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Constructing an “industry”: The case of industrial gases, 1886-2006¹

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Introduction

At the outset of chapter two of his highly influential *The Competitive Advantage of Nations*, Michael Porter declared that “Firms, not nations, compete in international markets”, thus placing the enterprise at the centre of the contemporary globalised economy. Further down the page, though, he inserts a third key term into the mix: “The basic unit of analysis for understanding competition is the industry.” “An industry (whether a product or service),” he continues, “is a group of competitors producing products or services that compete directly with one another”.² Here and in the rest of his very long book, Porter thus posits a straightforward relationship between an industry as the “basic unit of analysis” on the one hand, and the firms in that industry as the locus of competition and competitiveness on the other. But he does not explore this assertion any further.

Porter is not alone among historically oriented social scientists, most of whom likewise tend to take “industries” as given and are wont in particular to leave the relationship between industries and firms unexamined, essentially eliding firms and their industries. Business historians, for instance, quite understandably privilege the firm or enterprise in their research.³ The industry within which the firm operates may well figure prominently in their analyses, but the “industry’s” existence and characteristics are generally assumed rather than clearly analysed or defined, and the concept is usually static, something perhaps astonishing given that the scholars involved study change over time. For historically oriented evolutionary economists, on the other hand, the industry is the primary focus of analysis.⁴ The firm may figure

prominently—and indeed Murmann⁵ and others have brought them into their narratives as key actors—; but the industry remains at the centre. Nelson has argued that paying more attention to individual firms would be a wise move for economists, while more recently Dekkers and Bloch and Finch have argued that examining the interaction between firms and their industries is essential for understanding both.⁶ But even here, conceptions of “industries” are not clearly defined and, implicitly at least, are static.

Why does this matter? There are a number of reasons, which we will examine in some detail over the course of this article. But let us just start with one very good one: business historians and other historically oriented social scientists potentially have a lot to learn from one another. Until, though, we can all focus our attentions on a common—and commonly and clearly understood—unit (or units) of analysis, there will be natural limits to fruitful dialogue. Essentially, what we are arguing for is explicit articulation and recognition of “industry” and, more importantly, of “firm-industry interaction” as concepts which can usefully serve both business historians and social scientists in other disciplines. This will not break down disciplinary boundaries—that is not the intention here. Instead, it will enable a variety of disciplinary groups to utilise these concepts for their own purposes, essentially serving as what scholars in Science and Technology Studies (STS) have termed “boundary objects”.⁷

We have come to this view in the course of researching the case of the industrial gases industry, which has existed in some form or another for more than a century, and we will make our key points on the basis of this case, although we also contend that these points have more general validity. Among other things, we will suggest not only that the elision of firm and industry is problematic in a number of

ways, but also that it impedes a full understanding of both. The lack of clear analytical separation of firm and industry is problematic in the first instance because it prohibits careful examination of the relationship between the two. It also obscures the fact that industries are amorphous and protean, and that they are constructed by various actors over time, including firms and their managers, but also governments and industry associations among others. In essence, then, “industry” thus tends, in general usage, to be a static concept, even among those social scientists who emphasize the importance of historical development. A further key issue highlighted by this case study is that the imprecise designation of evolving relationships between firm and industry tends to obscure firm strategy and behaviour, not least since the firm almost never maps directly onto the industry (and indeed, the industry does not map directly onto the firm). Why might this be important? We would argue that the case study of the development of the industrial gases industry over the long term indicates that competitiveness requires firms to make judgements about how best to balance their capabilities and assets in a number of industries/sectors at the same time and through time.

In what follows, we first provide a broad introduction to industrial gases before turning to one central issue, the “construction” of the industry over time. The disjunction between firm strategy and behaviour and the “industry” is the subject of the following section. We then turn to the issue of competitiveness in the industry over time before coming to some conclusions in the final section.

Constructing an industry

Industrial gases have been termed “the invisible industry”,⁸ and for good reason. Very few scholars have examined it in any detail, with studies limited by and large to company histories.⁹ Otherwise, only one book-length overview exists, but it

is by an industry insider and is far stronger on technical than on economic and business issues.¹⁰ The industry is “invisible” in another sense as well. Despite some of its largest players occupying positions within the Fortune 500, they tend not to be very well known.

But what do the firms in this invisible industry do? Here we come to a first pass at defining “the industry”. The North American Industrial Classification System (NAICS) for 2007 seems to offer a very clear definition, indicating that it comprises establishments which in 2007 produced the goods listed in order of value in Table 1.¹¹ The products are used in a wide variety of applications, indeed in virtually every manufacturing process and in many services as well. Key applications include cutting and welding; oxygen for use in steel manufacture; nitrogen for fire and explosion protection in petroleum refining; nitrogen and other gases for a variety of purposes, including cleaning of clean rooms, in electronic component manufacture; neon and other gases in lighting; nitrogen for quick-freezing meat and other foodstuffs and this and other gases for “protective atmospheres” in food processing; and carbonated beverage production. There are many others. Indeed, there are very few manufacturing processes which do not involve use of industrial gases.

Table 1: Sales of industrial gases in North American in 2007 in descending order of value

Hydrogen and argon	
“Other industrial gases”	(Includes helium, xenon, krypton, and so on)
Nitrogen	
Fluorocarbon gases	
Oxygen	

Carbon dioxide	
Acetylene	
“Other”	

Source: US Census Bureau, NAICS 325120.

