when it first won substantial audiences, in part by reorienting its displays and labels to address first the ordinary visitor and second the technical visitor, as well as students and specialists (like Mumford, who visited in preparation for his book) (Follett 1978, 98).

The earliest sustained empirical discussion of market mechanisms that I know is the University of Chicago PhD dissertation that Edwin G. Nourse published in 1918. Attempting to understand the mechanisms and forces operating between farmers and city consumers to form prices, Nourse examined the Chicago Produce Market and drew attention to the unusual

value of focusing on a market *city* in contrast to earlier studies of markets in specific goods or classes of goods (Nourse 1918). Then worried by monopolies, Nourse soon addressed the relations between American agriculture and the European market (Grether 1958). While there had been occasional references to the price mechanism in the nineteenth century, it became increasingly common for economists to write of price and market mechanisms after World War I. Sometimes looking back to Adam Smith's discussion of the "higgling of the market," their main aim was to articulate the role that prices play in the equilibrium of supply and demand in the subjective or marginalist approach to economics that had emerged from the 1870s onwards, and they were often occasioned by postwar debates on planned economies and socialism. Together with Nourse's care in navigating the distinction between specific markets, these debates (and later, responses to the stock market crash of 1929) explain why such references to mechanisms amongst economic experts commonly raised critical questions about the generality of economic concepts. As we shall see, they also often turned on the awkward status of economic theories and their simplification in lay circles. Collectively these circumstances make it difficult to evaluate the accuracy of Mitchell's subtle point about "the economy," but they also highlight its significance.

Considering two very different accounts from 1921 will illustrate tensions of this kind between specific and general concepts amongst diverse audiences. The London School of Economics anthropologist Bronislaw Malinowski began a paper for *The Economic Journal* by noting that for the Melanesian islanders he had studied "national economy does not exist," if one means by that "a system of free competitive exchange of goods and services, with the

interplay of supply and demand determining value and regulating all economic life.” But he went on to argue against following the Leipzig professor of economic history Karl Bücher in assuming the only alternative was a pre-economic stage based on a single household satisfying their wants “without any more elaborate mechanism than division of labour according to sex, and an occasional spasmodic bit of barter.” Rather, Trobriand production, consumption and exchange were “socially organized and regulated by custom,” and governed by “a special system of traditional values.” Malinowski coined the term tribal economy to describe the new concept he had developed as a result of his fieldwork, and urged that comparative studies might elucidate “the nature of the economic mechanism of savage life” (Malinowski 1921, 12, 15). His writing illustrates an easy association between social mechanisms and economics, and a readiness to speak of a national economy – while arguing for a different form of economy. By contrast, in an account of risk and uncertainty later reprinted in an LSE series in 1933, the University of Iowa economist Frank Knight defined his discipline in terms of free enterprise, while also admitting this was a highly idealized conception. Writing that economics was the study of a particular form of wants-satisfying activity called free enterprise, which was prevalent in the western nations and “spread over the greater part of conduct,” he acknowledged immediately that it was “obviously not at all completely or perfectly competitive,” but asserted that just as clearly its general principles “are those of free competition” (Knight 1933 [1921], 9). Knight went on to stress the significance of recognising the assumptions underlying the application of the general principles of economics to complex facts, writing that neglecting this had led economic theorists to untenable and often vicious

deductions that naturally harmed the credibility of the science. Revealingly, Knight articulated this problem and its solution by developing at some length a comparison between theoretical economics and theoretical mechanics. Pointing to public appreciation of the limits of mechanics he argued it was necessary that “the contrast between these simplified [economic] assumptions and the complex facts of life be made as conspicuous and as familiar as has been done in mechanics” (Knight 1933 [1921], 9, 11).

