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Entry Barriers and the Structure of the Japanese Ammonium Sulphate Industry in the Interwar Period

Anil Khosla

(Previous Visiting Researcher, The Institute of Economic Research,
Hitotsubashi University
／Centre for Japanese Studies Leiden University)

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The Institute of Economic Research
Hitotsubashi University
Kunitachi, Tokyo, 186-8603 Japan

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Anil Khosla

Centre for Japanese Studies, Leiden University
Arsenaalstraat 1, 2300 RA Leiden
The Netherlands
Tel: +31 71 527 2213; Fax: +31 71 527 2215
and
Visiting Researcher, Institute of Economic Research
Hitotsubashi University, Naka 2-1, Kunitachi-shi
Tokyo, Japan
E-Mail: A.khosla@hccnet.nl; A.Khosla@let.leidenuniv.nl

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Abstract

Production of ammonium sulphate in Japan until the late1920s was dominated by just two firms. The received view is that foreign competition and limited market size were effective in ensuring a competitive industry structure and preventing new entry. This explanation, however, fails to account for extensive new entry in the midst of developing agricultural crisis and emergence of international overcapacity in the late 1920s. We find that while market size may have played a part, economically viable access to technology was a more important barrier to entry. Calculated risk taking could have mitigated the impact of this constraint.

For over two decades, until the end of 1920s, domestic production in the Japanese ammonium sulphate industry was dominated by two firms without eliciting new entry. Commonly held view is that in the absence of protection from foreign competition, the specter of cheap imports and the relatively small size of the market to justify the large-scale investments required, kept new firms out. However, it is not at all clear why new firms then decided to enter the industry towards late 1920s, in the midst of an ongoing agricultural depression and an emerging glut of ammonium sulphate in the international market. Also, the industry bucks the trend of concentration of capital, employment and production that characterized most of the Japanese economy during the 1920s[1]. In this paper we look into the process of growth and development of the Japanese ammonium sulphate industry and the structure of its production markets to find a clue to this anomaly.

Chemical fertilizers were important for the Japanese economy during the interwar period as a means to increase agricultural productivity and production. Extensive agriculture as a source of increased agricultural production was more or less exhausted. Use of high yielding varieties of crops was rising which required irrigation and input of fertilizers in increasing quantities. Yujiro Hayami has stressed that Japan's agricultural growth after 1912 was predicated on the growth of modern fertilizer industry. He attributes about 20 per cent of agricultural growth in the interwar period to increased use of marketed fertilizers[2]. Among various plant nutrients that fertilizers can provide for plant growth, nitrogen was known to be crucial. The Japanese farmers' use of soybean cake, a nitrogen rich fertilizer, in increasing amounts was a testimony to their awareness of this issue. High Japanese dependence on soybean cake as a source of nitrogen nutrient for plants was partly due to the unsuitability of Chili Saltpeter (sodium nitrate) for the wet agriculture practised in Japan[3]. Calcium cyanamide and ammonium sulphate, especially the latter, were found to be better sources of nitrogen for Japanese agriculture[4]. Again, Japan was becoming increasingly dependent on import of soybean cake from Manchuria, the supply of which could be uncertain in times of war. The growth of the nitrogenous fertilizer industry, specially the ammonium sulphate industry, was thus crucial for the Japanese economy.

A study of the Japanese ammonium sulphate industry during the interwar period, while important in itself, can also shed light on the impact of factors such as access to technology, high fixed costs, entrepreneurial initiative (risk taking), and the size of the market on the structure of production. Ammonium sulphate industry was. internationally, a growth industry with an important technological breakthrough occurring in early 1910s. This study, therefore, also provides an opportunity to look at changes in industrial organization as an industry matures. Homogeneity of ammonium sulphate as a product helps us to abstract from product differentiation as a source of non-competitive structure.

The turbulence of the ammonium sulphate market in Japan during the interwar period provides interesting insights. The onset of World War I substantially reduced imports giving the domestic nitrogenous fertilizer firms an opportunity to expand output. At the same time, cut off from the emerging international developments in production technology[5], the industry established itself in Japan as a relatively high cost industry. As World War I came to an end, and no governmental protection, the industry was faced with tough competition from a resurgence of imports. By late 1920s to early 1930s, the industry had matured technologically. As a result, new entry proliferated in Japan and elsewhere. Coupled with a sharp reduction in demand following the severe international agricultural depression in late 1920s, excess capacity emerged. The industry cartelised formed an international cartel with geographic division of the markets among major international players. Studying the implications of these developments on the structure production in Japanese ammonium sulphate industry was another objective. In what follows, we begin with a brief sketch of the process of growth and development of the Japanese ammonium sulphate industry within the context of technological developments at the international level.

Development of Japanese Ammonium Sulphate Industry

The Japanese ammonium sulphate industry at the beginning of World War I, was relatively young. The British were the first to produce ammonium sulphate fertilizers in the 1870s by making use of the waste gases from coke refining. This source of nitrogen as a plant nutrient emerged in response to increasing concern with what was termed “Nitrogen problem” and the possible difficulties in ensuring sodium nitrate (Chili Saltpeter) supplies as its agricultural use competed with its military use[6]. Gradually, production of ammonium sulphate spread to other countries as well, including Japan. The last decade of the nineteenth century saw a wave of successive technological advances causing a rapid expansion of output internationally[7]. By the beginning of World War I ammonium sulphate was becoming an important, even if not the largest, source of nitrogenous fertilizers in the world[8].

