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Abstract

By the late 19th century, the export of natural ice from Norway to Britain was a major trade, fuelled by the growing British consumption of ice. Although new technology eventually allowed the production of artificial ice, natural ice retained a strong market position until World War I. This dissertation investigates the rise and fall of the Anglo-Norwegian ice trade, including the reasons behind the Norwegian success (comparative advantage, proximity to Britain and long-standing trade relations with Britain) and the rapid and persistent growth of British consumption of ice (high urbanisation, and growth of food-processing industries). Furthermore, it seeks to explain the continued use of natural ice long after the introduction of artificial ice and mechanical refrigeration. Seasonal aspects and supply shocks were instrumental in promoting technological change, but the diffusion of the new technologies varied across industries, and was affected by economic and social factors.

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1. Introduction

"During the late tropical weather ice represented a real power in the community; just as in winter coal is an absolute necessity"
The Times*, *Sep 11, 1868

1.1 Background And Research Questions

The first merchant trading in Norwegian natural ice was the Englishman William Leftwich in 1822. Judged by Mr Leftwich's experience, little indicated that the trade in natural ice would be a booming industry later in the century. Upon arrival in London the ship was close to sinking and all the ice had melted.[1] However, by the turn of the century, Norway exported more than 1,000,000 tons of ice each year, with vessels going to Northern Europe, the Mediterranean, Constantinople, Africa and even as far as India. Britain was the primary market for Norwegian ice, with over half of its total exports going to the British Isles.[2] Similarly, Norway was more or less the sole provider of natural ice to Britain, with a market share of more than 99 per cent around the beginning of the 20th century.[3] However, within a decade, the market for natural ice more or less disappeared. Norwegian exports of ice in 1920 were only 5 per cent of the levels of 1910. The age of natural ice came to an end and was succeeded by artificial ice and mechanical refrigeration.

This thesis will focus on the expansion and decline of the Anglo-Norwegian ice trade, a trade that sheds light on important issues in global economic development, such as trade in natural resources, technology

[1] Gøthesen, G., *Med Is og Plank I Nordsjøfart* (Oslo, 1986), p. 118.
[2] Ibid., p. 209; Kragerø Museum, Norway, The Haakon Wiborg Papers (Wiborg's father and grandfather owned one of the largest companies in Norway); *Cold Storage and Ice Traders Review* (henceforth *Cold Storage*) (July 1903), p. 228.
[3] *Cold Storage* (July 1901), p. 106. In 1899 for instance, Norway exported 504,627 tons of ice worth £316,882 to Britain, which imported a mere 515 tons worth £308 from elsewhere.

transfer and structural change. The dissertation will try to answer four fundamental questions:

i. Why Norwegian ice?
ii. Which factors explain the strong and persistent growth of British imports and consumption of natural ice from around 1850 to about 1914?
iii. Technology and shocks: what factors lead to the decline of Norwegian ice exports to Britain?
iv. Why did natural ice retain a foothold in the market until the outbreak of World War I, despite the new and cheaper type of refrigeration?

The three first questions will be analysed by reviewing of the existing literature and the introduction of empirical evidence based on primary sources found in Norwegian and British archives. The last question will be approached through a more theoretical framework, looking at two very different sets of explanations. Firstly, was there a trajectory path for the consumption of natural ice and was there a path-dependent framework that was 'unlocked' by the outbreak of World War I? Or alternatively, was this decline an evolutionary process, where shocks only accelerated the ongoing technological and structural change? The theory of path dependence, as used by Paul David, is less relevant when explaining the Anglo-Norwegian ice trade. On the other hand, Joel Mokyr's frame of reference - in which technological change is a disorderly process - and Nathan Rosenberg's argument - that new technological regimes have gently declining slopes of cost reductions - seem to be more valid when explaining the demise of natural ice. Embedded in this analysis are the constraints, including seasonal, social, financial and technological, inhibiting the spread of artificial refrigeration.

1.2. Existing Knowledge

The integration of the global economy and the modernisation of Western economies in the 19th century changed the parameters of production, distribution and trade of foodstuffs. While economic historians have paid heed to mechanical refrigeration and its role in facilitating the integration of markets, assisting urbanisation and increasing living standards, our knowledge and understanding of refrigeration before the adoption of modern technologies is far more limited.[4] Natural ice remained a crucial means of refrigeration in Europe as well as North America right up to the Great War.[5] The benefits of ice in general were significant for dietary, economic and hygienic reasons. Food and drinks producers and suppliers were dependent on this commodity for preserving and cooling products. The imported ice was assisting the creation of the market for refrigeration, and was used in a multitude of trades, such as ice cream and other confectionary, drinks and restaurants, and was substantial in the growth of the fishing industry, brewing, and in transport and storage in the meat trade.

We know more about the extensive domestic and international American ice trades than about their European counterparts.[6] The leading European exporter of natural ice in the 19th century was Norway, and the largest importer was Britain. Still, this trade has attracted more interest from local than economic historians.[7] For the Norwegian side of the story,

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[4] See, among others, Mokyr, J., *The Lever of Riches* (Oxford, 1990), p. 141.
[5] Hård, M., *Machines are Frozen Spirit. The Scientification of Refrigeration and Brewing in the 19th Century - a Weberian Interpretation* (Frankfurt, 1976), p. 38.
[6] For the historical development of the American ice trade, see Anderson, O.E., *Refrigeration in America* (New Jersey, 1951). For a descriptive account of the American ice harvest, see Jones, J., *American icemen: an illustrative history of the United States natural ice industry in 1925* (Humble, Tex., 1984).
[7] This is particularly the case for the Norwegian literature. See Olsen, M., 'Issjau I Kragerø-distriktet', *Budstikker gjennom loka lhistorien*, Årsskrift 1981 (Kragerø, For Kragerø og Skatøy Historielag, 1981), pp. 14-35; Vaage, J., 'En utdødd virkshomhet; Isskjæring og iseksport', *Byminne*r, 1 (Kragerø, 1979), pp. 30-39; Gardåsen, T.K., 'Isblokkar viktig eksportvare. Isbruk i grenlandsfjordane 1835-1962', Slokvik, R. (ed.), *Kulturmenneske før og no* (Skien, 2004), pp. 124-135.

the historian Gøtheson offers a broad outline of the history of the trade in ice and timber.[8] However, Gøtheson is concerned mostly with the links between timber, ice and shipping than with the economic history of the ice trade *per se*, and the book has more of a narrative than an analytical character. For the British side of the story, the use of British icehouses and storage of ice have attracted the interest of Ellis and Beamon and Roaf.[9] However, the first real attempt to cover the British-Norwegian ice trade was the work of Robert David.[10] David focused on the demise of the Anglo-Norwegian ice, and his findings further our understanding of this trade. However, in many ways he tells a one-sided story as his primary sources and literature are exclusively of British origin. Moreover, the broader consequences are not obvious, as he does not apply either a theoretical or a comparative perspective in his analysis.

The lack of literature on the natural ice industry cannot be ascribed to the lack of source materials. On the contrary: there is plenty of contemporary material in both Norway and Britain dealing with various aspects of natural ice. Most of this material is in customs records, newspapers and trade journals.[11] These sources have played a crucial role in answering the four questions outlined above.

2. Why Norway?

2.1. Emerging Markets For Ice In The 19th Century

The use of cold for preserving foodstuffs is a far from modern invention: it can be traced back to 1100 B.C. through Chinese poems

[8] Gøtheson (1986).
[9] Ellis, M., *Ice and Icehouses through the Ages* (Southampton, 1982); Beamon, S.P., Roaf, S., *The Ice-houses of Britain* (London, 1990).
[10] David, R., 'The Demise of the Anglo-Norwegian Ice Trade', *Business History*, 37 (1995), pp. 52-69.
[11] On the British side, the main trade journals were *Cold Storage*, *Fish Trades Gazette* and *British Refrigeration and Allied Interests*. In Norway, Kragerø Museum's archives and the works of local historians are the most useful sources.

describing 'ice houses'.[12] The first references to icehouses in England can be found in the 16th and 17th centuries. Icehouses were used mainly for storing foodstuffs.[13] However, before the 19th century food preservation in Europe involved mainly the traditional techniques of salting, spicing, pickling, smoking and dehydration.[14]

The development of a commercial market for natural ice in the 19th century started in the urbanised areas of North America. The primary market was New York. The combination of hot summers, population growth, and the expansion of the brewing and meat packing industries led to a positive shift in demand for natural ice.[15] The Boston entrepreneur Wyeth invented and patented tools that advanced large-scale ice harvesting. Wyeth supplied the 'ice king' Fredric Tudor with ice for his growing markets. Tudor's vision was to export ice to the colonies, and his ice empire soon stretched from the West Indies to Australia.[16] He aimed his product towards the British gentry worldwide, offering the privileged classes ice for their iced drinks and for cooling saloons. However, Tudor did not focus on the British domestic market. The first export of American ice to Britain was in 1844, and was carried out by the Wenham Lake Ice Company, named after the Wenham Lake in Massachusetts. The ice from this lake was well received and admired in England for its clarity and purity, and the pure blocks of crystal ice from Wenham were a great improvement on the local ice. In fact, Wenham Ice was later to become known as a standard of quality rather than a given lake or company.

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[12] The first European source mentioning icehouses dates from the 5th century B.C., when Protagoras described how the Egyptians in the Nile valley made ice by putting containers on the roofs of their houses; see Thevenot, R., *A History Of Refrigeration throughout the world* (Paris, 1979), p. 23.
[13] Johnston, M.M., *Ice and Cold Storage - a Dublin History* (Dublin, 1988), p. 15.
[14] Anderson (1951), p. 7.
[15] Jones (1984), p. 30.
[16] Ibid., pp. 23-24.

American ice exports to Britain, however, faced substantial bottlenecks.[17] Above all, the distance implied huge losses of cargo as the ice melted during the Atlantic crossing. Moreover, the distance is also reflected in the transport costs. The combination of both factors limited supply and ensured relatively high prices of American ice in the British market.