Knight’s work shows that analogies with theoretical mechanics could be productive in clarifying the nature of economic knowledge; a study of Friedrich Hayek’s distinctive understanding of markets will show that he referred to the rhetorical dimensions of mechanical discourse even as he asserted a stronger basis for his views. Post war debates about economic planning, the rise of the Soviet Union and later World War II were all central to the development of Hayek’s thought. Combatting the strong distinctions often assumed in post World War II histories of economics and common understandings of the emergence of neoliberalism, Johanna Bockman and Ben Jackson have insisted on the significance of constructive dialogue throughout the interwar period. Models of socialism and of markets were often used hand in hand methodologically, and sometimes, as in the earlier work of Leon Walras, Vilfredo Pareto and Enrico Barone, they were combined. Far from being regarded as essentially antagonistic, under certain assumptions and conditions, socialism and markets were even regarded as equivalent. Whole economies were modelled mathematically but they were rarely thought to represent the heterogeneous conditions of political economy in any full sense (Pareto, for example, turned to sociology towards the end of his life in order to understand why abstract mathematical theories did not work out in

practice). As Bockman notes, early Soviet thinkers like Bukharin were also deeply familiar with neoclassical thought, because it provided important models and tools for socialist approaches and had to be critiqued. Jackson's close-grained study of the 1930s helpfully shows that leading neoliberal figures like Hayek at the London School of Economics, Walter Lippmann in New York and Herbert Simons in Chicago all reflected a similarly open perspective. Suspicious of the moral failures of nineteenth-century capitalism and liberalism, they emphasised value commitments shared with socialists, and also endorsed significant state regulation and redistribution (Jackson 2010). Collectively this research therefore highlights still more strongly the importance of the transition that Hayek's biographer Bruce Caldwell has charted, most evident in Hayek's well-known papers of 1937 on "Economics and Knowledge," and of 1945 on "The Use of Knowledge in Society" (Caldwell 2004).

Soon after moving from Vienna to London, in 1933 Hayek offered a historical portrait of the fortunes of the economist that tied the poor reputation of the science to the difficulty of recognising the proper nature of its subject matter – which he called a "highly complicated mechanism," but, following Ludwig von Mises, described more often as an "organism" (von Hayek 1933, 123 (for mechanism) and 123, 130-131 (organism)). In the 1937 paper in which he moved from thinking of markets in terms of the flow of goods, to knowledge, Hayek identified the problem that the perfect market that had to be assumed in equilibrium theories "must not be confined to the markets of all the individual commodities; the whole economic system must be assumed to be one perfect market in which everybody knows everything" (von Hayek 1937, 44-45). He then focused on explaining how individuals would acquire this

knowledge, allowing that it was extremely difficult to say what assumptions were required to establish a tendency towards equilibrium and claim the analysis applied to the real world (von Hayek 1937, 47). Still more important was dealing with a division of knowledge, which was analogous to and as significant a problem as the division of labour; it was the really central problem of economics as a social science. Hayek was identifying the point he thought needed to be resolved in the gulf between perfect knowledge and planning, and spontaneous individuals, asking how fragmentary knowledge in different minds could bring about a result that would otherwise require a knowledge that no single person can possess.

It was in 1945 that Hayek found a solution in the “price system” and wrote concretely and explicitly in terms of a general economic mechanism. The key elements of his view had in fact already been assembled a year earlier in his surprisingly influential argument against socialist planning, *The Road to Serfdom*, where they bore the explicitly moral perspective of that book’s political aims. There, Hayek described the price mechanism as impersonal and established an evocative contrast between on the one hand the price mechanism and impersonal forces of a competitive society, and on the other hand direct regulation by authority, the war machine, the state machine or the totalitarian machine. He argued that while people may submit to a suffering that could hit anyone (such as “the impersonal mechanism known by us as the price system”), it is much harder to submit to one resulting from the decision of an authority. “It may be bad to be just a cog in an impersonal machine,” he wrote, “but it is infinitely worse if we can no longer leave it, if we are tied to our place and to the superiors who have been chosen for us” (Hayek 1944, v, 27-29, 86, 112, on 36-37, 80) Hayek’s language shows that he

too associates mechanism generally with many of the negative connotations we have seen in earlier discussions, while also ascribing a distinctive moral advantage to “impersonal” mechanisms.