The Japanese production of ammonium sulphate also began with the by-product method using ammoniac gases escaping as waste in the production of coke and other refining industries (hence the name by-product ammonia method). The technology was simple[9] and given the economies of joint-production, it was quite profitable for the refining firms to produce ammonium sulphate as a by-product. The main drawback, however, was that production of by-product ammonium sulphate was supply and not demand determined. Therefore, expansion of ammonium sulphate supply was predicated on the growth of refineries rather than the price of the fertilizer in the market.

Though Japan succeeded in producing its first ammonium sulphate via by-product method in 1898[10], it was only in 1901 that Tokyo Gas succeeded in producing it commercially. Many other gas companies followed suit[11]. Though practically the only source of domestic supply, it could by no means meet the domestic demand. The industry was producing 467 tons of ammonium sulphate from this source in 1905, rising to 1,905 tons in 1908[12]. This compared to over 26,012 tons of ammonium sulphate imported in 1905 and 66,376 in 1908[13]. By the beginning of World War I, a number of gas, coke and smelting firms such as Miike Coal Mining and Yahata Steel Works were producing ammonium sulphate as a by-product.

In the intervening period, two new technologies for producing ammonium sulphate became available — the *electric arc* method and the *conversion method*. The former, developed in 1898 by Sir William Crooks and tried in 1902 in Norway and Sweden, had exceptionally high electric power requirements (about 70,000 KWH per ton) and was, therefore, soon rendered obsolete[14]. The other process, the so called conversion process, involved reacting calcium carbide with atmospheric nitrogen at high temperature to obtain calcium cyanamide. Calcium cyanamide was then treated to deliver ammonia and absorbed in sulphuric acid to obtain ammonium sulphate. Electricity requirements of this process, though still high, were about a fifth of those required by the electric arc method[15].

These alternative processes for producing ammonium sulphate, involved a certain level of technical knowhow for successful fixation of atmospheric nitrogen. At the time, Japan had a shortage of such skills.

Nihon Chisso Hiryo (Nichitsu), set up after merging Sogi Denki and Nihon Carbide in 1908, for this specific purpose, was the first in Japan to adopt the conversion technology for producing ammonium sulphate by obtaining a license to the Italian Frank-Caro process[16]. The technology was bought and introduced into Japan despite a lack a prior full scale testing of the product as a fertilizer. Prior production testing was also limited and indicates the foresight, technical knowledge and business acumen of Noguchi Jun, the founder of Sogi and Fujiyama Tsuneichi of Nihon Carbide[17]. With the adoption of this process, annual production of ammonium sulphate in Japan rose rapidly from just about two thousand tons a year in 1908 to around seven thousand tons in 1912. Still, domestic demand far outstripped production and this excess demand was being met by imports.

The first major growth spurt in the Japanese ammonium sulphate industry came about as a result of the unanticipated access to the market made possible by the beginning of World War I. Cyanamide conversion technology was the predominant method of producing ammonium sulphate during this period though production of by-product ammonium sulphate also expanded in the wake of expanding refining industry and the high profitability. Internationally, however, Germany succeeded in synthesising ammonia directly from atmospheric nitrogen without the need to fix it via calcium cyanamide around 1913. This invention revolutionised production of ammonia and ammonium sulphate by bringing down the production costs considerably. However, this technology was not adopted in Japan till mid 1920s.

As mentioned earlier, calcium cyanamide conversion process of fixing nitrogen and ammonium sulphate production was quite energy intensive. During the interwar period, availability of excess supply of electric power in Japan proved to be the most important facilitating factor in the development of the ammonium sulphate industry[18]. This excess supply of electric power was the result of the rapid growth in electricity generation capacity that began around the turn of the century. At the same time, carbide industry, the basis of ammonium sulphate production through the conversion method was also expanding. These twin developments, the growth of electric power generation capacity and the expanded production of calcium carbide were to prove immensely beneficial for the development and growth of the ammonium sulphate industry in Japan in the later stages[19].

Table 1 provides five year averages of ammonium sulphate production and its annual compound rate of growth in value and quantum terms between 1912 and 1939. Both the indicators show a sharp rise during World War 1. The reason for such an increase, more than a technological coup, was the beginning of WWI in 1914 that reduced imports of ammonium sulphate from Great Britain, the most important exporter to Japan, drastically. Prior to war, over 87 per cent of the Japanese consumption of ammonium sulphate was being provided for by imports[20]. The cessation of imports led to an unprecedented rise in prices and profits soared. This was a godsend opportunity for the domestic ammonium sulphate producers to get firmly established in the market. At first, Nichitsu was the main beneficiary of the new situation as it was the only one using the recently invented conversion process. in 1915, Hokkaido Carbide, under the leadership of Fujiyama, moved from carbide production to ammonium sulphate and changed its name to Denki Kagaku Kogyo (Denka). Nichitsu, the biggest producer of ammonium sulphate at the time, also expanded its capacity and production[21].