The 2007 NAICS definition is clear enough, but for our purposes, i.e. not only defining the industry, but also exploring the relationship between it and its “component” firms, is far from unproblematic. For one thing, and this may be unique to this particular industry, by far the lion’s share of production of some of the key goods listed in Table 1 above has been carried out by firms which are clearly outside the industry. In 1962, for instance, the top five companies producing oxygen gas were, in rank order, BASF (West Germany), Sasol (South Africa), Anic (Italy), and American Cyanamid and DuPont (USA).¹² Not one of them would have been counted as a “member” of the industrial gases industry as defined by NAICS, not least because none of them sold the oxygen they produced. The case of acetylene has at times been even more extreme in this regard. An East German study from the early 1970s, for instance, estimated that 95-99 percent of all acetylene used in production internationally was “self-produced” by chemical firms; the sales of acetylene by companies in the gases industry thus represented a very tiny minority of overall output.¹³

Not only is most production of at least some key industrial gases carried out by firms outside the industry, those “inside” it, and certainly the most successful of them, produce other things in “other” industries. This characteristic, of course, is far from unique to industrial gases. In any case, the point is this: companies which would normally be seen (and would see themselves) as industrial gases firms have been

involved in a number of other industrial sectors, some closely related and some not. For instance, Swedish industrial gases manufacturer AGA, founded in 1899, made stoves, lighthouses, and radiators—indeed “everything but the kitchen sink”—in the 1950s and 1960s before refocusing on gases in the 1970s.¹⁴ British Oxygen Company (BOC), founded in 1886, was involved over the course of the twentieth century in a number of unrelated areas of production, including manufacture of siphons, vocational computing training, and distribution of chilled foods for Marks & Spencer.¹⁵ German Linde AG (founded in 1879 to exploit refrigeration technology) also was engaged in areas outside of industrial gases. In addition to refrigeration, Linde was heavily involved in forklift construction, not clearly or closely related to industrial gases, while Air Products and Chemicals, as its name implies, has been active in the general chemicals business—perhaps more closely related—for some time.¹⁶ What is more, all of the major companies in the industrial gases industry—and four of them dominate world sales since 2006, i.e. Linde, French Air Liquide, US-based Praxair, and Air Products—are heavily involved in manufacture of industrial gases production apparatus, e.g. air separation units, liquefiers, and so on. This is clearly related diversification compared to, for instance, forklifts or ethylene plants, which Linde also began manufacturing later in the post-war period. On the other hand, design and production of plant and equipment are activities which belong in (more or less specialised) engineering industry, and are clearly not part of the specialist chemical processing and handling industry which constitutes industrial gases manufacturing. Firms and industries do not marry up very well using these definitions.

The problematic aspects of the NAICS 2007 definition are, moreover, intensified when it is applied historically. In order to demonstrate this, let us recall the

list of products of the industry by value in 2007 presented in table 1 and expand on it briefly. Argon and hydrogen taken together constituted about one-third of industrial gases sales in the United States in 2007, while nitrogen made up just under 14 percent and oxygen about 11 percent of the total. “Other industrial gases”, including for instance neon and krypton, accounted for 16.8 percent of sales in the United States, and fluorocarbon gases (which would not normally be in the product palette of companies which view themselves as industrial gases companies) 13.2 percent. Carbon dioxide represented about 6.7 percent of US sales in 2007, and acetylene accounted for just under two percent.¹⁷ However, neither the list of gases produced for the NAICS for 2007 nor the proportions of sales reported there conforms in the least to the “industrial gases industry” when it came into existence in the late 19th and early 20th century: at the time, it was focused exclusively on oxygen and (for some firms) acetylene. Thus, the NAICS list is in fact the product of historical development involving the interaction of firms and technologies in the construction of the modern industrial gases industry.

Let us unpack this construction of an industry through a brief historical overview of its development. Insofar as there is a conventional view of industrial gases, the branch started with production of oxygen, which accounted for a very large percentage of sales in the 1890s and early part of the 20th century.¹⁸ In fact, however, oxygen manufacture and sales existed before there was really anything like what might be called an industrial gases industry. Various processes for small-scale production of oxygen of relatively low purity were available by the mid-19th century, with markets mainly focused on limelight for theatre. British-based Brins Oxygen Company (later renamed British Oxygen Company, or BOC) was the first major producer, however, starting large-scale commercial production of oxygen in 1886.

Again, though, purity levels were higher than before but, at 90-95 percent, still relatively low, and markets were limited. In fact, in spite of attempts to develop new markets and products, limelight was “the only really important oxygen consumer” through the 1890s and into the new century.¹⁹ The financial consequences were severe. The chairman of Brins, for instance, publicly lamented the lack of new sales outlets for oxygen at the company’s annual general meeting in 1896. It was 1899, 13 years after the company’s founding, before it could distribute dividends, and even then the dividend payment became possible only because about half of the original capital of the firm was written off.²⁰

In 1895, less than ten years after Brins was founded, and in spite of this severely constrained market, Carl von Linde, working in Germany, patented an air liquefaction process which promised even greater levels of production at far higher levels of purity. Several competing processes followed, but none of them actually was able to deliver on the promise of greater purity levels for oxygen in large quantities until the development of rectification technology in the early years of the 20th century, which finally enabled effective separation of oxygen from nitrogen, the other main component of dry air. Fortunately for those producing oxygen, by then a large and growing market was emerging, i.e. cutting and welding based on oxyacetylene torches.²¹

This brings up an important point. Oxygen manufacturing until the early 20th century can be characterised not so much as an industry as a potential solution in desperate search of a problem.²² New applications for cutting and welding starting in the first decade of the new century provided a very large and lucrative problem that oxygen could help solve. Cutting and welding would thus sustain both existing and new oxygen producers for many years to come, and indeed they remain important

markets for industrial gases producers. The new applications also led these firms—some faster than others—to add acetylene production to their product palette. Many of these companies also diversified into welding equipment manufacture.