In his paper on knowledge a year later, Hayek was able to explicitly treat the coordination of information on the scale of the entire economy. Giving a rich example of how consumers react to the increasing price of tin to save and direct resources elsewhere even without knowing what has made the metal scarce, Hayek described the effects shifting through the economic system and wrote “the whole acts as one market,” because limited individual fields of vision overlap sufficiently to pass on the relevant information. Now he wrote:

It is more than a metaphor to describe the price system as a kind of machinery for registering change, or a system of telecommunications which enables individual producers to watch merely the movement of a few pointers, as an engineer might watch the hands of a few dials, in order to adjust their activities to changes of which they may never know more than is reflected in the price movement (Hayek 1945, 521, cf. Hayek 1944, 36-37).

The argument that you can reconcile imperfect individual knowledges to an economic system through prices allowed Hayek to proclaim the whole as one market – at the same time that he described the role of prices as a comprehensive information mechanism. Hayek’s changing perspective nicely confirms Mitchell’s argument about the gradual rise of general concepts of the economy. With its delicate negotiation of tensions between merely metaphorical and material instances of mechanism, his discussion also

indicates the creative role of the heterogeneous and multiplying concepts of mechanisation that I have traced here. By 1944 and 1945, Hayek had artfully absorbed the 1930s technocratic engineer into his vision of the individual watching prices, finding a way to reconcile disparate economic systems and incorporate the idea of general planning within the concept of the market itself.

Hayek's next paragraph takes up the problem of formal generality, only to dismiss it. He allows that the adjustments probably never meet the perfection of knowledge required of equilibrium analysis, but suggests economists should not be blinded to the true function of the price mechanism by applying the misleading standard of the assumption of perfection. Then he goes on to perform the conceptual feat of deliberately leading his readers to re-evaluate their understanding of the price mechanism. Remarkably, the linguistic foundation for this work was to strip his account of the explicitly moral and evocative language he had used in 1944 – there is no spectre of either the impersonal or grim machinery of *The Road to Serfdom* – and then to reinvest the price mechanism with his own understanding of it as “marvel.” Hayek uses this term explicitly to shock people out of the complacency of typical understandings of prices, to now regard as marvellous the way the information of a rise in price alone leads thousands to respond appropriately to scarcity.

It is revealing that one of our most significant historians of economics began his work investigating the relations between physics and economics with a book entitled *Against Mechanisms* (Mirowski 1988). Like Caldwell, Mirowski describes Hayek as naturalising the market in terms of information flow from

1945 onwards, drawing attention to the role of the Mont Pèlerin Society and other institutions to further Hayek's political and intellectual aims (Mirowski 2002, 232-41, 2007). In recent years extraordinary historical attention has been devoted to Hayek, and a new field of economic engineering has arisen around the idea of identifying desired outcomes and then constructing mechanisms (or institutions) to achieve them (Ashworth 2014, Caldwell 2004, 2016, Hodgson 1994, Lewis 2016, Mirowski 2007, Tuerck 1995, Maskin 2015). Yet at least in our studies of technology, historians of science have usually focused far more on the issues of identity raised on the borders of science and technology and pure and applied science, than on the engagement of industrial physics with its markets; something that the contributions to this issue will go some way towards addressing. Historians and sociologists have recently begun to explore the performative work that economists have achieved in creating markets, mostly considering financial institutions developed in recent decades (Callon 1998, MacKenzie, et al. 2007). I hope the present paper can clarify respects in which the interwar period may have been significant for changing understandings of markets and the free economy. Responding equally to profuse forms of mechanisation brought together in city streets and goods at the market, the valence of the machine, and the attraction of mechanisms, Hayek, for one, found a new accommodation to overcome the burden of perfection and find a general mechanism in prices. Exploring the extent to which understandings of mechanism are more or less than metaphor thus helps demonstrate the ways that mechanisms and the economy must be understood culturally, in order to modulate the diverse senses in which they are impersonal and marvellous or might express quite other relations.

Conclusion

There are several important features about counter-posing the diverse accounts and fields and settings that I have tried to draw together so rapidly here. One is that many of the figures I have discussed considered themselves to be part of a common discussion and a continuous history. For all his lambast against physics, Spengler had read avidly in the subject in the course of his doctorate in philosophy; Chase had visited the Soviet Union and Bukharin in turn noted both his work and Spengler's; socialists and neoliberals were in an intimate conversation through several decades. Yet as Omodeo has illustrated in a recent study of Bukharin, these connections have too often slipped from our understanding, partly because of the way they reached across disciplinary, national and political traditions that were pursued agonistically, sometimes throughout the interwar, post World War II and Cold War periods (Omodeo 2016). Extending our treatment of the Zeit- and Chrono-geist in more comprehensive and critical examinations of the historical authority and discursive context for contemporaries' claims, we should be ready to follow such links and test them more thoroughly than we often do.