2.2. Norway's Competitive Advantages

The American position in the European market was therefore vulnerable to other competitors, including Norway. Geographically, Norway was much closer to the British market.[18] Moreover, the climate was ideal for producing natural ice. At first, the ice came from the west coast. This part of the country has several glaciers, fjords and river estuaries and it was ice from here that was first harvested and shipped abroad. However, this was a costly and time-consuming process because of the long distances and though some places allowed the use of horses, in many places the ice had to be carried on people's backs.[19]

The centre of gravity of the ice exports soon shifted towards the south and southeast coasts of Norway. There were several reasons for this. First, while mountains and fjords dominate the west coast, the south and southeast coasts had a more gentle terrain and several lakes. Secondly, the inland climate was drier and colder, thus far better suited than the wet climate of the west coast. Thirdly, the ice export proved a perfect complement to the existing economic structure of these areas. The south and southeast coasts had several clusters of what have been dubbed the 'Siamese twins' of Norwegian foreign trade, namely shipping

[17] The New England initiative earned it an initial monopoly on the ice trade market, despite its high cost - £2 10 shillings per ton - which was due mainly to the high loss of ice the journey. David, R. (1995), p. 53.
[18] The sea journey from Kragerø, the most important port for Norwegian exports of ice, to London is approximately 590 nautical miles (NM), compared to 3,199 NM from New York to London and 1,232 NM from Reykjavik to London. See Hwww.MaritimeChain.comH
[19] Olsen (1981), p, 14; Gøthesen (1986), p. 133.

and timber. Timber was the prime domestic cargo for the shipping industry. Timber and timber products are voluminous goods, and require vast capacity in terms of available tonnage. The Norwegian merchant fleet had such capacity. In additions, the 'ice-mining was a ideal part-time occupation for both the local farmers and the shipping crews, as the winters were normally the slack periods. Moreover, through the trade in timber and shipping services the merchants in the South of Norway had established important trading networks with Britain.[20] Anders Nikolai Kiær, the first director of Statistics Norway in the second half of the 19th century, described the period between 1850 and 1879 as the golden age of Norwegian shipping.[21] Moreover, the timber industry faced rapid technological development in the second half of the 19th century. The mechanisation of the planing mills generated high volumes of sawdust, which proved useful to the ice trade as it was used on the ice-carrying vessels to prevent the ice from melting.[22] During the summer months due to the high demand the return cargo was usually ballast, while in the winter months coal was common.[23] These ships had to be strong to be able to carry the heavy loads, and had to be crewed by the very best sailors as the journey needed to be quick to minimise the loss of ice. Melting was a considerable problem, and the average loss was from between 5 to 10 percent. In addition, when the ice melted it lost its grip and started to move with the motions of the sea, creating a risk of accidents.[24] One of the main competitive advantages of the Norwegian

[20] Kiær, A.N., 'Historical Sketch of the Development of Scandinavian Shipping', *Journal of Political Economy*, 1, (1893), p. 333.
[21] Ibid., p. 342.
[22] The emphasis of the importance of sawdust can be found in numerous sources, including a letter from a Captain Olsen, quoted in the newspaper *Vestmar* (13 November 1880), p. 2.
[23] Kragerø Museum, Wiborg, H., 'Familen Wiborg og iseksporten I Kragerø', p.1.
[24] Gøthesen (1986), p. 144.

shipping sector was the skilled labour, and by the late 1870s, Norway had the world's third largest merchant fleet.[25]

2.3 Production Of, And Trade In, Natural Ice

Norwegian ice was first exported by foreign, mainly British, merchants, who possessed the know-how for production and marketing. British entrepreneurs found that Norwegian ice was of similar quality to Wenham ice but could be attained at a much lower price. In December 1864 the newspaper *Morgenbladet* reported that a foreign entrepreneur had bought Lake Oppegård and renamed it 'Wenham Lake'. Subsequently the ice from Oppegård was sold in England as "Wenham lake ice", posing as the famous American ice.[26] In 1868 *The Times* reported that the cubes of pure crystal ice seen on the fishmonger slabs and in the windows of the Wenham Lake Ice Company were in fact all produced in Norway.[27] By the 1880s and 1890s, Norway had gained control over its own market and Norwegian merchants and took over the ships that had previously belonged to the English ice merchants.
The transport of the ice from the natural lakes inland was a costly and risky business, as it was heavily dependent on a cold Norwegian winter and a warm British summer. Soon Norway was unable to produce enough ice to meet the foreign demand. This led to the establishment of artificial lakes on agricultural land closer to the ports. Icehouses were built to contain the ice for up to a year, increasing the storage capacity and the

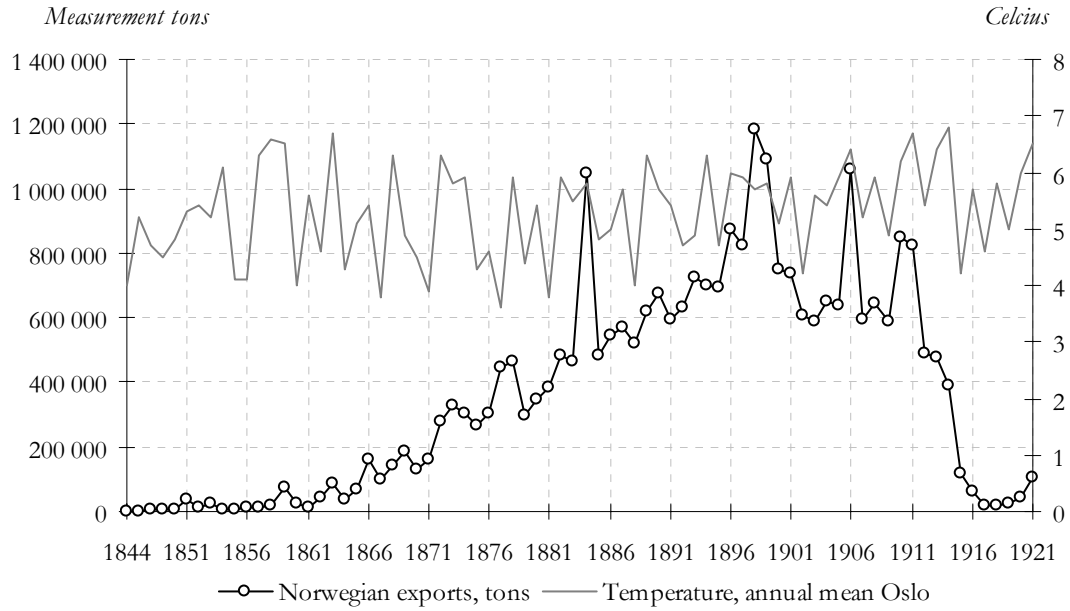
[25] The fleet consisted almost exclusively of sailing vessels with wooden bottoms, as metal hulls were prone to rust and sailing vessels offered cheaper freight rates than steamships. Windmill pumps were also fitted on the ships to pump the water away by the late 19th century. See *British Refrigeration and Allied Interests* (February 1899), p. 31.
[26] *Morgenbladet* (24 December 1864), p. 2; *British Refrigeration and Allied Interests* (February 1899), p. 31.
[27] *The Times* (11 September 1868), p. 5.

possibility of expanding the trade.[28] The creation of artificial lakes on the higher points close to the fjords became the best practice.[29] Long inclines constructed of boards were built through the forest, leading to long runners half a mile in length, which reached out into the harbours.[30] The ice industry brought significant income for areas in the southern part of Norway, as well as significant freight earnings for the shipping companies.[31] However, ice production and its export were capital-intensive and competitive.[32]

Graph 1 illustrates the rise, peak and decline of the ice export (left axis), and the annual average temperatures in Oslo (right axis).[33] We cannot observe any major changes in domestic temperatures that can explain the massive surge in exports of ice, as the temperatures seem to have been relatively stable, fluctuating between 3.8-7 degrees Celsius.

[28] Ouren, T., 'The Norwegian Ice Trade', in Proctor, D.V. (ed.), *Ice Carrying Trade at Sea* (London, 1981), pp. 31-55.
[29] Gøthesen (1986), p. 129.
[30] Interview with Mads Olsen, whose research confirms the trade's importance for the local population; *Harmsworth Magazine* (August 1901), p. 18.
[31] *Kragerø Blad* (13 December 1977), p. 1; interviews with Mads Olsen.
[32] Relatively few companies dominated the trade; the main firms in Kragerø were Wiborg, Dahl and Biørn*, Kragerø Blad* (13 December 1977), p. 2.
[33] *Historical Statistics 1994* offers a national average of annual temperatures. With an emphasis on the northern areas of the country, the national average is not a good yardstick of the climate in the ice exporting areas. The only stations in the index that cover the ice exporting areas are Oslo, Torungen lighthouse (Arendal) and Oksøy lighthouse (Kristiansand). Of these three, Oslo is the most representative indicator as the two lighthouses are, naturally, exposed to extreme weather conditions. Thus the data for Oslo have been used.

Graph 1: Exports of Ice And Annual Mean Temperatures In Oslo, 1844-1921



Source: *Statistiske oversikter 1948*, Utgitt and Statistisk Sentralbyrå (Oslo, 1949), table 121, p. 209; Norges Offisielle Statistikk XII, *Historical Statistics 1978*, Statistics Norway (Oslo, 1978), Table 1: 'Air temperatures, degrees centigrade', p. 10; Norges Offisielle Statistikk C 188, Historical Statistics 1994, Statistics Norway (Oslo, 1994), Table 2.7, 'Average air temperature at 10 meteorological stations', http://www.ssb.no/emner/historisk_statistikk/hs1994.html

The export of ice had a phenomenal growth, peaking in the late 1890s. Moses argues this expansion of ice exports mirrors the rising standards of living in Europe.[34] Britain represented the centre of gravity of social and economic change in Europe at this time. Indeed, Britain was the prime market for the Norwegian ice exports, with one notable exception. In 1898 the mild winter in Norway and the large German orders for ice meant that the British had to import ice from Finland, despite having the largest recorded import of Norwegian ice.[35]

[34] Moses, J., *Norwegian Catch-Up. Development and globalisation before World War II* (Aldershot, 2005), p. 74.
[35] *British Refrigeration and Allied Interests* (February 1899), p. 31.