(Table 1 about here)

As a result of these developments, domestic production of ammonium sulphate had expanded from an average of 7,000 tons per year in 1912-1913 to about 36,000 tons during 1914-1918, a hefty growth of 39 per cent a year. The rate of growth in value terms was much higher at 51 per cent reflecting the difficulties in meeting demand based on domestic production alone leading to a faster rise in prices. This was despite an average nine per annum per cent decline in consumption in the same period due, perhaps to the rise in prices. Once the war ended, imports re-entered Japan bringing down the prices after reaching a peak in 1919. The price decline boosted consumption which grew by over 23 per cent per annum. The rate of growth of output declined to about twenty percent in quantum as well as value terms while imports recovered. This indicates a relative price stability after an initial decline. The average figures, however, conceal the fact that a substantial part of the decline in growth rate in value terms was accounted for by a sudden decline in prices in 1920 and 1921 as a result of the agricultural depression. However, as exporters of ammonium sulphate re-established their production capacities, import competition in Japan increased. Still, it was not till the end of 1920s that price of ammonium sulphate fell below its prewar (1912) level[22]. The Japanese ammonium sulphate industry had established itself firmly during the war period and, as evidenced in the later developments, a resurgence of imports could not dislodge it despite its relatively high cost production technology.

As mentioned earlier, Germany had perfected the technology to synthesise ammonia directly from atmospheric nitrogen just before the beginning of WWI. Since nitrogen constitutes about 80% of the atmosphere, this technology, the Haber-Bosch process (named after the inventors), reduced costs of producing ammonia and ammonium sulphate considerably. The technology was put to commercial use for the first time in the Oppau factory of Badische Anilin und Soda Fabrik AG (BASF) in 1913[23] and was the most advanced technology of the time. Access to this technology was difficult and the the cost advantages high enough to induce the major ammonium sulphate producing countries to divert substantial resources in search for an alternative.

In principle, production of ammonia through synthesis is a very simple process. It involves combining one part by volume of nitrogen and three parts by volume of hydrogen to yield two parts by volume of ammonia[24]. Both the ingredients are easy to obtain and all that is required is an appropriate means to react the two. Since this chemical reaction accompanies a reduction in volume and release of energy (a rise in temperature), it is favoured by high pressure and low temperature conditions. However, low temperatures tend to slow down the speed of reaction. A catalyst can help get around this problem. Again, the need to maintain appropriate levels of temperature and pressure for sustained periods of time require technology to build equipment capable of withstanding such severe conditions over long periods of time. Thus, a proper catalyst and specialized equipment were absolutely essential factors in successful commercialization of the process[25].

These technological features of the synthetic ammonia process were instrumental in impeding the diffusion of technology through imitation. A number of European countries and the United States devoted substantial resources in trying to overcome the problems associated with ammonia synthesis but met with only partial success till the mid 1920s. Later, however, a number of alternative processes to synthesise atmospheric ammonia did became available[26].

These developments had a significant impact on growth and development of the ammonium sulphate industry in Japan. The increase in war time profits, based on a temporary suspension of imports was considered transitory and the prospect of low cost imports, based on the new, low cost technology, flooding the domestic market after the war was an important factor for a firm to consider before deciding to enter the industry.

The synthetic ammonia process for the production of ammonium sulphate was first introduced in Japan in 1923/24 by Nichitsu when it licensed a commercially, relatively untested process from Italy — the Cassale process[27]. This was followed, in the same year, by adoption of another commercially untested process — the French Claude process — by Daiichi Chisso Kogyo (related to the Suzuki Trading Company) a new entrant in the ammonium sulphate production[28].

Table 1 indicates a decline in growth of ammonium sulphate production to about 12 per cent in quantum terms during 1924-1928, rising to 18 percent in 1929-1933 period. In contrast to the previous periods, quantum rate of growth during the 1920s to early 1930s exceeded the rate of growth in value terms (four per cent for 1924-1928 and six per cent for 1929-1933) reflecting an unmistakably steep fall in prices. The averages, once again conceal some important information. After an initial fall in 1920-21, price of ammonium sulphate remained relatively stable or even rose somewhat till the onset of agricultural depression in 1927[29]. Thereafter, the prices declined sharply once again during the great crash in 1930 - 1931 and then started to increase. The observed decline in the quantum rate of growth during the 1920s can be attributed to two factors. A substantially higher base value of production during the previous decade, and reduced possibility for further quick growth in the absence of the more efficient technologies with the resumption of imports from Western Europe and the US. A resurgence of growth in the late 1920s, was made possible by the proliferation of technological alternatives to the Haber-Bosch process that allowed new firms to enter the industry.

The development and growth of ammonium sulphate industry in Japan during the 1930s was characterized more by technological diffusion, innovation and substitution of resources, rather than new inventions[30]. Commercial success of the new processes to synthesise ammonia encouraged new entry and production capacity expanded substantially. Showa Hiryo, for example, began production in 1931 using the process developed by Tokyo Industrial Experimental Laboratory (TIEL) in 1928 with a capacity of 150,000 tons a year. Other plants that started production towards the end of 1920s and early 1930s also ranged in capacity from 40,000 tons to 50,000 tons per year. Most of the new firms began production in early 1930s, just at the time when there was a glut in international ammonium sulphate markets and prices were declining. One would have expected a steep fall in prices or a shake out in the industry. But production during this period grew at about 15 per cent per annum in value as well as quantum terms (Table 1) indicating relatively stable prices. This seeming anomaly of price stability with increasing competition (increase in number of firms and productive capacity) in the industry was the result of cartelisation at the international as well national level. The international over-capacity forced the major exporters of nitrogenous fertilizers to come together under the International Nitrogen Convention (1930) and divide up the markets amongst themselves. Japan, tried to counter by entering into an agreement with this international cartel. The Fujiyama-Bosch agreement (1930) and later renegotiated Noguchi-Bosch agreement of 1931[31] were efforts in this direction. In 1932, Ammonium Sulphate Distribution Agency was established in Japan, covering all major producers of ammonium sulphate except those using the by-product method, with the express purpose of maintaining prices and control production of its members[32].