By the 1920s, then, an “industry” of sorts had finally emerged, although the continuing complexities of definition deserve to be highlighted. Some companies, such as Swedish AGA, moved in the opposite direction from many others, i.e. starting from acetylene production and applications and then embracing air separation. Some made the decision to combine oxygen and acetylene production and distribution later than others: BOC, for instance, did not do so until 1930.²³ Some manufactured air separation units and related equipment, while some bought such apparatus, and not all produced welding equipment.

But these are not the most important aspects of the construction of this industry. After all, we have not even mentioned some of the key products in the 2007 NAICS classification, and the ones which we have dwelt on thus far, oxygen and acetylene, accounted together for less than 13 percent of sales in that year. What about the other product categories? The truth is that most of them became part of the “industrial gases industry” only well into the 20th century, generally speaking only after the end of World War II. Argon constitutes a slight exception in this regard since it became part of the product portfolio of some of the same firms operating in oxygen and acetylene production and sales already by the 1920s owing to a dynamic process of technological innovation: desire for higher purity levels of oxygen for use in cutting and welding required removal of argon from air, and incremental innovation enabled some producers to capture the argon in significant quantities. Argon also proved useful itself in electric arc welding, as a shielding gas. Still, even in this case it

was not until the 1950s that argon became a major product in the palette of air gases firms.

Hydrogen, on the other hand, was mostly produced and used by mainstream chemical firms, i.e. by companies not involved in the industrial gases sector, until well after 1945, and the same was true for the other major air gas, nitrogen, which did not become a prominent product for industrial gases producers until large-scale and/or specialist applications were developed for food processing, oil refining, and semiconductor manufacture among others. The larger and more technologically advanced firms which produced and sold oxygen and acetylene such as German Linde, French Air Liquide, and US-based Linde Air Products (later Praxair) usually designed and made the equipment which enabled production of hydrogen and nitrogen, but they did not produce or sell much of these gases themselves during the first several decades of their existence.

Carbon dioxide is another example of a product which became a clear and essential part of the industrial gases industry only very late, indeed in the 1960s and 1970s. Far easier to produce than air gases at the purity levels required for industrial use, and far safer to handle than oxygen or acetylene, carbon dioxide was made and sold by a range of companies even before Brins began large-scale production of oxygen in the late 1880s. But these carbon dioxide producers by and large did not consider themselves part of the industrial gases business. Nor were they considered part of the business by those firms operating in industrial gases: the technological level was too low, and the markets for carbon dioxide too different from those served by the sophisticated oxyacetylene producers. The separation of these two “industries” from one another is articulated explicitly, for instance, in contracts signed between air gases producers on the one hand and carbon dioxide producers on the other in

Germany during the period 1926-1945. The agreements specified that neither side would sell in the other's area of concentration, something which required periodic updating as new applications for gas mixtures containing, for example, carbon dioxide and nitrogen were developed.²⁴ These contracts between air gases and carbon dioxide producers were far more modest than, but at the same time analogous to the "division of fields" agreements between firms in two other "industries", oil and chemicals, which were also starting to overlap uncomfortably in the same decade by the 1920s.²⁵

This separation of the two remained the case until large-scale applications were developed in the 1920s and 1930s for "dry ice". But it was really the development of metal-active gas welding using carbon dioxide after 1953 and the subsequent development of additional industrial applications that gradually prompted those industrial gases producers which still did not have a foothold in this area to gain one, although the emphasis here must be on the *gradual* nature of the process. It was not until the 1970s and 1980s that the traditional gases companies scurried to acquire traditional carbon dioxide producers, in the process driving up acquisition prices considerably.²⁶

All of these examples serve to reinforce the point that industrial gases industry as it exists in the early 21st century is dramatically different from the industry that firms producing oxygen and/or acetylene began to construct at the beginning of the 20th century. Firms in the industry initially established a primary focus on servicing cutting and welding applications (which involved production and/or distribution of gases, primarily oxygen and acetylene); gas-production and separation equipment; and cutting and welding equipment. These three areas remained central to it until at least the 1950s, although only a handful of companies performed all of these

functions. As mentioned, too, many of them, including this handful of leading companies, performed other functions as well.

Starting in the United States in the 1950s, companies reconceived themselves and their industry in terms of an ever-growing array of specialist and/or large-scale applications for a widening range of gases, something spurred on by technological change in other industries, increasing international competition, and an increasingly proactive stance in applications development by the gases companies themselves. Air Products, for instance, had already established significant research and development capability in 1949 and was actively pursuing new applications during the decade that followed and beyond.²⁷ By the late 1950s, Air Liquide had joined the American firms in establishing dedicated applications centres,²⁸ and German Linde followed in the 1960s. By the last third of the 20th century, all major players in the industry had such centres.²⁹

If we look at the industrial gases industry today, it is dominated by four very large companies: Air Liquide; Linde (which gained an approximately co-equal market share to the French firm by virtue of its acquisition of AGA in 2000 and BOC in 2006); Praxair; and Air Products. All four offer a full range of gases and work closely with customers to develop new applications. All four of them not only produce, sell, and distribute gases, but also produce and sell air separation units and other related equipment, and they all do so internationally. They are, for the most part, focused entirely on these two related areas, one involving chemical processing, advanced logistics capabilities, and technical services, and the other involving specialised engineering and construction. There is, in other words, now something like an industry in the sense used by Porter and many others, composed of firms which compete directly with one another. But this is a relatively recent phenomenon, indeed

really only since the late 1990s. Up until then, however, these and other firms were not always competing with one another, or competed in multiple industries, with implications for company strategy and behaviour and the “industrial gases industry”.