2.4 European Competitors

As a natural resource, ice was a commodity that could be exported by several countries apart from Norway. However, no attention has been paid to the other countries' failure to take advantage of this market. Finland, for example, has a cold climate and almost 200,000 natural lakes. Russia had a climate that was far more stable in terms of length of frost throughout the winter compared to Norway. British sources occasionally refer to the ice trade from Austria-Hungary, Russia, Finland and France.[36] However, as Norway accounted for more than 99 percent of British ice imports, it is hard to find continuous and systematic information. What does seem clear is that the second largest producer of ice in Europe was Austria-Hungary, with the Vienna Ice Company as the leading player.[37] However, the focus of the continental ice producers was the German market, and very little ice was exported to Britain.[38]

Norway had a dominant position in the European market in general and in the British market in particular.[39] Norway had a major competitive advantage with her many ports on the North Sea, and the short distance to the British market. It was ironic that the Baltic countries could not participate in the ice trade in the early spring because of ice in the Baltic Sea:

> *"Compared with the Swedish ports on the Baltic, the Norwegian ports offered the great advantage that they were open for navigation even in March, sometimes even earlier, while the Bothenian ports generally were shut up by the ice until the middle of May. Thus the Norwegian vessels could make voyage from Norway to Western Europe and back*

[36] *Cold Storage* (April 1901), p. 16.
[37] National Archives, Kew, BT31/3528/21519; *Cold Storage* (January 1900), p. 144.
[38] *Cold Storage* (November 1898), p. 90.
[39] Contemporary sources reveal the frustration of the Norwegian ice exporters who were unable to capture the American market. In his letter from New York, Captain Olsen accused the Americans of being 'selfish' and hinted at collusion between the American companies; *Vestmar* (13 November 1880), p. 2.

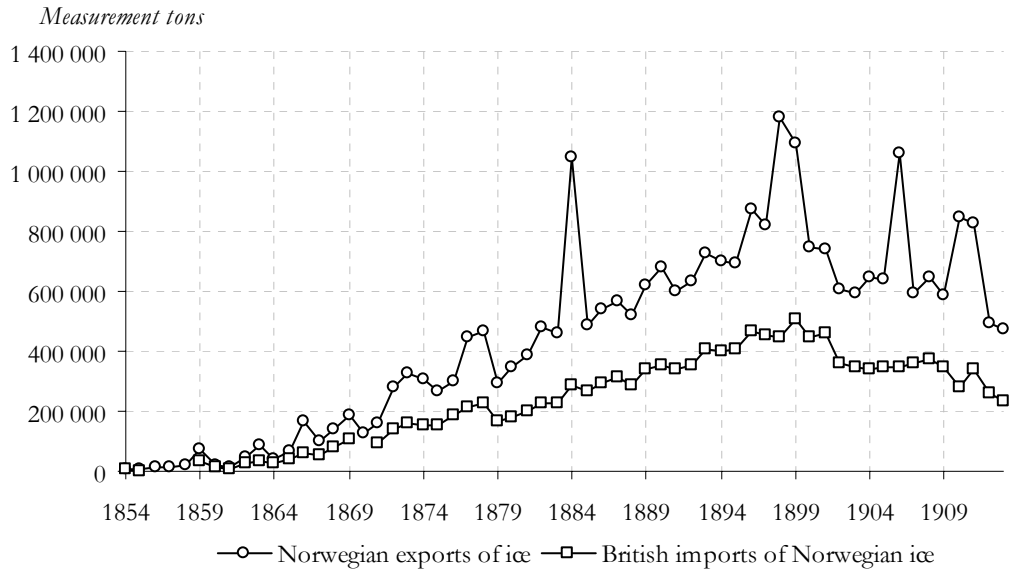
again, before the vessels belonging to the Bothenian ports could begin the navigation of the year". [40]

As we see in graph 2, Norwegian ice exports and English ice imports moved in accord with each other. In many ways, Norway enjoyed both first-mover and second-mover advantages compared to its European competitors. While the first-mover advantages can be ascribed to the pre-emption of scarce assets and buyer-switching costs, Norway had second-mover advantages by being able to use the American advances in technology and the British ice merchants' knowledge of the market.[41]

The ice export was significant for Norwegian development and can be seen as example of the 'vent for surplus' theory.[42] Ice was a plentiful natural resource in Norway. North has argued that international demand for export has been 'the prime mover' for economic development.[43] Furthermore, Hodne stresses that the economic history of Norway in the 19th century was an export-led story. He emphasised Norway's primary export growth, where free trade and the export of natural resources above subsistence levels allowed for specialisation and capital formation, which in turn allowed the Norwegian economy to catch up with the modernised economies.[44]

[40] Kiær (1893), p. 343.
[41] Lieberman, M.B., Montgomery, D.B., 'First-Mover Advantages', *Strategic Management Journal*, 9 (1988), pp. 41-58.
[42] Findlay, R., Lundahl, M., 'Natural Resources "Vent for Surplus" and the Staples Theory', *Columbia University – Department of Economics: Working Papers, 585* (New York, 1992), pp. 2-6.
[43] Ibid., p. 6.
[44] Hodne, F., *Norges Økonomiske Historie 1815-1970* (Oslo, 1981). p. 17.

Graph 2: Norwegian Exports And British Imports Of Ice, 1854-1913



Source: *Statistiske oversikter 1948*, Utgitt and Statistisk Sentralbyrå (Oslo, 1949), table 121, p. 209; National Archives, CUST4, 49-94; *Cold Storage* (July 1903), p. 228; *Cold Storage* (January 1915), p. 5.

3. Factors Explaining The Strong And Persistent Growth Of British Imports And Consumption Of Natural Ice From Around 1850 To 1920

3.1. Traditional And New Demand For Ice

American tourists in Britain operated as crucial agents in the promotion of high quality ice, as American crystal ice was instrumental in promoting British imports of natural ice. However, the use of ice for preservation of food was not new in Britain. The use of icehouses, where the ice was used for chilling drinks and preserving fish and meat, can be found in records as far back as the medieval period.[45] The use of ice spread around the time of the Restoration, mainly inspired by Royalists who had been in exile on the continent during the time of the Commonwealth. Thus, even before the American influence, the use of

[45] Johnston (1988), p. 26.

natural ice was progressing slowly but steadily.[46] However, the arrival of ice from North America (see 2.1) raised new scepticism about the quality of domestically produced ice, and local ice came to be regarded as impure and unhealthy.[47] Consequently, the Americans changed both the perception of the quality of ice as well as the way it was produced and harvested through the transfer of Wyeth's ideas and their adaptation.

This development coincided with the long-run metamorphosis of Britain's economy and society through industrialisation, modernisation and urbanisation. In this chapter I will start by identifying the main groups driving the positive shift in demand. Moreover, I shall look at some of the key factors characterising and explaining the long-term trends in the demand for ice, before moving on to the short-term trends and fluctuations. The very nature of this cargo leaves little doubt as to the importance of seasonal variations and changes in temperature. I argue that it was these short-term fluctuations that led, in the longer run, to further technological changes and a move away from natural ice as a means of refrigeration.

3.2. Groups Driving Demand

The British use of ice was increasing rapidly, and was driven mainly by three essential groups: consumers, producers, and the transport industry.

3.2.1. Consumers

Domestic consumers - British households, and those who purchased luxury foods and drinks – formed the first group. Compared to the American market, the diffusion of the use of ice in England was a slow process, particularly in the private households. This can probably be

[46] Ibid., p. 31.
[47] Gøthesen (1986), p. 116.

explained by the high wastage of ice, as few invested in iceboxes and storage devices for keeping the ice.[48] Rural consumers were also involved in this new demand, as by the middle of the 19th century the development of the railway network meant that ice imported from Norway could be supplied from large urban depots to the countryside, and could supply the icehouses all year round.[49]

3.2.2. Producers

Producers included a large range of different trades and industries, including the fishing industry, medicine and hospitals, technical institutions, the brewing industry, confectionary producers, and also the meat, poultry and the fruit and vegetable businesses. These different trades were perhaps the main customers for the increasing imports of natural ice.

3.2.3. Transport Industry

The third group can be categorised as the transport industry - the railways and road vehicles - which used ice for transporting a multitude of different products to the domestic market. While mechanical refrigeration became a necessity on long-distance journeys from such places as Australia, Argentina, and America, natural ice retained a firm grip on transport over shorter distances, such as the vans and railways connecting the ports and the domestic market.[50]

3.3. Distributors: Linking Supply And Demand

The ice normally reached London in spring and was either put into barges and covered with tarpaulin, or was shipped onto vans and taken

[48] *Cold Storage* (May 1905), p. 148.
[49] Beamon, Roaf (1990), p. 28.
[50] David, R. (1995), p. 63.

either directly to customers or to huge ice wells at Shadwell and King's Cross.[51] The major challenge for the distributors was to organise efficient depots. Ice merchants procured their ice stocks from Norwegian suppliers, whose prices reflected different qualities of ice. The crystal ice was a luxury good used for table purposes, and had to be collected from the interior of Norway, as this ice was clear and very hard.[52] The more porous and white type of ice was more prominent in the various meat industries and the fish trade. The marked difference between the American and British trade was the absence of distribution of ice to private homes in Britain. Also few ice merchants sold ice alone; ice was complementary to their other business. Ice for private consumption in Britain was bought usually at the fishmongers, butchers and chemists.[53]

One of the leading ice merchants in England was the firm of Messrs. Leftwich and Company. From 1880 onwards, this company built a network of ice wells around London, and kept at least 1,000 tons of ice at all times. The shipments from Norway varied; a large shipment would be around 900 measurement tons. The selection of ice was a vital part of the business, choosing the quality that would satisfy customer demand and minimise waste through melting.[54]

The competition among ice merchants was fierce, consequently leading to lower prices. The ice merchants were competing for the different groups of industries. Though prices were reduced, the purchasers still found ice too dear. One example was the London's Butchers Trade Society, which in 1905 protested against United Carlo Gatti, Stevenson and Slatters Ltd., who operated with a minimum price of 25 shillings a ton. The protest led United's main competitor, the North

[51] *Harmsworth London Magazine* (August 1901), p. 19.
[52] *Cold Storage* (February 1899), p. 124.
[53] National Archives, LAB2/638/TBD121/A/5/1920, p.4; *Harmsworth London Magazine* (August 1901), p. 20.
[54] *Cold Storage* (June 1899), p. 36.