I can point to both the scope and limitations of my own endeavour to establish interrelations between subjects usually treated separately by noting that in 1940 the anthropologist Melville Herskovits began the first major textbook dedicated to the emerging field of economic anthropology with a chapter entitled "Before the Machine." He made the point that most people still live without machines and outlined the varied effects of industrial processes in a machine society before developing his comparative discussion of specific facets of economic activities amongst primitive peoples (Herskovits

1940). This paper has explored discourse on the machine to establish the coherence of thinking in terms of machine society and a machine age, but just as Herskovits pointed to a critical lacuna beyond machine society, I have emphasised difficult, creative ambiguities within it. The first section of this paper examined the rise of an international discourse on the machine and a machine age that was given a new inflection by the variety of forms of mechanisation pervading life, and by World War I. Authors discussing machines often moved between physics and mechanics in particular as an image of the intellectual life of science, and the engineer as the master of the machine, but they were also concerned with understanding industrial entrepreneurship. Tracing the generality of their discourse allows us to identify common themes structuring what have often been approached as distinct national contexts. The two final sections explored how artists and an economist responded to a profusion of machines and mechanisation with a creative emphasis on collage documenting the city in Dada and film, and the articulation of a new form of generality in the price system as an economic machinery – the free market economy.

In the interwar period many recognised an ambiguously pervasive profusion of forms of mechanisation in the meeting of diverse systems, people and goods in city streets and markets. Perhaps this is mundane and everyday, caught in a documentary film. Perhaps it is threatening in its abstraction and desiccation, machined and rigid. Perhaps it is radiant or marvellous in its impersonal freedom. In the tensions between these possibilities I think we see the extraordinary novelty of the machine age, when modern life was possibly, projectively mechanical to such creative or destructive effect.

- Agar, Jon. *The Government Machine: A Revolutionary History of the Computer*. History of Computing. Cambridge, Mass. ; London: MIT Press, 2003.
- Ashworth, William J. "The British Industrial Revolution and the Ideological Revolution: Science, Neoliberalism and History." *History of Science* 52, no. 2 (June 1, 2014 2014): 178-99.
- Bertoloni Meli, Domenico. *Thinking with Objects : The Transformation of Mechanics in the Seventeenth Century*. Baltimore: The Johns Hopkins University Press, 2006.
- Biro, Matthew. *The Dada Cyborg: Visions of the New Human in Weimar Berlin*. Minneapolis: Univ. of Minnesota Press, 2009.
- Bix, Amy Sue. *Inventing Ourselves out of Jobs? America's Debate over Technological Unemployment, 1929-1981*. Studies in Industry and Society. Baltimore/London: Johns Hopkins Univ. Press, 2000.
- Bukharin, N.I. "Theory and Practice from the Standpoint of Dialectical Materialism." In *Science at the Cross Roads: Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931 by the Delegates of the U.S.S.R.*, 1-23. London: Kniga, 1931.
- Caldwell, Bruce. "F. A. Hayek and the Economic Calculus." *History of Political Economy* 48, no. 1 (March 1, 2016 2016): 151-80.
- . *Hayek's Challenge: An Intellectual Biography of F.A. Hayek*. Chicago: Univ. of Chicago Press, 2004.
- Callon, Michel, ed. *The Laws of the Markets*, Sociological Review Monograph. Oxford: Blackwell, 1998.
- Carson, Cathryn, Alexei Kojevnikov, and Helmuth Trischler, eds. *Weimar Culture and Quantum Mechanics: Selected Papers by Paul Forman and Contemporary Perspectives on the Forman Thesis*. London/Singapore: Imperial College Press/World Scientific Publishing, 2011.
- Chase, Stuart. *Men and Machines*. London: J. Cape, 1929.
- Cook, Simon. "Our Eyes, Spinning Like Propellers": Wheel of Life, Curve of Velocities, and Dziga Vertov's "Theory of the Interval." *October* 121 (2007): 79-91.
- Einstein, Albert. *Über Die Spezielle Und Die Allgemeine Relativitätstheorie: Gemeinverständlich*. Braunschweig: Vieweg, 1917.
- Feldman, Seth. "'Peace between Man and Machine': Dziga Vertov's *Man with a Movie Camera*." In *Documenting the Documentary: Close Readings of Documentary Film and Video*, edited by Barry Keith Grant and Jeanette Sloniowski, 19-34. Detroit: Wayne State Univ. Press, 2013 [1998].
- Follett, David. *The Rise of the Science Museum under Henry Lyons*. London: Science Museum, 1978.
- Forman, Paul. "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology." *History and Technology* 23 (2007): 1-152.
- . "Weimar Culture, Causality and Quantum Theory, 1918-1927: Adaptation by German Physicists and Mathematicians to a Hostile Intellectual Environment." *Historical Studies in the Physical Sciences* 3 (1971): 1-116.
- Freeman, R. Austin. *Social Decay and Regeneration*. London: Constable, 1921.
- Graham, Loren R. "The Socio-Political Roots of Boris Hessen: Soviet Marxism and the History of Science." *Social Studies of Science* 15 (1985): 705-22.