The disjunction between firm strategy and behaviour and “the industry”

Given the notion of Porter and others that industry is the fundamental unit of analysis in analysing company strategy and behaviour, we might expect that these would be predicated largely by a given company’s view of its competitors’ capabilities, their anticipated strategies, and the implementation of those strategies. This, however, has not been the case for much of the twelve decades of the industrial gases industry’s existence. In its initial phase, between 1886 and just around the time of the outbreak of the First World War in 1914, the industry was characterised by rapid growth and technological change, in particular after the invention of several liquefaction processes, of rectification for effective air separation, and of a range of devices for oxyacetylene cutting and welding. There was also some international competition as Linde and then Air Liquide invested in the United States (in competition with one another) and the United Kingdom (in competition with BOC), for instance. But even before the European conflict broke out, however, international competition was lessening as companies came to agreements on sharing intellectual property and on geographic division of labour.

The Great War effectively stamped out international competition in major markets, with gentlemen’s agreements guaranteeing that each of the key gases firms would not have to face competition from any of the other key companies in its “home market” (which in the case of BOC and Air Liquide included the British and French empires respectively), although there was some competition between them in third markets such as Italy. It was a situation which remained in place until the early 1960s.

Within the national borders of some of the major gas-producing nations, on the other hand, there was initially quite a bit of competition, especially as the synergies between oxygen and acetylene became evident. BOC, for instance, did not have any presence in acetylene during the 1920s, but moved to cooperate more and more closely with acetylene producer Allen Liversidge during that decade before taking the smaller company over in 1930. It also faced potentially serious competition from Metal Industries Ltd's subsidiary Oxygen Industries in the early 1930s. Oxygen Industries had purchased the UK rights to new liquid oxygen production, distribution, and storage technologies which promised to revolutionise aspects of the industry. Again, BOC's answer to the potential competitor, following the threat of a lawsuit, was to take Oxygen Industries over in 1933.³⁰ From that point forward until the late 1950s, BOC was effectively Britain's "Ministry of Oxygen".³¹ Indeed, in 1956 the British Monopolies Commission found that the company controlled 98.5 percent each of the markets for oxygen and acetylene market, a situation the Commission suggested needed to change, but which took several years beyond the publication of the report before it did so.³²

Air Liquide's position in France was analogous to that of BOC in Britain during this same period, and it, too, had a near monopoly in its home market. Germany, the third major market for gases, was somewhat different in that there were, during the interwar period, two major gases producers, Linde and Chemische Werke Griesheim, and they were joined after World War II by a third, Messer, which had to that point focused almost exclusively on gas equipment design and construction.³³ The fact that Griesheim became part of the massive IG Farbenindustrie AG in 1925 meant that much smaller Linde was in a potentially precarious position, but even before the creation of the IG, the firms had agreed to split markets geographically and

to found a joint venture, Vereinigte Sauerstoffwerke, or VSW, for the distribution of gases.

The final major market, indeed by the 1920s already the largest of them all, was the United States. Like in Germany, there was more than one “champion”, although there, unlike Germany, explicit division of fields and markets agreements were illegal. Again, though, there was little direct competition, not least owing to the fact that the market was so large, and there was therefore room for regional players to establish themselves. This pattern was reinforced in turn by one of the salient characteristics of oxygen distribution during the first several decades of the industry’s existence: metal cylinders used for distribution of compressed gas weighed up to ten times as much as the oxygen they contained, and they therefore were uneconomical to transport over long distances. By the time that effective alternative means of distribution using liquid oxygen became widespread in the 1940s and beyond, the regional players, often “mom and pop” establishments, not only had close relationships with their customers; they also had long since written off the cost of their quite expensive steel cylinders, which were still a key means of distribution, especially to the ranks of small and medium-sized customers. A company challenging them would have had to invest in a large number of cylinders, something which would be ruinously expensive. So it is no surprise that this tended not to happen.³⁴

In other words, what we are dealing with here, at least from the last couple of years before 1914 through the 1950s, was an “industry” in which only very limited international competition took place, and in which precious little competition took place within national borders either, at least in the major industrialised countries. There was some important cooperation across international borders, especially in technological development, and the plant-building operation of some of the key

companies were often somewhat internationalised, with the exception of course of the period during the wars themselves. But given that crucial aspects of Porter's notion of an "industry" were missing for the most part, it is not surprising that the strategy and behaviour of individual firms differed markedly.

Swedish-based AGA, with the smallest home market among the major industrial gases companies, was, not surprisingly, the most internationalised among them in sales, investment, and outlook. It used its international orientation and extensive global sales experience to establish a major presence in a number of small markets, in particular in South America, but also in smaller European states. But AGA's strategy and behaviour were not determined exclusively, nor even largely, by the gases business per se. Until the 1970s, its managers did not see the company as part of the gases business. Instead, it was a vehicle for exploiting numerous, often not obviously related, inventions. Beginning in that decade, there was a conscious decision by management to "return to gas", involving divestment of many unrelated business lines.³⁵

BOC, dominant in a much larger home market than AGA's, especially given its virtual monopoly over the countries of the British Empire as well as the United Kingdom, quite understandably behaved quite differently. Unchallenged in the UK gases business by the early 1930s, the company was as highly profitable as it was dull. It relied heavily on technologies developed in Germany and France rather than developing many of its own, and BOC was really adventurous—and even here to a limited degree—only in its use of some of its considerable profits to invest in calcium carbide production capacity (used for manufacture of acetylene) in Odda, Norway, during the 1930s in the run-up to the Second World War, and, from the 1920s to the 1960s (and to some extent afterwards) in unrelated diversification of various sorts.³⁶

There were three other major players in the “industry” in the interwar period and beyond, and they, too, pursued widely different strategies, again in keeping with the lack of a clearly defined industry and also in keeping with the lack of fit between the individual firms and the industry. US-based Linde Air Products, by the 1920s the largest oxygen producer in the world, was involved with production of plant and equipment as well as gases. But the fact that it was a division of the Union Carbide and Carbon Company (later Union Carbide Corporation), founded in 1917, meant that its strategy and behaviour was often constrained and/or determined not so much by its industry as by the broader considerations of the corporation as a whole.