Pole Company, to offer minimum prices of 18 to 20 shillings per ton. North Pole's offer made them the main supplier of ice to the meat trade. However, the main strategic aim of the company was to supply the fishing trade, which was the largest purchaser of Norwegian ice.[55]

3.4 Development In The Short And The Long Run

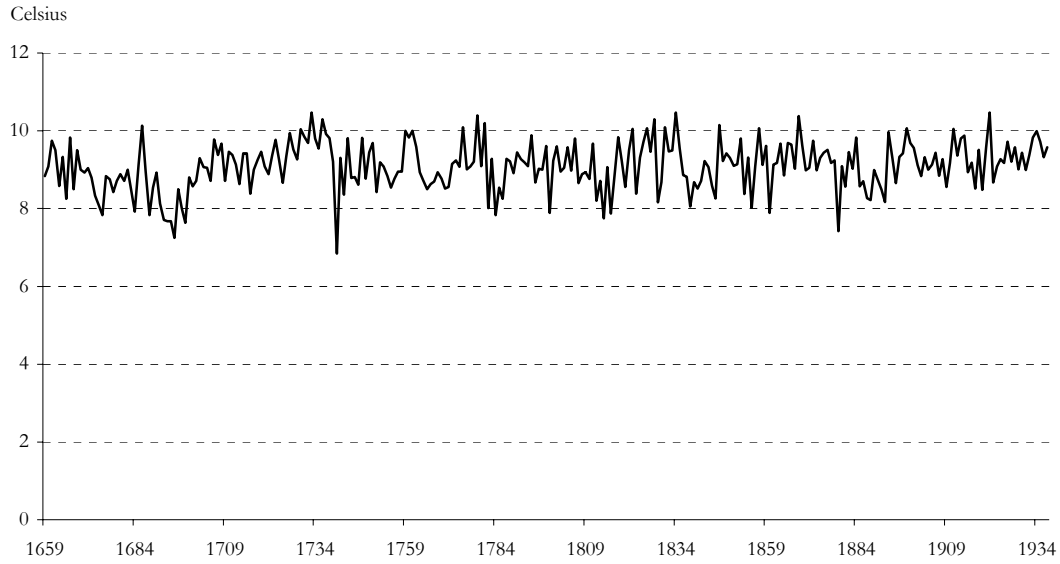
The main long-term changes include environmental and climatic adjustments and the major changes in the British society, such as urbanisation, structural and societal changes. One of these changes was the transformation of the ethnic composition of the inhabitants of the urban eras. Cities in general and London in particular faced an increasing proportion of foreign travellers as well as more permanent immigration – both groups adding to the development of new markets in order to meet new needs.

3.4.1. Long-Term Temperatures

As the demand for ice was rising, the common perception at the time was that the climatic changes and rising temperatures were the main factor increasing the British public's use of ice.[56] However, as graph 3 illustrates, the long-term temperatures were not noticeably different. The observations of annual average temperatures in Britain, stretching from 1659 to 1934, point to the relative stability of the British climate.

[55] *Cold Storage* (April 1905), pp. 98-99.
[56] *Harmsworth London Magazine* (August 1901), p. 19.

Graph 3: Annual Average Temperatures In England, 1659-1934



Source: British temperatures: British Atmospheric Data Centre.[57]

3.4.2. Urbanisation And Structural Changes

The largest quantities of Norwegian ice (see table 1, p. 24) went to London. Urbanisation and population growth changed the overall structure of consumption. The growth of cities gave manufacturers access to larger markets, and as sales volume depends on the cost related to the transport of goods to the market, cost falls as the urban area grows. This process becomes self-reinforcing and has been called a "positive feedback effect",[58] and creates thick labour markets and reduced costs in transport and human capital. By 1851, 39.5 percent of the population of England and Wales resided in cities of more than 10,000 inhabitants.

[57] All data on British temperatures derive from the Meteorological Office datasets, held at the British Atmospheric Data Centre (BADC). The BADC's database is operated by the Natural Environment Research Council (NERC). Subsets are subject to strict conditions of use. Thus, please do not quote the series presented in this thesis, but rather contact the NERC directly at:
Hhttp://badc.nerc.ac.uk/data/list_all_datasets.htmlH

[58] N. Sedgley & B. Elmslie. 'Do We Still Need Cities?' Evidence on Rates of Innovation from Count
Data Models of Metropolitan Statistical Area Patents', paper presented at the '5th International Atlantic Economy Conference', Lisbon, March 2004.

Moreover, average wage levels almost doubled between 1845-54 and 1905-13, rising from £33.7 to £60.[59] England's urban growth and its early economic maturity meant even as late as 1910 its ratio of urban to rural population was twice that of continental Europe.[60]

Structural changes and rising wages dramatically changed consumption patterns as an inevitable consequence of the urban way of life.[61] The increased social mobility and the growth of the middle classes and their purchasing power played a significant role in creating new markets for mass culture and services.[62] The growth of pubs, hotels and the increased consumption of whisky and champagne fuelled demand for ice. The urban population was also dependent on food supplied from outside, leading to further shifts in terms of food distribution.

The prevailing structure could not cope with the increase in demand as well as the increased supply of cheap foodstuffs, and from the 1870s mass production and mass consumption changed the business of selling food. Economies of scale were not new to this period, but production evolved and progressed gradually over the last three decades of the 19th century.[63] Bulk buying by entrepreneurs helped create a network of branch shops.[64] The food industries expanded along with population growth, and in the maturing urban areas there was a growing need for cooling for transporting and preserving food.[65] Thus the increased use of ice was essential for the development of the growing food industries, particularly fish, confectionary, dairy, brewing, as well as the meat, fruit and vegetable trades.

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[59] O'Brien, P.K., Keyder, C., *Economic Growth in Britain and France* (London, 1978), p. 73.
[60] P. Bairoch, P., *Cities and Economic Development* (Chicago, 1988), p. 290.
[61] O'Brien, Keyder (1978), p. 69.
[62] Hohenberg, P.M., Lees, H.L., *The making of Urban Europe 1000-1994* (Cambridge, Ma., 1985), pp. 272-281.
[63] Mokyr (1990), p. 114.
[64] *Science, Technology and Everyday Life 1870-1950*, ed. Chant, C. (London, 1989), p. 258.
[65] Thevenot (1979), p. 53.

The influx of immigrants to the metropolis also brought new foodstuffs, with consequences for the import of Norwegian ice. By 1850 there were 250,000 Italians in Britain; of these sixty percent resided in South East England, and were instrumental in creating a new market for ice in restaurants, shops and hotels.[66] The most important entrepreneur who realised the huge possibilities of ice in the catering industry, particularly for the mass production of ice cream, was Carlo Gatti, who was also among the first to acquire a license to cut ice on the Regent's Park Canal.[67] However, he also saw the possibilities of using Norwegian ice, and his first recorded contract with Norwegian ice can be found in September 1856, where he placed an order for 400 tons of ice with J. Dhall of Kragerø.[68] His ice business flourished and soon after 1857 he had as many as 60 vans and carts, apart from his own ice cream businesses. The confectionary business was largely seasonal and took place between early spring and late autumn.

Structural changes were also taking place in industries outside the cities. The growth of the fresh fish industry was part of a new development linking the fishing towns and the urban areas, as in Grimsby in 1848, where new docks were connected to an additional large new wharf (2,431 feet long). In August 1853, the railway link to the docks was opened. The consequence of the railway and its connection with London was a rapid growth of population, and the industry expanded rapidly.[69] Ice was also used to transport the fish to London, and Grimsby was the first to preserve fresh fish for the London market, giving it a massive advantage over other fishing towns. In 1858, the first smacks from Grimsby also used ice at sea. This drastically changed the nature of the

[66] Crowhurst, B., *A History of the British Ice Cream Industry* (London, 2000), p. 11.
[67] National Archives, LAB2/638/TBD12/A/5/1920, p. 13; Kinross, F., *Coffee and Ices: The Story of Carlo Gatti in London* (Sudbury, 1991), p. 25.
[68] Kinross (1991), p. 27.
[69] Gillet, E., *A History of Grimsby* (London, 1970), p. 215.

trade by allowing longer voyages, and larger quantities of fish could be brought back for sale.[70]

3.4.3. Temperature Changes In The Short Term

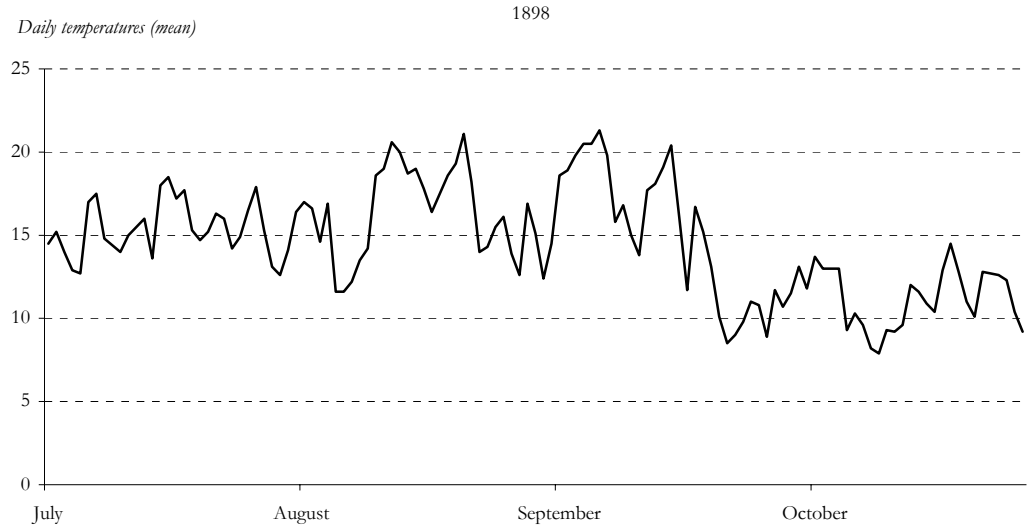
Short-term trends such as seasonal and temperature variations had a large impact on the demand for ice. Furthermore, it was these fluctuations and shocks that effected various interest groups and created not only a higher demand for natural ice, but created the impetus for the technological changes that changed the trade altogether.