Having discussed the process of growth and development the context of the changing technological environment, let us now turn to the structure of production in the industry in Japan and changes therein.

Production Structure

Except for the early 1900s and shortly during and after World War I, production of ammonium sulphate using the by-product ammonia method was never a major source of supply in Japan. Since this process made use of waste gases from refineries or gas companies, supply from this source was unresponsive to changes in prices. It is therefore, safe to assume that such firms were unable to influence prices and, hence, were relatively insignificant in terms of affecting the production structure of the industry.

Only two major players, Nichitsu and Denka, dominated the production of ammonium sulphate in Japan till late1920s. Both were using the cyanamide conversion method for fixing atmospheric nitrogen though Nichitsu introduced the synthesis technology in 1923. New entry occurred only in very late 1920s with

Daiichi Nihon Jinzo (Jinzo hereafter) starting production in 1928. Most other entrants began production in the early 1930s using a variant of the synthesis technology. A quick glance at Table 2, presenting the available data on production shares of major Japanese ammonium sulphate producers substantiates this observation. The share of these two firms ranged from 75 to 90 per cent of the total production with the highest share registered during the WWI period.

Looking at the shares of the individual firms through the 1920s, we find major changes in the Production share of Nichitsu in 1921 (a loss of 7%), 1925 (a loss of 10%), and 1930 (a gain of 18%). In contrast, Denka saw its share decline by 5% in 1921, rise by 8% in 1924 and decline steeply by 12% in 1930. The decline in the production share of both the leaders in 1921 was possibly due to a sudden increase in the production of by-product ammonium sulphate following the expansion of the metal refining industries during World War I[33]. With growth in production using the conversion process failing to keep pace with the growth in total supply, the share was bound to fall. The rise in the share of Nichitsu in 1930 reflects, partly, the beginning of production by Korean Chisso Company, a major subsidiary of Nichitsu, and partly an increase in capacity utilization rate.

(Table 2 about here)

The movements in the share of Denka and Nichitsu provide an interesting insight into the production structure of the Japanese ammonium sulphate industry during the 1920s. In the available literature, we find repeated references to the superiority of Nichitsu over Denka in terms of production costs. While the former had its own electric power generation capacity, the latter encountered substantial difficulties in obtaining electric power repeatedly as it depended almost exclusively on purchased electricity[34]. Again, Nichitsu must have reaped first-mover advantages in mid twenties by shifting to the synthetic ammonia process. Denka, however, stayed with the calcium cyanamide process with higher energy requirements[35]. The vulnerability of Denka to such cost disadvantages is also clear from the rapid fall in its share of production during the 1930s as new companies, all using the synthetic ammonia process, came into existence. However, during the 1920s, Denka not only continued to operate, but was able to maintain and even increase its share of the domestic production (Table 2). This counter-intuitive movement in the share of Denka indicates the possibility of imperfections in the Japanese ammonium sulphate industry allowing profits despite high-cost production technology. The surge in cheap imports after World War 1 also do not seem to have impacted the ability of Denka to stay in the market.

The movements in the share of Nichitsu in the 1920s also draw attention to the possibility of non-competitive markets up to the late 1920s. Despite being a relatively progressive and better firm compared to Denka, its share showed a sharper decline. This makes sense only if Nichitsu was in a position to make excess profits through controlling its output and supplying less to the market. In other words, Nichitsu may have been a price leader with some control over price setting in the industry. In the price-leadership model, the leader is able to set a quantity of its own dictated by its marginal cost and the marginal revenue curves, and then sell at a price determined by the height of demand curve at that output. The follower usually takes the price as a datum and tries to sell as much as it can at that price. That this was a real possibility is suggested by the fact that Nichitsu was operating at 50-70% of its capacity right through to 1926-27, where after it expanded its output to near full capacity[36]. This rise in output to near full capacity appears to have been in response to an increase in competition from imports[37] and the expected new entry in the domestic market. It appears that Nichitsu was holding on to extra capacity as a strategic threat against new entry and may have been successful at least till late 1920s[38].

Though we are interested primarily in the production structure of the ammonium sulphate industry to the 1920s, a brief look at the 1930s can bring the issues in a sharper relief. As production from a number of new firms entering the industry towards the end of 1920s began arriving in the market in the early 1930s, production concentration in the top two firms decreased. Still, the top six companies accounted for over 80 per cent of total production. As Table 2 shows, however, the ranking of the firms was becoming highly fluid. By 1932, Denka had lost its position as the second largest producer to Showa Hiryo. By 1936, it was only the fifth largest producer after Nichitsu, Mitsui (Miike and Toyo Koatsu), Showa Hiryo and Sumitomo Chemicals. In between the rankings had been changing quite frequently. It was no longer possible for Nichitsu to continue its role as the dominant player in the market[39]. As discussed in the previous section, the Japanese ammonium sulphate industry had consolidated itself in this period by forming an association which effectively acted as a cartel in setting production levels and prices in conjunction with the International Nitrogen Cartel[40]. We can, therefore, characterise 1930s as an imperfectly competitive phase though declining share of the dominant firms and often changing ranking points to greater fluidity in the market.