Linde and Air Liquide, in contrast, remained independent companies. Moreover, they shared technological leadership in the industry, continuing the traditions established by Carl von Linde and Air Liquide founder Georges Claude, who had together been responsible for some of the key breakthroughs in air separation. It was a position of technological strength and international leadership that both companies have managed to maintain to the present. Yet even here, strategy was fundamentally different in each case. Essentially, Air Liquide pursued a strategy based on identifying itself as a gases company which also built plant. In stark contrast, Linde’s behaviour was based on the notion that it was an engineering company which happened also to sell gases.³⁷ Thus, Air Liquide tended not to sell plant to anyone else in the gases industry, although it did of course sell considerable numbers of air separation units and other apparatus to users in the steel, chemicals, and other industries. What this meant, then, was that throughout its existence Air Liquide has also been extremely international in outlook and orientation, not just on the plant-building side, but also in the area of gas production and distribution.

Linde, on the other hand, happily sold its plants not only to companies in other industries, but also to others in the gases industry, although in Germany and a few other markets always under the proviso that the purchaser would limit its sales and distribution of gases geographically. Until the 1990s, it was not very international. Moreover, its gases business was, until the 1980s and 1990s, the poor cousin to its engineering division. With this self-conception, then, it is not surprising, then, that the company for many years retained its longstanding interest in refrigeration (which predated its development of air separation technology). It had also, before the war, begun to produce tractors and machine tools, and the firm eventually branched out into forklift design and manufacture among other things. Linde's behaviour as a firm for most of its history cannot be explained by using the industrial gases industry as the sole, or even the most important, unit of analysis. The same is true for the other gases producers in varying degree, including those which, owing to constraints of space, we cannot explore in further detail in the context of this article.

Competitiveness in the industrial gases industry over time

Without direct competition, at least at the international level, it is impossible to talk about international competitiveness in an industry, and this was the case for most of the first five to six decades of the industrial gases industry's existence. International competition in the industry did finally begin during the 1950s, however, unleashing a process in which the industrial gases industry gained clearer contours and began to shape and be shaped by companies who increasingly identified themselves as being firmly in it. The process, however, took decades.

Although there were many factors bringing about increased international competition, including gradual lowering of barriers to international trade and flows of capital, American-influenced antitrust legislation, and American-led multinational

foreign direct investment, the proximate cause in the case of industrial gases was a newcomer to the industry, Air Products Company (AP). Founded in 1940 by Leonard Pool, a former salesman for two relatively small American gases firms, Burdett Oxygen Company and for Compressed Industrial Gases, AP eventually grew to become one of the four largest industrial gases corporations in the world. It was the only one of the four founded after 1907, and thus is remarkable in its successful entry into an industry dominated by first movers.³⁸

Pool started AP with an ambitious new concept, the idea of selling the milk—the oxygen—rather than selling the cow—the air separation unit. The idea was to sell oxygen to large users—mostly steel mills—from a nearby plant owned by AP rather than the user. AP could then sell excess gases from the production process—including not only oxygen, but also nitrogen, argon, and other noble gases—to clients of various sorts in the surrounding area. It was an audacious plan, one based on Pool's realisation of the potential of relatively new “tonnage” technologies, which enabled unprecedented production of oxygen at ever-increasing levels of purity.³⁹

If Pool's concept was ambitious and audacious, his new firm had to make do initially with much more modest pickings. His engineers were fortunate to have the opportunity of honing their skills and technology in preparation for what they hoped would be the eventual realisation of Pool's master plan by virtue of contracts from the US military as it made intensive preparations for, and then became involved in fighting, the war. New aviation technology involved high-altitude flights, which in turn required that pilots be supplied with oxygen carried on board. Between 1940 and 1945, AP produced large numbers of small air separation units for use at US Army (and Navy) Air Force installations as well as those of US allies around the world. When the conflict was finished, that market collapsed, of course, but the fledgling AP

was able to use its experience to take advantage of burgeoning US production in the immediate post-war period to begin to realise Pool's dream. Short on capital, the newcomer was able on the basis of contracts with large steel firms to borrow money from banks to construct new air separation units on site. Sales—and rapid amortisation—were guaranteed through the combination of “take or pay” contracts with the steel producers, and additional income flowed in from piggybacking sales of excess gases to smaller companies. In the process, AP moved from being a specialist engineering firm (the small air separation units for the armed forces, for instance, did not entail gases sales) to an enterprise with a strong presence in both engineering and gases. The company was innovative in other ways as well, emphasising customer service, developing more efficient delivery techniques, and pioneering in the co-development of applications for nitrogen with food processors.⁴⁰

The other way in which AP was innovative was in its strategy of internationalisation which it pursued opportunistically starting already in the late 1940s, at first in Britain. The foreign incursion began with licensing agreements for small-scale plants—in other words purely in the area of engineering—and then moved on to a joint venture to construct on-site plants. By the late 1950s, the JV had proven unworkable, and so Air Products Limited was formed as a 100-percent subsidiary of the still small American firm. We have described in detail the process by which AP challenged BOC's virtual monopoly in the British industrial gases industry, so there is no need to do so again here.⁴¹ Suffice it to say that AP took advantage of the short-term opportunity offered for entering the UK market in the wake of the Monopolies Commission report and some restrictions placed on BOC by the Commission to replicate its US on-site strategy, taking particular advantage of its innovations in customer service, delivery techniques, and financing and also of the know-how it had

amassed in the food-processing industry in the States. By the mid-1960s, AP was firmly established in the UK and had begun to move into the Benelux countries and Germany, again challenging existing cosy arrangements.