> *"What chiefly regulates the demand for ice is firstly the winter secondly the summer."*[71]

What is consistent in the literature from this period was the focus on ice being a necessity during warm summers. While the use of ice was steadily increasing, the temperature shocks were closely linked to the scale of Norwegian exports. Graph 4 shows the extent of the heatwave that struck England in the late summer of 1898. England was experiencing an 'Indian summer', which created a very high demand for ice.

[70] Ibid., p. 230.
[71] *Cold Storage* (February 1910), p. 35.

Graph 4: Temperatures In Britain, 1898



Source: as for graph 3.

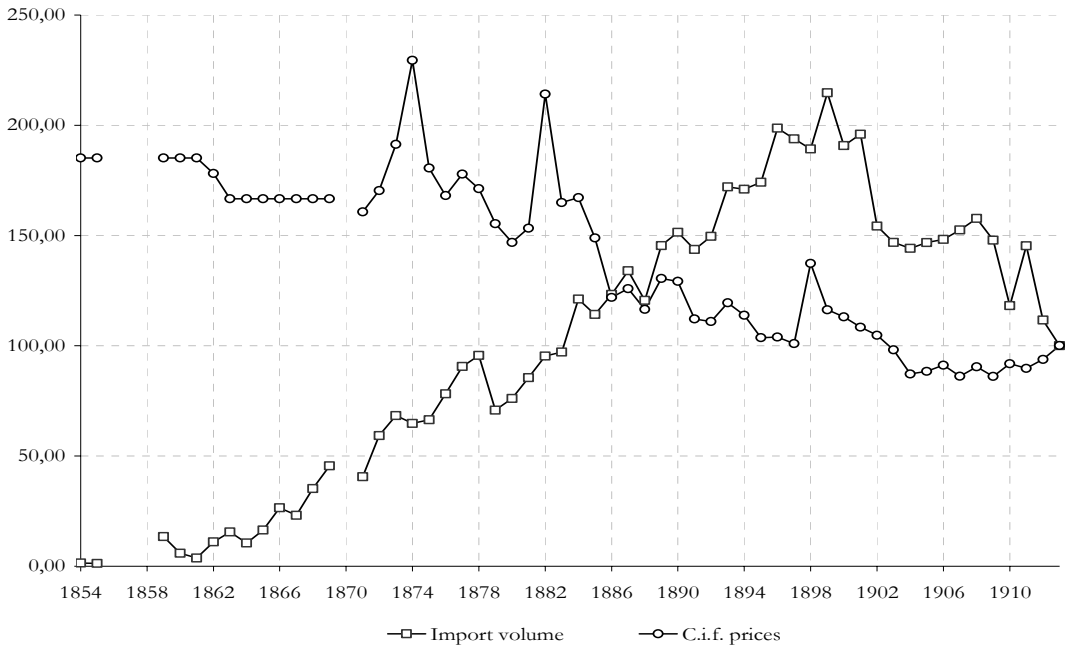
The trade press noted rising prices and “an ice famine in London”, compounded by the public’s reluctance to use artificial ice, which was “said to endure just half the time that the natural snow-water-block-ice from Norway does”.[72]

This ‘ice famine’ was due to shortages of imported ice as Norway was unable to meet the demand. Mild winters in Norway in 1898 and 1899 forced suppliers to use lakes far in the interior, and the higher costs meant higher prices in those years. This was also an impetus for the establishment of ice manufacturing companies and refrigeration machinery by the largest consumers of Norwegian ice. The low supply was also due to a very mild winter in Germany, and huge German advance orders for Norwegian ice for the summer season reduced the quantity available for the English market.

[72] *Cold Storage* (August 1899), p. 64.

3.4.4 Falling Prices And Freight Rates

Graph 5: British Imports Of Norwegian Ice, 1853-1913: Price And Volume Indices (1913=100)



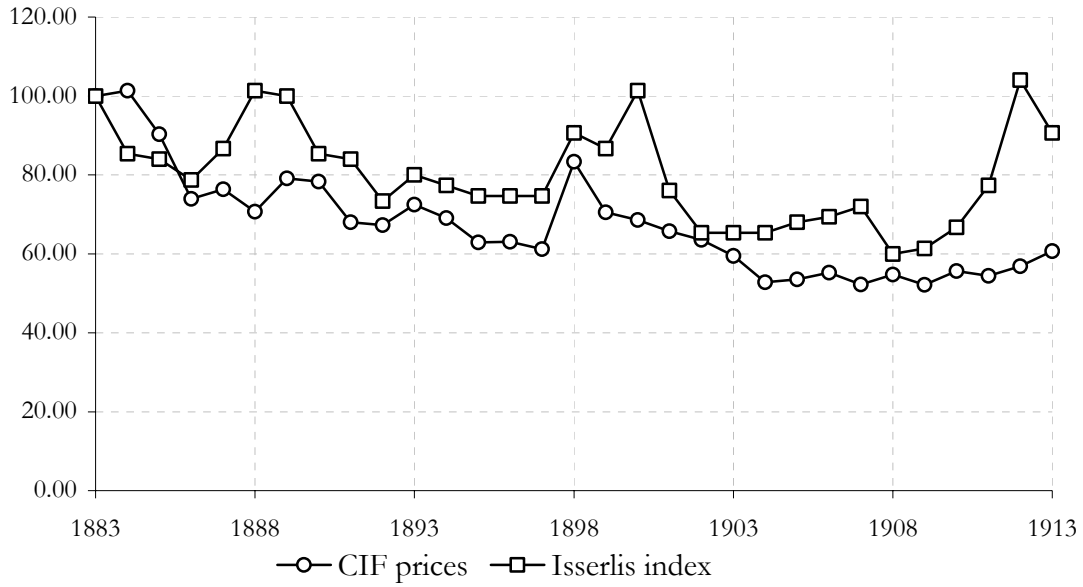
Sources: National Archives, CUST4, 49-94; *Cold Storage* (July 1903), p. 228; *Cold Storage* (January 1915), p .5.

Another factor driving demand was the falling price of natural ice. Norwegian and English merchants competed fiercely for the various trade groups, and consequently the producer of natural ice had to lower its prices to compete with artificial ice, which was not burdened with extensive transport costs. However, the ice trade must also been seen in the larger context, where international freight rates were playing a part in lowering prices.[73] Graph 5 expresses the first attempt to offer annual series of import figures and fixed price estimates for the years 1853-

[73] There is no doubt that these are c.i.f prices; see for example *Cold Storage* (August 1900), p. 153; Kragerø Museum, bb sjoefart 88, Telegraphic Address and letters Hutchinson & Co., Leith, 14.10.1894; *Fish Trades Gazette & Poultry, Game and Rabbit Trades Chronicle* (July 1905), p. 28.

1913.[74] The prices of Norwegian ice show a clear, falling trend. The prices here are expressed as the price per measurement ton of ice imported. However, as these figures are referring to c.i.f, or cost insurance freight, this might partly be explained by falling transport costs. Indeed, when comparing the fall in freight rates (Graph 6) with the fall in ice prices for the period 1883-1913, a pattern of close correspondence emerges.

Graph 6: British Import Prices Of Norwegian Ice And The Isserlis Freight Rate Indices 1883-1913 (1883=100)



Sources: British imports as for graph 5. For the Isserlis freight rates, the calculations are based on the data reproduced in Klovland, J.T., 'Business Cycles, Commodity Prices and Shipping Freight Rates: Some Evidence from the Pre-WW1 Period', p. 23. See: http://www.econ.ku.dk/kgp/doc/Workshopfrms/jantoreklovland.pdf

[74] The prices for 1853- 1870 ought to be read with care, as they are sporadic and appear to be fixed prices. The figures derive from sources giving both value and volume of the British imports of ice. The customs records state that the prices before 1870 are estimates, whereas the price around 1870 has been extrapolated. Thus, when choosing the base year, rather than going for the first observation year, I have chosen the last year of the series, i.e. 1913.

4. Technology And Shocks

4.1. New Technology

The demand structures led to a preference for a more elastic supply of ice. Many of the growing trades were demanding an all-year supply of ice, and the temperature shocks led to initiatives to develop the new technology of refrigeration.

The development of refrigeration involved contributions from many countries.[75] The science of thermodynamics was well understood by 1875, and by that time four different types of machines to produce cold had been developed. These were machines relying on the compression and evaporation of liquefiable gases, such as the Perkins' ethyl ether compression machines (1834); machines expanding pre-compressed air; Gorrie's air cycle machine (1844); and absorption machines, such as Ferdinand Carre's ammonia absorption machines relying on the evaporation of water and reduced pressure.[76] Australia, with no natural ice and huge potential for meat exports, was among the first to put the Perkins machines into use.[77]

This development meant that artificial ice was not in direct competition with the natural type. Instead, cold storage and dry cooling technology could offer major advantages, particularly consistency, and was more efficient in preserving meat. The first attempt to ship meat across the oceans was carried out by Bell in 1877. The refrigeration process was achieved by ice containers filled with natural ice, circulating a current of air through the ice by means of a fan.[78] However, the air machine was improved and commercialised, and from 1879 such machines were installed in the British ships that began transporting meat

[75] Anderson (1951), p. 5.
[76] Thevenot 1979), p. 35.
[77] Cooper, A.J., *The World Below Zero: A History of Refrigeration in the UK* (Buckingham, 1997), p. 25.
[78] Critchell, J.T., Raymond, J., *A History of the Frozen Meat Trade* (London, 1912), p. 25.

across the oceans.[79] The development of imports of lamb, beef and mutton from Australia, America and Argentina had linkage effects in Britain, as many new ice and cold storage companies were founded to support this trade.