One final intriguing observation about the structure of the Japanese fertilizer (ammonium sulphate was by far the biggest component of it) industry in Japan during the interwar period is that its profit performance was the best during the 1920s[41]. The average rate of profit for this industry at 13.6 per cent was higher than for the Chemical industry as a whole at 13.1 per cent, machinery at 9.6 per cent and even manufacturing as a whole at 12.9 per cent. In contrast, it was at the bottom of the rung during the 1914-17 and 1931-40 periods. Though not pertaining to ammonium sulphate industry directly, these simple calculations show that the fertilizer industry was doing much better than other major growth industries of the period.

Given the concentration of production in the ammonium sulphate industry and the higher than average profits in the fertilizer industry during whole of the 1920s, why did new firms fail to enter the market? In the next section we try to explore some of these factors.

Nature of Entry Barriers

Bain refers to three major types of barriers to new entry — economies of scale, legal and semi-legal barriers and factor market imperfections[42]. In this section we look at the the barriers affecting the Japanese ammonium sulphate industry during the 1920s.

We have previously mentioned that almost all processes used for producing ammonium sulphate in Japan were imported from abroad. Throughout the period under consideration, except for the Fujiyama process for producing ammonium sulphate through cyanamide conversion (used by Denka and a variant of Frank-Caro process used by Nichitsu)[43] and the Tokyo Industrial Experimental Laboratory (TIEL) process (developed in the late 1920s and utilized by Showa Hiryo)[44], there was hardly any significant Japanese contribution to technological development in this industry. Imported technology is not easily diffused by the domestic firms in their own interests. Tthe foreign parents, more often than not, impose various types of restrictions on such diffusion. The possibility of new entry at the domestic level in such circumstances gets restricted to entrepreneurs with international contacts and resources, who are active and knowledgeable enough to hunt for and discriminate between alternative technologies, and are ready to assume reasonable risks. This can make all the more difference if the technology is cutting edge and there is little previous accumulation of information.

In case of ammonium sulphate industry, specially the synthetic ammonia process, these conditions were quite severe. First, the production technique itself was quite specialized and required high level of skills. Second, construction of the production facilities also needed special types of containers and machinery calling for new type of skills in complementary industries like iron and steel and metallurgy. Japan was deficient on both these counts specially up to the early 1930s as these complementary industries were just beginning to develop in the early twentieth century and the accumulation of skills was relatively low[45]. While such factors can definitely affect the structure of domestic production, we believe that, in case of ammonium sulphate industry, access to technology at reasonable prices and high fixed costs (giving rise to economies of scale) were the most important factors in keeping new entry at bay. Let us explore these two issues further.

Access to Technology and Set up Costs as a Barrier

To explore access to technology as an entry barrier, we base our analysis on company histories where information on the process of establishment of the firm and introduction of technology is most likely to be available. Table 3 is based on company histories of some of the major firms in the Japanese ammonium sulphate industry. It provides information on the type of technology considered for adoption or actually adopted and tries to collate available information on the cost of introducing such technology. The picture presented is certainly not complete in all respects but fairly well reflects the relative cost of adopting various technologies.

(Table 3 somewhere here)

Two major firms entering the ammonium sulphate production in early 1930s were the Sumitomo Chemical Industries (related to the Sumitomo zaibatsu) and Toyo Koatsu (related to the Mitsui zaibatsu).

Both these zaibatsu groups, along with Mitsubishi, another prewar conglomerate, had been interested in producing ammonium sulphate since around World War I period[46]. They were interested in the Haber-Bosch process, the most advanced technology in the industry at the time. Due to ongoing War, however, it was not easy to get hold of the license. Given the efficiency and low costs of combining atmospheric nitrogen and hydrogen to obtain ammonia, many countries were interested in finding an alternative to this technology. General Chemicals of America partially succeeded in developing such a modified process and Sumitomo investigated the process rather closely for adoption. It came very close to buying this license with another company, Sankyo and in conjunction with Mitsui and Mitsubishi, entering a provisional agreement[47]. But, production using this method in the US stopped immediately after the War, the process never came to be developed fully.