Indeed, AP's actions in Europe in the late 1950s and during the 1960s precipitated a flurry of activity not only among the European firms which were being challenged directly, but also by Union Carbide's Linde Division (formerly Linde Air Products) and even the much smaller Japanese-based Nippon Sanso, which was prominent in its home market and was in the process of developing specialist expertise in the demanding field of gases for the electronics industry. By the late 1960s, the key European players and Nippon Sanso were, for their part, actively working to enter the US market, something which they did during the 1970s, not incidentally using financing and other techniques which they had learned from Air Products. All of these companies were now active in co-developing applications for industrial gases with their customers, a pattern very different from that which characterised the decades during which cutting and welding dominated sales and outlook. Oxygen and acetylene became correspondingly less important in the product palette of companies in the industry, and those palettes grew to embrace new and different gases.

In other words, the industrial gases business, through increased international competition, was gradually beginning by the 1970s to resemble an industry in Porter's sense. Still, this was still far from complete. BOC, for instance, continued to deliver chilled food to Marks & Spencers; German Linde continued to make forklifts; and Air Products had branched out into organic chemicals production and sales. These firms acted on the basis of trying to optimise and coordinate strategy in relation to more than one industry at the same time. On the other hand, Union Carbide's Linde

Division and German-based Messer and Griesheim, which by 1965 had merged to become the Messer-Griesheim Division of Hoechst AG, continued as relatively small divisions of very large corporations whose strategies were again developed in relation to competing demands from several “industries” at the same time. The one major exception here was French-based Air Liquide (AL), a company which never wavered from viewing its primary function as being a gases firm. AL simultaneously recognised that capabilities in specialist engineering of gases production and handling equipment on the one hand and welding and cutting equipment on the other were essential to realising this primary function.⁴²

The technological, commercial, and financial recasting of the industrial gases business beginning in the United States in the 1950s and spreading from there around the world favoured the AL model and eventually prompted other companies to imitate it. The broadening of the product palette and the capabilities required for co-development of applications technologies with companies in a range of other industries required drawing upon experience and personnel from around the world. It also required considerable amounts of capital, reinforcing the need for economies of scale and scope. Finally, and this is particularly important, the coexistence of capabilities in gases production and technical services on the one hand with specialist engineering of production and handling equipment on the other proved crucial. Not only did these activities complement one another financially—gases production and services counted as one of the smoothest and most lucrative of sectors owing to long-term contracts and high profit margins, while engineering could also be lucrative, but was more “lumpy” and subject to business cycles and other short-term disturbances. More than that, the two complemented one another in terms of competitiveness since

engineering activity allowed direct access to customers and the consequent opportunity to co-develop new applications.

By the 1990s, virtually all of the other large firms in the industry had begun to adopt the AL model.⁴³ Air Products was already well on the road to this. The same was true for Praxair, which was divested from Union Carbide Corporation (UCC) and established as an independent firm in 1992 in the wake of the 1984 Bhopal disaster. Unlike the UCC Linde Division which was simply a division within a large and varied corporation, Praxair was from the start of its existence tightly focused on the core gases and engineering businesses which were emerging as central to competitiveness in this evolving industry.

The ways in which the other three major European players, German Linde, AGA, and BOC, positioned themselves between the 1980s and 2006, however, illustrate especially well the centrality of the AL model in terms not only of competitiveness, but also survival as independent firms. As mentioned previously, Linde had long considered itself a specialist engineering company which happened also to sell gases. Beginning in the early 1980s, under CEO Hans Meinhardt, Linde rediscovered gases as the essential complement to its specialist engineering activities and began to invest in new capacity here through targeted acquisitions, especially in the United States and smaller European states. After 1990, Linde expanded into the transition economies of eastern and central Europe and remained on the lookout for further opportunities to expand its activities in its gases business.⁴⁴

AGA, too, realised that it needed to refocus on the gases business in order to remain competitive, and it accordingly divested itself of most of its non-core businesses in the 1970s and early 1980s. It continued to be active internationally, with particular strength in South and Central America. Besides this decidedly global

orientation and outlook, the crucial difference between AGA and Linde lay in the fact that the Swedish firm had only limited engineering capability—it bought its air separation plants and associated equipment for its worldwide operations from other companies, mostly from Linde, which between 1950 and 1997 provided AGA with 37 plants. Already in the mid-1990s, however, owing to the growing realisation that the know-how and access to customers associated with gases production and distribution engineering were essential to remaining competitive, AGA CEO Lennart Selander decided that the only way to achieve this was through a strategic alliance with Linde, which was concluded in 1997. For its part, Linde was able to gain exclusive and guaranteed sales to AGA as a major customer for its engineering services. More than that, Linde was able to use the strategic alliance as a stepping stone towards moving closer to its long-term strategic aim of recalibrating the balance between gases and engineering: the German firm took over AGA in 2000. The Swedish company's activities, virtually all in the area of gases sales and distribution, and virtually all in geographic areas in which Linde was not yet present, fundamentally redefined the German firm, making it at one fell swoop much more international and much more of a gases company with complementary capabilities in engineering.⁴⁵

British BOC had more plant-building capability than did AGA, but it relied heavily on technology from others. As the industry evolved and possession of these technological capabilities became more and more central to competitiveness, it became clear that BOC would also have to seek out a partner or partners. By 1999, Air Liquide and Air Products had made a joint offer for a takeover of the British company, but the proposed 50:50 acquisition was blocked by the US Federal Trade Commission (FTC). In 2006, however, in an audacious move, Linde took over BOC. Because Linde's US interests before the acquisition were very much smaller than

those of Air Liquide and Air Products, FTC approval was forthcoming, subject only to some small divestment in the United States. The acquisition increased still further the German firm's evolving international orientation, considerably extending its interests in gases production and distribution. In the process, Linde became virtually co-equal to Air Liquide as joint leaders in the industry worldwide, with each of the firms accounting in 2006 for about 20 percent of international sales of industrial gases. Air Products and Praxair each had a market share of about 14 percent. No other company had a market share of more than four percent.⁴⁶ An industry along the lines suggested by Porter had finally emerged, albeit well over 100 years after the industrial gases branch had originally come into existence.