On the consumer side, the most important social carrier of mechanical refrigeration was the brewing industry. Many brewers wanted to reduce their reliance on natural ice, as the product was bulky and burdensome to handle, and the insecurity of its supply persuaded many brewers to change.[80] Refrigeration in brewing, and eventually in other trades, was transformed by the work of Carl Linde, the first scientist to enter the commercial market. Linde, a professor of the theoretical mechanical engineering at the Munich Polytechnic, was the first to analyse mechanical refrigeration systematically from the point of view of thermodynamics.[81] Thanks to his work, the technology shifted focus from absorption to vapour compression.

The fishing industry in Grimsby invested in mechanical refrigeration and ice making machinery shortly after the shock of 1898. As illustrated in table 1, Grimsby was the second largest importer of Norwegian ice. However, after the turn of the century the imports of Norwegian ice fell drastically, from 68,390 tons in 1901 to 23,340 tons in 1902. This reflected the installation of new ice making machinery. The fishing industry needed an all-year supply of ice, and the seasonal aspect of Norwegian ice made it problematic. However, despite the new ice machinery, the industry was still dependent on the Norwegian imports, although the availability of manufactured ice stabilised prices. In Grimsby, ice prices remained at 10s/3d per ton during the hot summer of 1899,

[79] Thevenot (1979), p. 45.
[80] Hård (1976), pp. 236-237.
[81] Ibid., p. 19.

while at Hull and Fleetwood, ports that were more reliant on imported ice, prices rose to 16s/3d a ton.[82]

Table 1: Imports Of Norwegian Ice By Ports, 1901-1905

	1901	1902	1903	1904	1905
London	206,978	185,257	183,460	172,609	180,915
Grimsby	68,390	23,340	26,250	17,760	16,660
Fleetwood	10,261	8,000	10,189	12,736	14,898
Liverpool	17,117	17,296	12,917	11,945	12,864
Hull	19,529	15, 190	6.660	10,240	11,520
Shoreham	8,661	7,845	7,633	8,409	7,945
Penzance	4,852	7,145	7,582	8,198	7,365

Source: 'Tons of Norwegian imported ice from various ports in the United Kingdom, for a five year period' *Cold Storage* (January 1906), p. 3.

Nevertheless, the shocks did not mean immediate changes across England. The *Ice and Cold Storage Traders Directory for 1900* lists 103 cold storage and ice factories in Britain and Ireland, with 23 in London alone. Nevertheless, the register also acknowledges that there were 117 towns in England with a population above 15,000 without public cold stores. These included such towns as Brighton (population 120,401), Blackburn (130,000) Portsmouth (182,585).[83]

4.2. New Health Arguments

Another jolt to the natural ice trade was the new scientific interest in bacteriology. Research on the purity of natural ice was part of the growing concern stimulated by the 'germ theory' of disease, and was not favourable to the natural ice traders. The producers of the new

[82] David, R. (1995), p. 60.
[83] *Ice and Cold Storage Traders Directory: Handbook for 1900* (London, 1900), p. 48.

mechanical ice making equipment stressed that their purification was assured by distillation.[84]

In 1876 the *Lancet* wrote about American reports on the dangers of impure ice causing intestinal disorders, and warned that similar dangers could be present in Britain.[85] However, in 1905 the same journal reported "Norwegian ice… is of excellent quality, pure, sparkling, and clean" and that "no harm is likely to accrue" from its use.[86] Nonetheless, government initiatives for the control and standardisation of food and water quality gave new institutional weight to the controversy. In 1877 the Institute of Chemistry was established, to apply chemistry to public health problems, in particular the chemical and microscopic analysis of water, food and drugs. By 1899 the Local Government Board agreed to accept the Institute's certificate as the qualification for the new post of Public Analyst, which was to be set up under the revised Sale of Food and Drugs Act of 1900. Now Public Analysts were inspecting and testing food, water samples and drugs in the larger towns of Britain.[87] In 1904, reports by Assistant Medical Officer, W.H. Hamer, commissioned by the London County Council, noted that although the ice was clean when it arrived at the ports, the danger of contamination was present during the storing and the transport from wharf to customer. His report concluded that artificial ice was more hygienic.[88]

Norwegian ice, once prized for its purity, came under attack from the mechanical refrigeration lobby. As the journal *British Refrigeration and Allied Interests* reported in 1899:

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[84] Anderson (1951), p. 111.
[85] *The Lancet* (15 June 1876), p. 95.
[86] Quoted in *Cold Storage* (January 1905), p. 16.
[87] *Science, technology and Everyday Life*, p. 289.
[88] David, R. (1995), p. 58.

"Natural ice imported to this country is collected from lakes, which, without doubt, receive the surface drainage from the surrounding country…it is nauseating to think of that."[89]

Not only was this an attack on the use of Norwegian ice for table purposes, it was also a call to the various food trades to adopt the new ice-making machinery.

4.3. Continuity

Despite the various shocks to the ice trade, mechanised production was unable to meet demand as late as 1911, when the daily consumption of ice was 2000 tons a day, while artificial ice-makers were capable of producing only 500 tons per day.[90] This meant that the greatest supply was still coming from Norway, and London was still receiving 20 vessels each day. Most towns outside London were also still dependent on imports during the warm months.[91] Moreover, while many large businesses could invest in ice-making machinery, other trades and consumers where more reluctant to change. Businesses transporting ice over short distances, such as the railways and the road hauliers found it unnecessary to invest in new equipment. Tanks containing ice and salt freezing mixtures were the predominant means of transporting the large quantities of frozen meat that arrived from abroad as late as 1912.[92] Equally, private consumers and small shops continued to purchase natural ice. Public opinion did not alter despite Hamer's report, and the public still believed that Norwegian ice was of superior quality and durability. This general belief persisted despite tests as early as 1899,

[89] *British Refrigeration and Allied Interests* (Feb 1899), p. 31.
[90] *The Times* (26 July 1911), p. 13.
[91] Ibid.
[92] Critchell, Raymond (1912), pp. 344-345.

where a 50-lb block of manufactured ice outlasted an equivalent block of natural ice by six and a half hours.[93]

4.4 World War I

"How the Norwegians must curse the war... it is likely to receive its death-blow, as retailers awake to having small ice-making plants of their own"[94]

Historically, any shock such as the disruption or total blocking of an accustomed source of supply has played a crucial part in stimulating technological change. The outbreak of war being the most apt example, with the imposition of a previously nonexistent constraint, and new searches for a substitute, and a more productive process was the consequence.[95] World War I accelerated the ongoing trend that had unfolded since the initial shocks. Its impact was favourable to the refrigeration trade, which exploited the fears of ice shortages. The German blockade of the North Sea damaged the natural ice trade. Reports in 1915 doubted whether demand (apart from demand from hotels and restaurants) would be reduced as a consequence of the war. However, with ice consumption estimated to be 300,000 tons a year, ice-making plants were supplying only a third.[96] Total imports of ice for the first half of 1915 were 21,182 tons, compared with 107,136 tons for the same period in 1914.[97] The change was largest for the small retailers such as fishmongers and butchers, who had not invested in mechanical refrigeration. The mechanical refrigeration trade press warned the various

[93] *Cold Storage* (September 1899), p. 82. A British refrigeration company also claimed that 42 tons of artificial ice would be equal to 50 tons of natural ice for fishing vessels, arguing that natural ice was put on board at thawing point, whereas artificial ice was put on board at a temperature of 23 degrees Fahrenheit (-5 degrees Centigrade). See *Cold Storage* (February 1899), p. 124.
[94] *Fish Trades Gazette and Poultry, Game & Rabbit Trades Chronicle* (April 1915), p. 29.
[95] Rosenberg, N., *Perspectives on Technology* (Cambridge, 1976), p. 121.
[96] *Cold Storage* (March 1915), p. 48.
[97] *Cold Storage* (July 1915), p. 164.

trades of the risks that the war could impose on their businesses, and urged them to install refrigeration or ice-making machines on their premises.[98]

Subsequently the war was instrumental in changing the habits of small businesses and those industries that were less reliant on a constant supply. However, its role was only to accelerate a development that was already taking place. Therefore technological change was not only due to the war or artificial refrigeration, but also the short-term fluctuations shown in graph 3, which determined the demand for an elastic supply, and ensured the gradual replacement of natural ice by mechanised production. This process of change shall be analysed through a theoretical framework in the fifth part of this paper.

5. Decline And Technological Change

5.1 Theories And Constraints

The process of technological change in Britain from natural to artificial types of refrigeration was not universal as we have seen, and what is surprising in this development is while artificial ice was less expensive than natural ice and was gaining a foothold in the market, why was not more machinery acquired? While determining which factors led to this prolonged decline of the natural ice I shall look at theories that take a less neo-classical approach. While the neo-classical approach assumes that firms will choose the technique that maximises their profit, prevailing theories assume there are choices of technology, that the process of change is far more complex and disorderly, and acknowledge both technological and social constraints. Firstly, a path-dependence framework, assuming there was a trajectory path for the consumption of natural ice, shall be applied. Secondly, an evolutionary approach shall be

[98] *Cold Storage* (March 1915), p. 48.

discussed, with a more varied framework in which changes are more gradual, and influenced by a broad set of factors that included the seasonal nature of ice, the social perceptions as well as the high cost and technical limitations of the ice-making machinery.

The interesting aspect of this case study is that when looking specifically at ice (rather than refrigeration and cold storage) the two different technologies were near-perfect substitutes. Therefore the cost per unit of ice should determine the best option. Natural ice was more expensive than artificial ice, largely because of transport charges.[99] However, the trade press shows that natural ice was still significant up until the Great War.