After the end of the War, around 1918-19, the attention this group shifted to the Haber-Bosch process and a consortium, Eastern Nitrogen Association, comprising the three largest zaibatsu groups, Mitsui, Mitsubishi and Sumitomo, along with five other companies interested in synthetic ammonia process was set up to study the possibility of adoption of this process[48]. Even though Germany was defeated in the War, details of this process were not readily available. The difficulties involved were formidable and even the British efforts to get hold of technological details by visiting the Oppau factory of the BASF proved to be of no avail[49]. The conditions imposed by BASF for the use of this technology, were extremely stringent. For a factory producing 100,000 tons of ammonium sulphate a year, construction and equipment costs were estimated at ¥50 million, the licensing fee at ¥5 million plus a royalty of ¥25 per ton of ammonia produced[50]. Even for the financially well endowed consortium such as Eastern Nitrogen Association, the conditions were unpalatable and the idea of setting up a production facility based on this technology was shelved. Table 3 shows that just the cost of construction based on this process worked out to be ¥500 per ton, far in excess of any of the other processes considered or actually adopted in Japan. Assuming a 10-year productive life, this would add ¥50 per ton to the price, or ¥33 if the life of the plant was taken to be 15 years, at full capacity. Alternatives, though available, were as yet commercially untested and the consortium was not ready to take the risk of testing new technology.

It is interesting to note that it was precisely during this period that Nichitsu also began its search for synthetic ammonia technology. In 1921/22, Noguchi, the architect of Nichitsu, was able to get hold of a license for the Italian Cassale process. This process had been invented relatively recently and was still in experimental stages. Buying such untested technology was, of course, a courageous step and Nichitsu was the first in the world to make use of this particular technology[51]. The licensing fee was ¥1 million, only a fifth of what BASF was demanding for the Haber-Bosch process. Initial test production was only about 25,000 tons (target capacity of 60,000 tons per year) almost one fourth the scale required for the Haber-Bosch process. Nichitsu began producing synthetic ammonia and ammonium sulphate by towards late 1923. Just as in case of introducing the cyanamide conversion technology in 1908, this move by Noguchi was a testimony to his technological awareness and business astuteness. In contrast to the Eastern Nitrogen Association led by relatively conservative zaibatsu, Noguchi was ready to take calculated risks.

Around the same time, Suzuki Trading Company, another up and coming zaibatsu, also obtained a license for another relatively untested technology, the French Claude process of synthesising ammonia, developed in 1919 and registered in 1920. The company did set up a small pilot plant in 1924 and succeeded in synthesising ammonia. But technical difficulties and small scale of production did not allow it to become a going concern[52]. In 1927, with the onset of the financial crisis, Suzuki went bust and the license was bought, along with plant and equipment, by Mitsui's mining division at a very cheap price (Table 3)[53]. Suzuki Trading was paying a relatively high royalty fee of ¥40 per ton. Before Mitsui took over, however, it renegotiated royalty payments to one third of the original level[54]. Mitsui group thus entered the market for ammonium sulphate under the name of Miike Chisso Hiryo in 1931-1932.

Among other consortium participants, Sumitomo entered the industry in late 1920s using the American, Nitrogen Engineering Corporation (NEC) license for which it paid ¥450,000 as licensing fee, one tenth of the fee demanded for Haber-Bosch process[55]. Such a steep decline in licensing fee was made possible by the development and successful commercialization of a number of new technologies for synthesising ammonia which gave the buyers a degree of bargaining power. Sumitomo Chemical began production in 1931.

Other firms entering the ammonium sulphate production in the 1930s were not even contemplating entry until late 1920s. The most important of these was Showa Hiryo which established a plant based on the Tokyo Industrial Experimental Laboratories (TIEL) license. TIEL, being a government institution, did not charge any licensing fee. Even the royalty payments were very soft[56]. Prior to this, Showa Hiryo was trying for the German Woody process, that required ¥1.5 million in licensing fee only and about ¥8 million for the equipment. Another alternative considered was the Italian Fauser process with a licensing fee of ¥800,000, equipment for about ¥2-3 million and a royalty of about 2.5% of the selling price. Both these propositions were for plant capacity of 100,000 tons of ammonium sulphate a year. With the low costs of establishment using TIEL process, the firm was able to set up a plant with a capacity of l50,000 tons per year and entered the market in 1931-1932[57].

Discussion above clearly indicates shows that access to production technology at economically viable costs was probably a formidable barrier to new entry during the 1910s and early 1920s on two counts. First, alternatives to the state of the art production technique were either unavailable or, when available, commercially untested. Second, the costs of construction, equipment, licensing and royalties were simply too high. In the latter half of the 1920s alternative technologies proliferated and costs of technology acquisition fell. Thus, until around 1926-27, licensing and capital costs appear to have acted as formidable barriers to new domestic entry.

Fixed Costs, Scale-Economies and the Size of the Market

High fixed costs (cost of licensing, equipment, construction and royalties) can affect entry decision of a firm but these are not insurmountable problems if the industry can generate sufficient profits. The funds needed for investment can be found. We mentioned earlier that Eastern Nitrogen Association, the financially strong consortium led by the powerful zaibatsu groups, Sumitomo, Mitsui and Mitsubishi, shelved the idea of entering the ammonium sulphate market using the Haber-Bosch technology due to high costs. The consortium must have felt that at such high level of fixed costs, profitability of the firm could not be ensured[58]. High fixed cost industries show economies of scale which reduce unit costs substantially as production expands. Market size (demand), therefore, becomes an important issue. If the market is not big enough to absorb the increase in capacity needed for fully exploiting the economies of scale, the costs can stay high. The consortium must have felt that the expected increase in demand in the Japanese market was not large enough to justify such a large plant. In the early 1920s, the consortium estimated that domestic demand for ammonium sulphate will increase by about 80,000 tons per year which was less than the minimum scale required for profitable production with the Haber-Bosch process[59]. Unfortunately, all the cost data needed for calculating economies of scale in a rigorous manner are not available for different processes. It is, however, fair to assume that since production involved volumes of gases, per unit cost of constructing larger plants was less than that for smaller plants.