- Grether, E.T. "Edwin Griswold Nourse." *Journal of Marketing* 22, no. 4 (1958): 417-19.
- Hall, Karl. "Contribution to Fashioning Global Patent Cultures (Permission to Cite Required)." (Forthcoming 2017?).
- Hård, Mikael. "German Regulation: The Integration of Modern Technology into National Culture." In *The Intellectual Appropriation of Technology: Discourses on Modernity, 1900-1939*, edited by Mikael Hård and Andrew Jamison, 33-67. Cambridge, MA: MIT Press, 1998.
- Hård, Mikael, and Andrew Jamison, eds. *The Intellectual Appropriation of Technology: Discourses on Modernity, 1900-1939*. Cambridge, MA: MIT Press, 1998.
- Hart, David M. *Forged Consensus: Science, Technology, and Economic Policy in the United States, 1921-1953*. Princeton Studies in American Politics : Historical, International, and Comparative Perspectives. Princeton, NJ/Chichester: Princeton Univ. Press, 1998.
- Hayek, F. A. *The Road to Serfdom*. London: George Routledge and Sons, 1944.
- Hayek, Friedrich A. "The Use of Knowledge in Society." *The American Economic Review* 35 (1945): 519-30.
- Henderson, Linda Dalrymple. "Einstein and 20th-Century Art: A Romance of Many Dimensions." In *Einstein for the 21st Century*, edited by Peter Galison, Gerald Holton and S.S. Schweber, 101-27. Princeton: Princeton Univ. Press, 2008.
- Hentschel, Klaus. *Interpretationen Und Fehlinterpretationen Der Speziellen Und Der Allgemeinen Relativitätstheorie Durch Zeitgenossen Albert Einsteins*. Science Networks Historical Studies. Vol. 6, Basel/Boston: Birkhäuser, 1990.
- , ed. *Physics and National Socialism: An Anthology of Primary Sources*. Basel/Boston/Berlin: Birkhäuser, 1996.
- Herf, Jeffrey. *Reactionary Modernism: Technology, Culture, and Politics in Weimar and the Third Reich*. Cambridge: Cambridge University Press, 1984.
- Herskovits, Melville J. *The Economic Life of Primitive Peoples*. New York/London: A.A. Knopf, 1940.
- Hessen, B. "The Social and Economic Roots of Newton's 'Principia'." In *Science at the Cross Roads: Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931 by the Delegates of the U.S.S.R.*, 1-62. London: Kniga, 1931.
- Hilliard, Christopher. *English as a Vocation: The Scrutiny Movement*. Oxford: Oxford University Press, 2012.
- Hodgson, Geoffrey M. "Hayek, Evolution, and Spontaneous Order." In *Natural Images in Economic Thought: Markets Read in Tooth and Claw*, edited by Philip Mirowski, 408-48. Cambridge: Cambridge University Press, 1994.
- Jackson, Ben. "At the Origins of Neo-Liberalism: The Free Economy and the Strong State, 1930–1947." *Historical Journal of Film, Radio and Television* 53 (2010): 129-51.
- Jakobsen, Kjetil, Ketil G. Andersen, Tor Halvorson, and Sissel Myklebust. "Engineering Cultures: European Appropriations of Americanism." In *The Intellectual Appropriation of Technology: Discourses on Modernity, 1900-1939*, edited by Mikael Hård and Andrew Jamison, 101-27. Cambridge, MA: MIT Press, 1998.
- Jamison, Andrew. "American Anxieties: Technology and the Reshaping of Republican Values." In *The Intellectual Appropriation of Technology:*