Conclusions

The purpose of this article has not been to call into question the notion of an "industry" per se. Government economic statistics certainly use the concept, and those statistics, while they have to be deployed and analysed with caution, are certainly useful for all engaged in historically oriented social science research. The behaviour of firms and other actors also indicates that industries most certainly exist. There are, after all, industrial trade associations and journals where companies join together for the purposes of lobbying governments and discussing issues of common interest and importance such as safety and standards. Companies also act, at least in part, on the basis of their assessment of the actions that need to be taken in order to guarantee their competitiveness in relation to other firms operating in the same product, service, and/or geographic market.

Instead, the purpose here has been threefold. First, we have used the case of industrial gases business over some 12 decades to illustrate the dangers of a static view of an "industry". The industrial gases industry did not exist in any meaningful

way before the late 19th and early 20th century, and even then it was heavily oriented to oxygen and acetylene for cutting and welding, a very different product palette involving very different technologies from much of what firms in the industry produce and sell today. This heavy reliance on oxygen and acetylene and related technologies as key products remained the case for many decades, but even then it is difficult to speak about an industrial gases industry since competition was minimal, certainly internationally: firm strategy was determined less by the actions or anticipated actions of competitors than by national, regional, and/or local markets. It was only with gradual internationalisation beginning in the 1960s and developing fully over the following five decades that an industry along the lines suggested by Michael Porter emerged. The decades were characterised by growing concentration, usually by means of acquisitions, as well as by gradual convergence of the structure and strategy of the world's large industrial gases firms, developments which have culminated in the dominance internationally of four very large firms, two based in the United States, and two in Europe. It follows from this analysis, by the way, that we cannot tell with any degree of certainty how this "industry" will develop in the future, but the analysis suggests that it may well be different from the way it is now owing to changes in technologies and markets.

Our second purpose here has been to show some of the ways in which a more dynamic view of industry in combination with recognition of the imperfect overlap between firms on the one hand and industries on the other will allow a better understanding and analysis of both. Actors from firms and trade associations define industries, but firms themselves are very often involved in more than one industry, something which affects their competitive strategies, the options available to them, and, to some extent at least, the industries in which they are active.

Our third purpose has been to establish that “industries” are, to a large degree, constructs in a number of senses, and it is important to separate these types of constructs analytically from one another. They are of course constructed by government and/or consultancy statisticians for the purpose of economic and business analysis. And they are also constructed in a different way by trade associations. But it is important to keep in mind that neither of these ways of constructing an industry captures anything in relation to firm strategy or inter-firm dynamics. After all, companies which build single family houses using timber frames and those which build concrete high-rise apartment blocks would both be classified in statistics as being part of the construction industry and may well belong to the same building trades associations. But they probably would not compete directly with one another. Similarly, in the industrial gases industry, small and medium sized firms focusing on regional or local production and/or distribution would be included in government for industrial gases sales, and they may well belong to a national or regional industrial gases trade association or even the International Oxygen Manufacturers Association. But they do not compete in any meaningful way with the large companies which we have focused on here. For our purposes and for those of many other historically oriented social scientists studying business, however, the concept of industry has to be understood in a third sense, i.e. the locus of competition among individual firms or parts of firms. In other words, the key focus has to be on industry as a market or related markets in which firms compete with one another.

Finally, readers may ask whether the industrial gases industry is *sui generis*. Although we hope that we have already addressed potential objections about the representativeness of our case, two other brief examples may make it clearer that it is. We have already referred to the case of the chemicals and the oil industry in the 1920s

and 1930s. While they had no doubt been entirely separate until that point, developments in catalysts and other technologies, as well as the belief that oil was running out, caused the two to become much more similar, leading to potential competition (or in this case, cooperation).⁴⁷ Today, the top competitors of German chemicals giant BASF, for instance, include not just Dow Chemical and Du Pont, but also BP, Royal Dutch Shell, and Total.⁴⁸ The latter three compete with BASF in some chemicals markets, but BASF also competes with them in the oil and natural gas business through its Wintershall subsidiary. A similar dynamic can be observed just now in the telephone, television, and internet provision industries, which were previously largely separate from one another. In recent years, they have started to compete heavily, with companies like British Telecom moving in one direction, and those like Virgin Broadband moving in the other, resulting in competition between firms which previously had nothing to do with one another in what is essentially a new industry.

In sum, then, we argue that industries matter, but that it is important to be clear precisely how, which is a question that can only be addressed historically.

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ENDNOTES

¹ This article is based on research carried out between 2007 and 2013 on the history of the international industrial gases industry from the 1880s to the present. Linde AG financed the research and was influential in enabling us to gain access to extensive archival material, for which we are grateful. But the company was contractually obliged not to interfere with either the research itself or the results. For a fuller discussion of the evolution and development of industrial gases, see Stokes and Banken, *Aus der Luft*.

² Porter, *Competitive Advantage*, 33.

³ E.g. Chandler, *Scale and Scope*.

⁴ E.g. Malerba, "Innovation"; Klepper, "Disagreements".

⁵ Murmann, *Knowledge*.

⁶ Nelson, "Why do firms differ"; Dekkers, *(R)Evolution*; Bloch and Finch, "Firms and industries".

⁷ E.g. Star, "This is not".

⁸ IOMA, *The invisible industry*.

⁹ Butrica, *Out of thin air*; Dienel, *Linde*; Leszenski, *100 Per Cent*.

¹⁰ Almqvist, *History*.

¹¹ US Census Bureau, NAICS 325120.