Table 3 indicates that most new entrants during the 1920s, including Nichitsu, were opting for large scale, ranging from 60,000 to 150,000 tons per year capacity. In the case of Suzuki's Daiichi Chisso also, the intended capacity was 50,000 tons per year though only 6,000 tons was built and the firm had to close down within three years[60]. Similarly, Sumitomo Chemicals faced severe losses in the early years because of its smaller scale[61]. However, to introduce such large capacity, the market must be able to absorb the increased supply without resulting in too sharp a decline in prices and profits. In what follows, we try to estimate the impact of an additional capacity of 60,000 tons or 100,000 tons per year on the price of ammonium sulphate in Japan at various points of time during the 1920s. This is done by estimating the self-price elasticity of demand. Since a decision to enter the industry depends, among other things, on profit expectations, probability of a steep decline in post-entry price can be an important consideration in the decision to stay out.

Demand Function for Ammonium Sulphate

We estimate an indirect demand function, in the sense that it is derived from the profit maximization condition of the farmers. Since substitution between fertilizers (providing a particular nutrient) and other factors of production is expected to be non-existent for all practical purposes, we assume the production function to be separable[62] so that for nitrogenous fertilizers, we can write the profit maximization condition as

$$\pi = P_a Q_a(\, . \, , f(F_1, F_2; H), \, . \,) - P_1 F_1 - P_2 F_2$$

where, π is farmers' profit, P_a is the price of agricultural commodities, $Q_a(. , .)$ is the agricultural production function, F_1 nitrogenous fertilizer 1 (ammonium sulphate here), F_2 nitrogenous fertilizer 2 (soybean cake here), P_1 the price of ammonium sulphate, P_2 the price of soybean cake, and H is a shift parameter (approximated here by proportion of total cropped area under improved seed varieties of rice).

In this model, the quantity demanded of the fertilizer is a function of its own price, the price of its substitute, the prices of the agricultural commodities received by the farmers and the area under major improved varieties of seeds. Here we assume that the proportion of cropped area under improved varieties of rice seeds, H, to be exogenous to the farmers calculations in the short run. This assumption is justified on the grounds that introduction of improved seed varieties depends also on irrigation facilities and a lack of such facilities inhibits adoption of improved varieties even if fertilizer is available. Construction and the extension of irrigation facilities are, to a large extent, dependent on factors exogenous to the farmers' budget constraints (e.g., government subsidies etc.) and can be treated as lying outside farmers' short run budget considerations.

The profit maximization condition allows us to specify the demand function for ammonium sulphate as:

$$D = g\left(\frac{P_1}{P_a}, \frac{P_2}{P_a}, H\right)$$

For our analysis, we use current prices for the fertilizers but one year lagged prices for agricultural produce on the assumption that farmers cannot accurately estimate the prices that would obtain once the produce comes to the market and use previous year's prices as a rough guide. The basic data on P_1, P_2, and D used in the estimation is annual data over the period 1912 to 1939 from Norinsho, *Hiryo Yoran*[63]. Data for the price of the agricultural produce (P_a) is the index of prices received by the farmers from Umemura Mataji et. al., *LTES, 9*[64]. H, the area under improved variety of rice seeds is calculated from Hayami and Yamada, *Agricultural Productivity*[65]. Since we use fertiliser consumption as the explained variable, ‘H’ parameter is important in capturing the shift in the demand function as a result of greater use of improved varieties requiring greater input of fertilizers.

We opted for a log linear estimation as represented below:

$$\log D = a + b_1 \log P_1' + b_2 \log P_2' + b_3 \log H$$

where P_1' and P_2' are the current prices of the two types of fertilizers divided by the price of the farm products in the previous year. The signs on the coefficients b_1 and b_2 are assumed to be negative and positive respectively as demand for ammonium sulphate is expected to fall with a rise in its own price and rise with a rise in the price of the substitute. For 'H', a rise in the area under improved seed varieties is expected to shift the demand function to the right and hence it is expected to be positively related to demand.

The results of the regression equation are presented in Table 4. All coefficients carry proper signs. However, the coefficient of cross-price elasticity, b_2, is insignificant and most of the variation in demand is explained by movements in the price of ammonium sulphate relative to agricultural prices and the area under the HYV of crops. The coefficient of determination, adjusted $\underline{R}^2$, is fairly high at 0.92. The table presents results including the relative price of soybean cake fertilizer (a) as well as excluding it (b).

(Table 4 about here)

Since we used a log linear specification to estimate the model, b_1 represents the price elasticity of demand for ammonium sulphate and it is, therefore, possible to calculate the change in price (ΔP_1) required for a given change in demand (ΔD). Our calculations indicate that in 1921, the price of ammonium sulphate would have had to decline by around ¥34-36/ton (20 per cent)[66] to absorb an extra 60,000 tons of the fertilizer and by ¥56-60/ton (30 per cent) to absorb 100,000 tons, the capacity of the Haber-Bosch process under consideration at that time. By the time Nichitsu entered the market with Cassale technology in 1923, the same extra amounts of production would have required price falls of ¥28-30/ton (15 per cent) for 60,000 tons (the full capacity under Cassale process adopted by Nichitsu) and ¥46-50/ton (25 per cent) for 100,000 tons. In late 1920s, the situation became much easier. In 1929, for example, a 60,000 ton additional capacity required the price to drop by less than ¥10 (eight per cent) and 100,000 tons could be absorbed at the cost of bringing down the price by ¥15/ton (12 per cent). In 1931, when a number of new firms began producing ammonium sulphate, the prices had to come down by eight to ten per cent to absorb such large amounts of output[67].