- Discourses on Modernity, 1900-1939*, edited by Mikael Hård and Andrew Jamison, 69-100. Cambridge, MA: MIT Press, 1998.
- Joffe, A.F. "Physics and Technology." In *Science at the Cross Roads: Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931 by the Delegates of the U.S.S.R.*, 1-4. London: Kniga, 1931.
- Joravsky, David. *Soviet Marxism and Natural Science, 1917-1932*. Studies of the Russian Institute, Columbia University. New York: Columbia Univ. Press, 1961.
- Jordan, John M. *Machine-Age Ideology: Social Engineering and American Liberalism, 1911-1939*. Chapel Hill: Univ. of North Carolina Press, 1994.
- Ketabgian, Tamara. *The Lives of Machines: The Industrial Imaginary in Victorian Literature and Culture*. Ann Arbor: University of Michigan Press/digitalculturebooks, 2011.
- Knight, Frank H. *Risk, Uncertainty and Profit*. Series of Reprints of Scarce Tracts in Economic and Political Science. London: London School of Economics and Political Science, 1933 [1921].
- Kojevnikov, Alexei. "The Phenomenon of Soviet Science." *Osiris* 23 (2008): 115-35.
- Kotkin, Stephen. "Modern Times: The Soviet Union and the Interwar Conjunction." *Kritika: Explorations in Russian and Eurasian History* 2, no. 1 (2001): 111-64.
- Kuenzli, Rudolf E., ed. *Dada, Themes and Movements*. London: Phaidon, 2011.
- Lenard, Philipp. *Deutsche Physik in Vier Bänden*. 4 vols München: J.F. Lehmann, 1936.
- Lewis, Paul. "The Emergence of "Emergence" in the Work of F. A. Hayek: A Historical Analysis." *History of Political Economy* 48, no. 1 (March 1, 2016 2016): 111-50.
- Mackay, John. "Film Energy: Process and Metanarrative in Dziga Vertov's "the Eleventh Year" (1928)." *October* 121 (2007): 41-78.
- MacKenzie, Donald A., Fabian Muniesa, and Lucia Siu. *Do Economists Make Markets? On the Performativity of Economics*. Princeton, NJ/Woodstock: Princeton University Press, 2007.
- Makela, Maria. "The Misogynist Machine: Images of Technology in the Work of Hannah Höch." In *Women in the Metropolis: Gender and Modernity in Weimar Culture*, edited by Katharina von Ankum, 106-27. Berkeley, CA/London: Univ. of California Press, 1997.
- Malinowski, Bronislaw. "The Primitive Economics of the Trobriand Islanders." *The Economic Journal* 31, no. 121 (1921): 1-16.
- Maskin, Eric S. "Friedrich Von Hayek and Mechanism Design." *The Review of Austrian Economics* 28 (2015): 247-52.
- Mayer, Eduard von. *Technik Und Kultur: Gedanken Über Die Verstaatlichung Des Menschen*. Berlin: Hüpeden & Merzyn, 1906.
- McLaren, Angus. *Reproduction by Design: Sex, Robots, Trees, and Test-Tube Babies in Interwar Britain* [in English U6 - viii + 235 pp.]. University of Chicago Press, 2012.
- Mirowski, Philip. *Against Mechanism: Protecting Economics from Science*. Totowa, NJ: Rowman & Littlefield, 1988.
- . *Machine Dreams: Economics Becomes a Cyborg Science*. Cambridge: Cambridge University Press, 2002.