5.2. Path Dependence

Path dependence, in Paul David's interpretation, refers to the process of economic allocation that involves not only determinants such as technology, factor endowments, preferences and institutions, but depends also on conditional events.[100] David's first example was that of QWERTY keyboards, the layout of which was inherited from typewriters, although the superior DSK (The Dvorak simplified keyboards) improved keyboards were available.[101] In this view history matters, as technologies can not always 'shake free' from their past, and a technological path can have 'lock-in' effects where economies can end up using sub-optimal technology. The theory does not assume perfect foresight or a path of pareto-optimal equilibrium, as different equilibriums existed for different agents. Furthermore the reason for this development is due to information imperfection, which makes it unlikely that a decentralized process can get

[99] National Archives, LAB2/638/TBD121/A/5/1920, p. 15.
[100] Guinnane, W.T., Sundstrom, A.W., Whatley, W., *History Matters, Essays on Economic Growth, Technology, and Demographic Change* (Stanford, 2004), p. 63.
[101] David, P., 'Clio and the Economics of QWERTY', *American Economic Review*, 75 (May 1985), p. 332.

everyone to change collectively.[102] These processes have special stochastic dynamic systems and in applying this theory one needs to ask whether economic efficiency is attained in the prevailing technology.[103] David identified three conditions that might interrelate and make technological change path dependent: the technical interrelatedness of system components, the 'quasi-irreversibility' of switching costs, and the positive externalities in terms of increasing returns to scale.[104]

Analysing the first condition in this context, few technologies apart from transport were interrelated to the technology of natural ice production. This condition seems more relevant to modern technology and perhaps less relevant to the utilisation of a natural resource such as ice. The switching cost however, is highly relevant, given that the initial sunk cost was significant, and so was the risk involved with the new machinery. However, with the third condition there are no obvious positive externalities in this context, though we know little about the multiple regional or sub-networks that were present in this trade.[105] Another part of this theory that partly applies to this case is the information imperfection in terms of the common misbelief that the natural ice was harder and more durable. This might be partly due to the extended use of natural ice. However, there were no signs of total 'lock-in' effect in this story. While some industries were more reluctant to alter their techniques, other firms and industries used both technologies in a complimentary way. As we saw in chapter three, the seasonal variations and deficiencies in supply in 1898 made several large firms invest in new technology. For example, the ice merchants would purchase ice from abroad to add to the stock of the less expensive artificial sort. For as long as the new equipment was

[102] David, P., 'Path Dependence and the Quest for Historical Economics: One more Chorus of the Ballad of OWERTY', *Discussion Papers in Economics and Social History,* 20 (Oxford, 1997), p. 35.
[103] Ibid., pp. 18-19.
[104] Guinnane et al (2004), p. 63.
[105] Ibid., p. 88.

unable to produce enough ice to meet demand, the use of natural ice was only supporting the process of change.

Liebowitz and Margolis have criticised the theory of path dependence by pointing out that an agent's choices of product can be as much a case of market failure as a lock-in effect.[106] While this criticism is valid to a certain extent, in that agents were influenced by the promoters of the new equipment, this progress was far from universal and did not entirely replace the existing technology. In this case Arrow's criticism of the theory - that the most significant source of path dependence is the irreversibility of investment, rather than increasing returns to scale – is more persuasive.[107]

Subsequently we can deduce that this process cannot be explained through David's framework of path dependence. Instead, Mokyr's evolutionary concept of macro-inventions, micro-inventions and constraints, and Rosenberg's observations on the process of diffusion seem more appropriate in this context.

5.3. The Evolutionary Approach

The process of transition from one technology to another was, in this context, not a case of shifting along the production frontier. Technological change is often a disorderly process, as Mokyr points out, and is better explained by modern evolutionary biology than by the tools of economics.[108]

[106] Liebowitz, S.J., Margolis, S.E., 'Path Dependence, Lock-in, and History', *Journal of Law, Economics & organization*, 11/1 (1995), pp. 205-226.
[107] Guinnane et al (2004), p. 23.
[108] Mokyr (1990), p. 114.

5.3.1 Seasonal And Cost Restraints

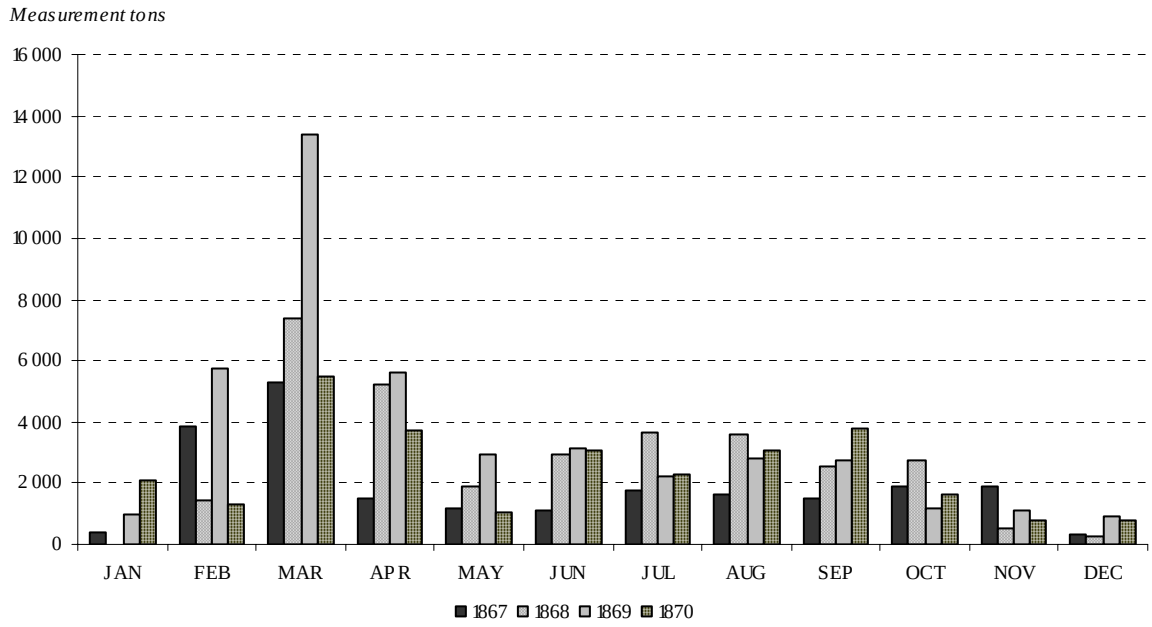
"Those who have not the bulk of business nor the capital to lay out, which machinery calls for, may rest well content with the modern non-mechanical contrivances"[109]

What becomes apparent was that that incentive structure was linked intimately to the nature of the different trades involved. Many of the larger companies in brewing and fishing, and trades dependent on cold storage rather than ice, such as the meat industry, invested readily in the new technology.

The extent to which companies chose to mechanise ice production depended on the rewards and penalties, and on the feasibility of the new technology for their use. This also depended on the environmental or climatic discrepancies and on the institutional pressures, which were greater for different trades at different times. For industries such as fishing and brewing there was a clear dependency on an all-year supply, and during shocks the natural ice was both expensive and inadequate. However, for other industries the benefits of technological change were less obvious, as for example for the ice cream producers and ice merchants Gatti, for whom the two operations were complimentary and largely seasonal.

[109] *Fish Trades Gazette & Poultry Game & Rabbit Trades Chronicles* (March 1905), p. 30.

Graph 7: Monthly Exports Of Norwegian Ice, 1867-1870

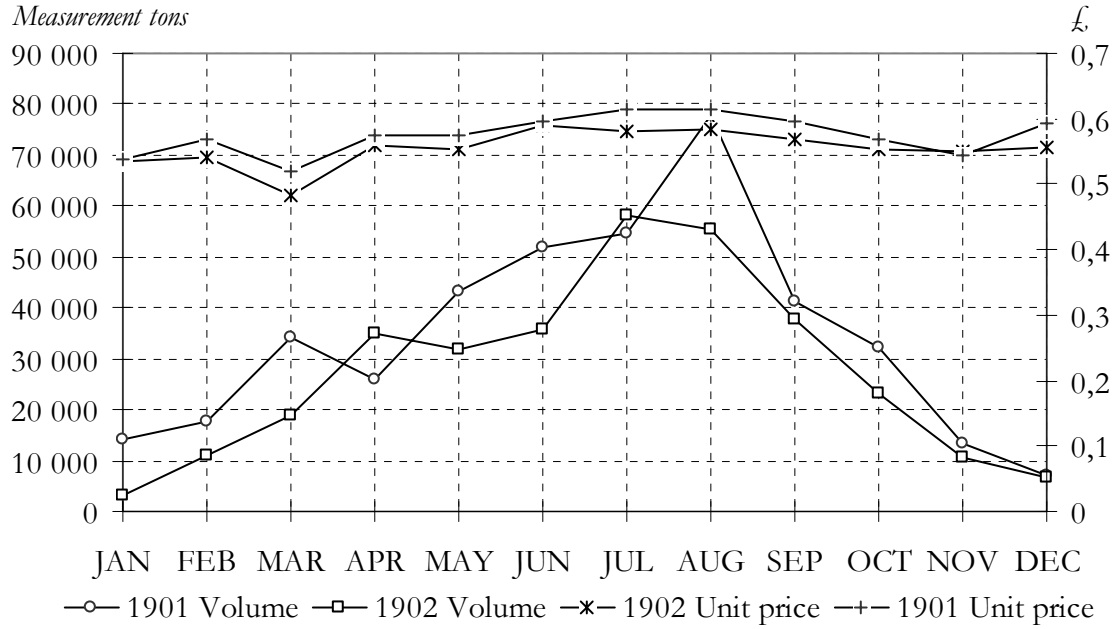


Sources: C. No. 3, *Tabeller vedkommende Norges Handel og Skibsfart I Aaret 1867*, Departementet for det Indre (Christiania, 1869), table 6, p. 19; C. No. 3, *Tabeller vedkommende Norges Handel og Skibsfart I Aaret 1868*, Departementet for det Indre (Christiania, 1870), table 6, p. 23; C. No. 3, *Tabeller vedkommende Norges Handel og Skibsfart I Aaret 1869*, Departementet for det Indre (Christiania, 1871), table 6, p. 23; C. No. 3, *Tabeller vedkommende Norges Handel og Skibsfart I Aaret 1870*, Departementet for det Indre (Christiania, 1872), table 6, p. 69.

As can be seen in graph 7, the seasonal peaks for exports were in March and April, though ice was traded on a smaller scale throughout the year.[110] Unfortunately, it is not possible to find corresponding figures for the British imports of natural ice before the end of the 19th century. However, when looking at the import figures for 1901 and 1902 by month, it is obvious that the imports peaked in the summer months (see graph 8 below).

[110] Monthly ice export figures for Norway are available only for 1867-1870.