¹² Notiz Abschrift aus *Nachrichten aus Chemie und Technik*, 7 March 1962, p. 67, in BASF Unternehmensarchiv, Ludwigshafen, G1101-1105.

¹³ Drewes, *Technische Gase*.

¹⁴ "The Gas Company", 8.

¹⁵ BOC, *Around the world*.

¹⁶ Dienel, *Linde*; Butrica, *Out of thin air*.

¹⁷ US Census Bureau, NAICS 325120.

¹⁸ BOC, *Around the world*; Dienel, *Linde*; Almqvist, *History*.

¹⁹ BOC, "The birth and development of an industry," (unpublished manuscript, 1946), in BOC Archives located at the Linde Unternehmensarchiv in Munich (hereafter BOC LUM, Box 425, 18, 19-26; quotation, 18. For limited initial markets and the centrality of limelight, see also Gardner, "One hundred years", 3.

²⁰ BOC, "The birth", pp. 26, 29; UK Monopolies Commission, *Report*, 9.

²¹ Almqvist, *History*, 108-109, 111.

²² We owe this phrase to Ulrich Wengenroth, who has been a member of the advisory board for this project since autumn 2007. He made the comment at a meeting in Glasgow in August 2010.

²³ BOC, "The birth", 44.

²⁴ Various contracts and agreements between 1926 and 1945 in BASF Unternehmensarchiv, Ludwigshafen, in files numbered: I 201 Nr. 316; and 1316.

²⁵ Stokes, "From the IG Farben," 227-229.

²⁶ For instance, AGA and Air Liquide acquired the longstanding German market leader in carbon dioxide, Rommenmüller, in 1976. Letter of Sven Ägrup to Kohlensäurewerke Rommenmüller, Bad Driburg, 1 December 1978 in AGA Archive, held in Föreningen Stockholms Företagsminnen, Stockholm, (hereafter AGA Archive), file E5 RC13. Ron Weir describes the spiralling price that a key traditional British producer of the gas, Distillers Company, could command from industrial gases companies when it decided to sell its carbon dioxide subsidiary in the 1980s. Ron Weir, "The history of the Distillers Company", vol. 2 (unpublished manuscript), chapter on Carbon Dioxide 1981-85 draft, November 2008. We are grateful to the late Dr Weir's wife, Alison Weir, for allowing us access to this section of his nearly completed manuscript.

²⁷ Butrica, "The organization".

²⁸ Jemain, *Les conquérants*, 151.

²⁹ Jörg-Michael Willke, presentation and conversation at the Linde AG Applications Center in Munich, 22 November 2010. The authors are grateful to Dr Willke, Michael Graf, Henning Tomforde, Wilfried-Henning Reese, and Dr Dirk Hüpperich of Linde AG for an enormously fruitful discussion on that day, and to Klaus Schönfeld, at that time head of Corporate Heritage at Linde AG, for not only arranging, but also participating actively in this meeting and discussion.

³⁰ BOC, "The birth," 44, 49.

³¹ "International gas man", 39.

³² UK Monopolies Commission, *Report*; Banken and Stokes, "The trauma".

³³ Koch, *Ein Unternehmen*; Leszenski, *100 Per Cent*.

³⁴ Interview with Dexter Baker (Air Products), 28 October 2008, Allentown, Pennsylvania.

³⁵ Almqvist, “Technological change”, esp. 32.

³⁶ BOC, *Around the world*.

³⁷ Almqvist, *History*, 201-202; Jemain, *Les conquérants*, 42.

³⁸ Butrica, *Out of thin air*.

³⁹ Butrica, *Out of thin air*, esp. 13.

⁴⁰ Interview with Dexter Baker (Air Products), 28 October 2008, Allentown, Pennsylvania; AGA Group Planning, “Innovation in Gas Applications,” February 1974, in AGA archive, file E5 SA1.

⁴¹ Banken and Stokes, “The trauma”.

⁴² Jemain, *Les conquérants*.

⁴³ The one exception to this trend was Airgas Corporation, founded in 1980. Airgas focused entirely on cylinder sales and distribution and has had little engineering capability. Its business model is unique in the modern industrial gases industry, involving acquisition of small regional distributors and, eventually, buying the packaged gases business of Air Products. Its existence and success have had to do with a combination of the unusual structure of the American market, with its large number of regional distributors, and the strategic decision by Air Products and other larger American producers in the first decade of the 21st century to move out of the cylinder business. The larger American firms soon realised their mistake, and Air Products tried unsuccessfully to acquire Airgas in 2010. See Krantz, “Airgas”; <http://www.prnewswire.com/news-releases/air-products-offers-to-acquire-airgas-for-6000-per-share-in-cash-83614327.html> <accessed 12 April 2012>.

⁴⁴ Various Vorstandsprotokolle of Linde AG starting in 1979, in LUM 37 A 06; interview with Dr Gunnar Eggendorfer, former member of managing board, Linde AG, 10 September 2008, Pullach, Germany; Dienel, *Linde*, esp. 195-237.

⁴⁵ Linde Process Engineering and Contracts Division, “Linde Air Separation Plants for AGA,” 2 June 1996, and Linde AG, Press Release: “AGA AB and Linde AG form alliance in cryogenic air separation technology,” 18 June 1997, both in LUM, no file number, Standort 54 E 4; interview with Lennart Selander, 23 November 2010, Pullach, Germany.

⁴⁶ Dr Peter Vocke, Linde AG, “The world market for industrial gases,” presentation in Munich, 8 October 2007; Dr Peter Vocke, Linde AG, “Tier 2. Marktanteile, lokale Bedeutung und regionale Besonderheiten der Gasfirmen mit Jahresumsatz kleiner [als] 1 Mrd. US\$,” presentation in Munich, 25 September 2008.

⁴⁷ Stokes, “From the IG Farben”.

⁴⁸ Datamonitor, *BASF SE*, 29.