- . "Naturalizing the Market on the Road to Revisionism: Caldwell on Hayek's Challenge." *Journal of Institutional Economics* 3 (2007): 351-72.
- Mitchell, Timothy. *Colonising Egypt*. Cambridge Middle East Library. Cambridge: Cambridge University Press, 1988.
- . "Economics: Economists and the Economy in the Twentieth Century." In *The Politics of Method in the Human Sciences: Positivism and Its Others in the Social Sciences*, edited by George Steinmetz, 126-41. Durham/London: Duke Univ. Press, 2005.
- . *Rule of Experts - Egypt, Techno-Politics, Modernity*. Berkeley: University of California Press, 2002.
- Moellendorff, Wichard von. "Das Technische Motiv." *Die Zukunft* 85 (1913): 415-20.
- . "Der Ingenieur." *Die Zukunft* 80 (1912): 425-32.
- Müller, Falk. "The Industrializing Electron: Aeg, Electron Optics and the Beginning of Electronics in Germany." *Science in Context* (2018?).
- Mumford, Lewis. *Technics and Civilization*. Chicago: Univ. of Chicago Press, 2011 [1934].
- . *Technics and Civilization*. New York: Harcourt, 1934.
- Nourse, Edwin Griswold. *The Chicago Produce Market: A Study of Market Mechanism as a Factor in Price Determination*. Hart, Schaffner & Marx Prize Essays, Xxv. Boston: Houghton Mifflin, 1918.
- Oldenziel, Ruth. *Making Technology Masculine: Men, Women and Modern Machines in America, 1870-1945*. Amsterdam: Amsterdam University Press, 1999.
- Omodeo, Pietro D. "After Nikolai Bukharin." *History of the Human Sciences* 29, no. 4-5 (2016/10/01 2016): 13-34.
- Ostwald, Wilhelm. *Energetische Grundlagen Der Kulturwissenschaft*. Leipzig: Alfred Kröner Verlag, 1909.
- Rabinbach, Anson. *The Human Motor: Energy, Fatigue, and the Origins of Modernity*. New York 1990.
- Rathenau, Walther. *Der Kaiser: Eine Betrachtung*. Berlin: S. Fischer Verlag, 1919.
- . *Zur Kritik Der Zeit*. Berlin: S. Fischer, 1925 [1912].
- Riskin, Jessica. *The Restless Clock: A History of the Centuries-Long Argument over What Makes Living Things Tick*. Chicago: Univ. of Chicago Press, 2015.
- Rodgers, Daniel T. *Atlantic Crossings: Social Politics in a Progressive Age*. Cambridge, MA: Harvard Univ. Press, 1998.
- Ruse, Michael. "Darwinism and Mechanism: Metaphor in Science." *Studies in History and Philosophy of Science Part C* 36, no. 2 (2005): 285-302.
- Ruttmann, Walther. "The Filming of Berlin." *New York Times*, May 20 1928, 108.
- S. Hirzel Verlag. "S. Hirzel Leipzig, Träger Des Nobelpreises Für Physik Für Das Jahr 1918, Dr. Max Planck, Für Das Jahr 1919, Dr. Johannes Stark." *Physikalische Zeitschrift* 20, no. 23 (1919): IV.
- . "Verlag Von S. Hirzel in Leipzig Soeben Erschien in Neuer Vermehrter Auflage, Über Relativitätsprinzip, Äther, Gravitation, Von P. Lenard, Preis 5 Mark." *Physikalische Zeitschrift* 21, no. 13 (1920a): II.
- . "Verlag Von S. Hirzel in Leipzig, Kollegien-Hefte." *Physikalische Zeitschrift* 21, no. 11 (1920b): V.
- Schatzberg, Eric. "From Art to Applied Science." *Isis* 103, no. 3 (2012): 555-63.
- . "Technik Comes to America: Changing Meanings of Technology before 1930." *Technology and Culture* 47 (2006): 486-512.