Graph 8: Monthly Ice Imports Into England And Wales, 1901 And 1902



Sources: *Cold Storage* (January 1902), p. 288; *Cold Storage* (January 1903), p. 12.

As the information on seasonal variations from the Norwegian and British sources are available only for different ends of the observation period, we can only speculate why the main exporter and the main importer climaxed at different times of the year. One explanation, as pointed out by Ouren, is that from 1870s to the early 1900s the use of icehouses improved storage facilities in Norway, and made it possible for the exporters to be more consumer-oriented.[111] In the 1860s and 1870s natural ice was the only available technology. However, at the start of the 20th century several large companies within the fishing, brewery and meat transport industries had already adopted the new technology of artificial ice and mechanical refrigeration.

[111] Ouren claimed that the peak in the exports during the first quarter of the year was not connected with specific demand from the British fishing industry, but was rather a consequence of climatic conditions in Norway and the desire to have an outbound cargo when going to London looking for freights at the start of the shipping season. See Ouren (1981), p. 41.

Therefore, in 1901 and 1902 most of the demand for natural ice came from small businesses, leisure-related industries such as ice cream vendors and hotels. For businesses operating in markets of complimentary goods for ice, the second and third quarters of the year were natural peaks. As a result, it looks as if there was a shift in seasonal dependency from the supply to the demand side between the 1860s and the early 1900s.[112] This meant their incentive for investing in new technology for artificial ice was restrained by the seasonal demand for ice in these trades, as the switching costs were less feasible for the short demand periods, and hindered the creation of economies of scale in these trades.

However, the technology of refrigeration was a different technology altogether. Ice had the disadvantages of creating a damp atmosphere and melting could cause substantial damage to goods. Hence, when consulting contemporary newspapers and reports, it becomes clear that what had started as a market for natural ice had separated into different markets. Some industries, in particular the fishing industry, went ahead with the transition to artificial ice. However, for other industries such as meat, brewing and dairy producers, the question was not one of natural or artificial ice, but whether it would be financially viable to invest in refrigeration machinery.

The imperative argument in favour of refrigeration was the predictability of costs, as once the sunk investment was made, the running costs were relatively low and stable – a sharp contrast to the cost structure when relying on natural ice.[113] However, the banks' reluctance

[112] The use of ice also created new market possibilities for the Norwegian fisheries in terms of fresh fish. From the 1860s onwards, fresh mackerel, salmon and herring were exported to the British market. Here the two trades were highly complimentary, as the British network of icehouses and wells could allow for the transportation of Norwegian fresh fish to the interior. See Hodne (1985), p. 124f.

[113] One report in the trade press suggested that for a storage room of 700 square feet, it would cost £275 for the machinery, gas engine and fitting costs. The running cost

to lend money for refrigeration machinery was discussed frequently in the trade journal *Cold Storage and Ice Traders Review*. It seems the main reason for this was the mismanagement and failure of one company, the London (Riverside) Cold Storage Company, which had long-term consequences for the industry.[114]

5.3.2. Social Restraints

Mokyr noted the importance of a favourable environment for technological progress. Systems have a built-in stability, and resistance is inevitable, and to a certain extent is necessary for a society to function.[115] Another restraining factor is social resistance. Artificial ice met with heavy resistance from those with vested interests in the natural trade but the public was also persuaded that artificial ice was less durable than the natural kind. Hence this involved not only the consumer groups, but also the trades dependent on ice. As an ice merchant in Liverpool found in supplying the railway, he could obtain more money selling natural ice than he could by selling factory ice, because of the common impression that the latter would melt more quickly.[116]

Moreover, many people were reluctant to use artificial ice, not only because of a fear that they could come into contact with ammonia, but also for aesthetic reasons. While the first reason was more justified, artificial ice was opaque due to the microscopic air bubbles. This was less crucial for the fishing industry, but the crystal ice from Norway was usually preferred particularly for table use despite being more expensive. By the turn of the century, new methods such as water agitation to drive out the air succeeded in eliminating the opacity of artificial ice. However, this was

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would be 6-7 shillings per week, while the cost of ice was volatile and could fluctuate from 30 shillings to £3 per week. *Cold Storage* (March 1904), p. 83f.

[114] *Cold Storage* (May 1908), p. 110.

[115] Mokyr, J., 'Technological Inertia in Economic History', *Journal of Economic History*, 52 (1992), p. 328.

[116] *British Refrigeration and Allied Interests* (Feb 1899), p. 87.

a costly process, mainly because of the high price of coal and ammonia.[117] This allowed Norwegian Crystal to remain competitive in the market for crystal ice.[118]

5.3.3. Macro And Micro Inventions, And The Broader Context

As Mokyr acknowledges, the essential feature of technological progress is that macroinventions and microinventions are not substitutes but complements.[119] Mokyr's ideas can be discerned in the history of refrigeration,[120] where the subsequent micro-inventions were essential for the decline of the use of natural ice. The history of refrigeration also supports Rosenberg's claim that inventions have gently declining slopes of cost reduction flowing from their technical contributions.[121] An initial invention is usually crude, and often has to undergo many improvements and refinements before its widespread adoption. Early machinery for the production of artificial ice was not only expensive but could also be dangerous: explosions were not unusual in the early days. The machinery was also often unreliable: for example, in 1909 the Dublin firm of Messrs McCabes experienced continuous problems with its factory compressor, and was obliged to buy ice from Oslo to keep up with demand.[122] It was not until the technology had improved that firms of various types invested in the necessary equipment.

The reasons for the slowness of change, however, appeared to be less related to information flows, as suggested as a usual technological

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[117] *Vestmar* (30 June 1900), p. 2.
[118] While opaque ice cost 2 shillings per ton, the clear ice cost almost 3 shillings per ton; Cooper (1997), pp. 13-14.
[119] Mokyr (1990), p. 13.
[120] See Thevenot (1979); Mokyr, J., 'Science, Technology, and Knowledge: What Historians can learn from an evolutionary approach', paper presented at the 'Evolution of Science' Conference, Santa Fe, 16 May 1998 (1998), p. 18: Hhttp://www.faculty.econ.northwestern.edu/faculty/mokyr/papers.htmlH
[121] Rosenberg (1976), p. 192.
[122] Johnston (1988), p. 71.

constraint by Hagerstrand.[123] The trade press at the time was highly active in promoting the new available technology. Instead the forces of restraint and change also fit into the larger picture of British economic development between 1850 and 1920. Britain's relative decline has been a much-debated topic.[124] From a position of dominance, 1870 Britain's international role diminished after 1870.[125] Shortcomings in science and technology, and institutional constraints in the form of a lack of financial backing have been suggested as reasons for this decline. However, despite the passing of Britain's economic predominance, the country's highly urbanised economy and rising wages meant that the boom in the food and drinks industries, together with the growing demand for luxuries, ensured that natural ice remained important despite its higher price.[126]

The rate of change, as noted by Mansfield, was faster where the outcome was more profitable and where the investments were less severe.[127] This picture supports the evolutionary ideas, where the development of technology is not a uniform process, but was heavily dependent on the size, capital and the nature of the businesses involved. The process of technological change can in this case be understood only by looking at both the micro and macro pictures of Britain's relative maturity and stagnation, as well as its institutions and its social and technological restraints.

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[123] Inkster, I., *Science and Technology in History* (London, 1991), p. 16.
[124] For an overview of this debate, see Pollard, S., *Britain's Prime and Britain's Decline* (London, 1989), p. 51; and more recent findings Crafts, N.F., 'Long Run Growth', in Floud, R., Johnson, P. (eds), *The Cambridge Economic History of Modern Britain, vol. II* (Cambridge, Cambridge University Press, 2nd ed., 2004), pp. 1-24.
[125] *The Golden Age: Essays in British Social and Economic History, 1850-1870*, (eds) I. Inkster, I., Griffin, C., Hill, J., Rowbotham, J. (Aldershot, 2000), p. 143.
[126] *British Refrigeration and Allied Interests* (May 1899), p. 87.
[127] Mansfield, E., 'Technical Change and the Rate of Imitation', *Econometrica*, 2/4 (October 1961), p. 63.

6. Conclusions

The Anglo-Norwegian ice trade was a short-lived adventure, and this is perhaps why it has almost entirely escaped the literature. However, its role was significant and portrays the development, processes and nature of technological transfer and change in Europe before the Great War. While this paper could only focus the role of ice from one of the prime exporter and importers in Europe, natural ice was a global trade and deserves further analysis.

Norwegian exports to the British market had a long trajectory, as the timber trade had paved the way for later trades. It was this advantage that enabled Norway to take a less peripheral role in the trade, and gain a near monopoly in the largest market at the time. However, the Norwegians were heavily indebted to American ingenuity and technology transfer, as well as English enterprise and English efforts to find alternative and less expensive solutions. However, the Norwegian comparative advantage in terms of location, climate, and shipping left them with few contenders from the European or Russian shores.

The sudden rise in demand for ice was related to both long-term and short-term changes. The long-term trends were crucial in creating an increased demand. The large structural changes, particularly urbanisation and population growth all required changes in the way food was supplied. The improvements in living conditions and increased life expectancies were due to improvements in and awareness of hygiene and food preservation, and the various groups such as consumers, producers and transport pushed up the demand for Norwegian ice.

During the hot summers of 1898 and 1899, the ‘ice famines’ were instrumental in speeding up the use of mechanical refrigeration, the technology that had already become common in refrigeration ships transporting meat from Australia, Argentina and America. However, this process was gradual, with different trades adopting the new technology at

different rates, and was by no means immediate or universal in the British market. The resistance, both founded and unfounded, changed slowly as the technology evolved, and issues such as costs, health and safety entered the debate. However, it was not until the second shock of the First World War, when the supply of natural ice was almost completely cut off, that most consumers, producers and especially the transport companies were left with little choice but to seek new technologies. Nonetheless, natural ice had played a significant role in shaping the market. Without doubt it paved the way for refrigeration and its use had assisted the process of modernisation, in terms of urbanisation, the growth of new food industries and the integration of markets. It was undoubtedly an exogenous variable fostering British urbanisation and expansion; however, natural ice was the forerunner of a much larger creation of networks that aided the integration of markets on a global scale.

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