- Scott, James C. *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven/London: Yale Univ. Press, 1998.
- Simmel, Georg. "Extract from 'the Metropolis and Mental Life'." Translated by Kurt H. Wolff. In *Modernism*, edited by Michael H. Whitworth, 182-89. Malden, MA: Blackwell, 2007 [1903].
- Sombart, Werner. *Der Bourgeois; Zur Geistesgeschichte Des Modernen Wirtschaftsmenschen*. München: Duncker & Humblot, 1913.
- . "Technik Und Kultur." *Archiv für Sozialwissenschaft und Sozialpolitik* 33 (1911): 305-47.
- Spengler, Oswald. *Der Untergang Des Abendlandes. Umriss Einer Morphologie Der Weltgeschichte. 1. Band: Gestalt Und Wirklichkeit. 4., unveränderte Auflage* ed. München: Oskar Beck, 1919 [1918].
- . *Der Untergang Des Abendlandes. Umriss Einer Morphologie Der Weltgeschichte. 2. Band: Welthistorische Perspektiven*. München: Oskar Beck, 1923 [1922].
- . *Heraklit: Eine Studie Über Den Energetischen Grundgedanken Seiner Philosophie*. Halle: Hofdruckerei C.A. Kaemmerer & Co., 1904. Der metaphysischen Grundgedanke der heraklitischen Philosophie (Koktanek gives this as the title of the dissertation, and the alternative listed above as the title of its publication in *Reden und Aufsätze* (München: C.H. Beck, 1937).
- Staley, Richard. "The Fin De Siècle Thesis." *Berichte zur Wissenschaftsgeschichte* 31 (2008): 311-30.
- Tuerck, David G. "Economics as Mechanism: The Mind as Machine in Hayek's Sensory Order." *Constitutional Political Economy* 6, no. 3 (01/1995 1995): 281-92.
- Turvey, Malcolm. "Vertov: Between the Organism and the Machine." *October* 121 (2007): 5-18.
- van Dongen, Jeroen. "Reactionaries and Einstein's Fame: 'German Scientists for the Preservation of Pure Science,' Relativity, and the Bad Nauheim Meeting." *Physics in Perspective* 9, no. 2 (2007): 212-30.
- Veblen, Thorstein. *The Engineers and the Price System*. New York: Harcourt, 1963 [1921].
- Volkov, Shulamit. *Walther Rathenau: The Life of Weimar's Fallen Statesman*. New Haven: Yale Univ. Press, 2012.
- von Hayek, F. A. "The Trend of Economic Thinking." *Economica*, no. 40 (1933): 121-37.
- von Hayek, F.A. "Economics and Knowledge." *Economica* 4, no. 13 (1937 1937): 33-54.
- Wazeck, Milena. "The 1922 Einstein Film: Cinematic Innovation and Public Controversy." [In English]. *Physics in Perspective* 12 (2010): 163-79.
- . *Einstein's Opponents: The Public Controversy About the Theory of Relativity in the 1920s*. Translated by Geoffrey S. Koby. Cambridge: Cambridge Univ. Press, 2014.
- . *Einsteins Gegner. Die Öffentliche Kontroverse Um Die Relativitätstheorie in Den 1920er Jahren*. Frankfurt am Main: Campus, 2009.
- Werskey, Gary. "Introduction: On the Reception of Science at the Cross Roads in England." In *Science at the Cross Roads: Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931 by the Delegates of the U.S.S.R.*, xi-xxix. London: Frank Cass & Co., 1971.

- . *The Visible College: A Collective Biography of British Scientists and Socialists of the 1930s*. London: Free Association Books, 1988.
- Wilson, Daniel C. S. "J.A. Hobson and the Machinery Question." *Journal of British Studies* 54, no. 2 (2015): 377-405.
- Wise, M. Norton. "Forman Reformed, Again." In *Weimar Culture and Quantum Mechanics: Selected Papers by Paul Forman and Contemporary Perspectives on the Forman Thesis*, edited by Cathryn Carson, Alexei Kojevnikov and Helmuth Trischler, 415-32. London/Singapore: Imperial College Press/World Scientific Publishing, 2011.
- Zavadovsky, B. "The 'Physical' and 'Biological' in the Process of Organic Evolution." In *Science at the Cross Roads: Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931 by the Delegates of the U.S.S.R.*, 1-12. London: Kniga, 1931.