This results of the above exercise indicate that a technology with high fixed costs and large capacity, such as the Haber-Bosch process considered by the Eastern Nitrogen Association, may have been difficult to implement in the early 1920s. The substantial increase in domestic production capacity that it entailed would have required a steep fall in prices and hence profits. However, it does not preclude the possibility of using a technology with somewhat lower costs and smaller optimum scale, such as the Cassale process used by Nichitsu to enter synthetic ammonia production in 1923. The decline in prices required for such a smaller plant would have been much smaller, even in the depressed situation in 1921, the time when the Eastern Nitrogen consortium was assessing the possibility of entering the market.

Implications and Conclusions

From the discussion in this paper on one thing is clear. Free trade in ammonium sulphate, though it may have constrained the non-competitive behaviour by the domestic firms, did not necessarily render the Japanese market competitive. For one, a competitive market formulation cannot explain the peculiar movement in the production shares of Nichitsu and Denka, given the cost structure of the two firms. One would expect Nichitsu, the more efficient of the two, to expand production to take full advantage of scale economies when faced with severe import competition, squeezing Denka out in the process. Instead, we see its share decline and that of Denka rise. Second, while the shift by Nichitsu to synthetic ammonia process in 1923 can be interpreted as a move to compete effectively with imports, it fails to account for the continuing adverse movements in its share of the domestic production. Furthermore, the continued existence of the inefficient Denka, producing with the relatively expensive cyanamide conversion method, in the face of rising imports also testifies to the inability of unrestricted imports to wipe out excess profits in the domestic market.

It is plausible to infer, from the peculiar movements in the production shares of the two incumbent firms, that Nichitsu was acting as a price leader in the domestic market[68]. If so, it can also explain why Nichitsu was carrying surplus capacity during the early part of this decade. Excess capacity in a high fixed cost industry can be used as a strategic variable to deter new entry[69]. If the new entrant believes that the incumbent can and will increase production and lower prices if faced with new entry, he may decide not to enter. Excess capacity can thus be used as a credible threat against new entry. As noted earlier, Nichitsu and Denka, especially the former, had substantial excess capacity in the early 1920s and were in a position to raise production further. Since our demand function analysis did not consider this possibility of increased production by domestic incumbents, the size of the actual decline in price for the new entrant could be much larger. This may have acted as an added deterrent to new entry. We do know that Nichitsu increased its rate of capacity utilization once the threat form increased imports and new entry in the domestic market became real in the late 1920s. However, by then the expanded size of the market and developments on the technological front had rendered this strategy to deter entry more or less redundant.

Another inference of this study is that by late 1920s, the size of the Japanese market in relation to scale economies was becoming less of an issue. How far did this factor act as an effective barrier in the early 1920s is, however, not clear. On the one hand, our calculations indicate that adoption Haber-Bosch technology with its large scale (100,000 ton/year) and high set up and licensing costs would have been highly risky at best. On the other hand, expansion of production capacity by Nichitsu using synthetic ammonia process in 1923 indicates that a slightly smaller plant with lower set up and licensing costs could possibly be sustained by the market. However, only a limited number of alternatives to Haber-Bosch technology were available at the time and, when available, these were commercially untested . As the experience of Suzuki's Daiichi Chisso indicates, implementing such untested technology was not always easy and successful. Even Mitsui, who picked up Daiichi Chisso's facilities (after it went bankrupt) at a very cheap price, had to struggle for quite some time to get the process working. Technical knowledge, business acumen and attitude towards calculated risk taking, therefore, also appear to have played a part in determining the possibility of new entry. The Eastern Nitrogen consortium was perhaps conservative in its calculation of potential increase in demand and hence risks. It estimated domestic market to grow by about 80,000 tons a year in the early 1920s. In the event, the market nearly doubled from 185,000 tons a year during 1919-1923 to 360,000 tons a year in 1924-1928, rising by another 200,000 tons a year during 1929-1932. The steep decline in price of ammonium sulphate was partly responsible for expanded market, especially in the 1929-1933 period, but in the first half of the 1920s, the prices were relatively stable.

It is thus clear that availability of tested, commercialised technology at a reasonable cost was a major factor in keeping new entry into the Japanese ammonium sulphate markets at bay in the early 1920s. Pessimistic expectations about the size and growth of the Japanese market by potential new entrants, overestimation of import competition and existence of domestic excess capacity also played a part. A substantial reduction in costs of technology acquisition and implementation in the late 1920s was responsible for a rush of new entry. However, this new entry may not have been accomplished even with declining set up costs had the size of the market also not increased substantially. With domestic market demonstrably large enough to support multiple producers and costs low enough to compete with imports, new firms began setting up in the business. Though the industry had to cartelise to survive during the 1930s, a strong and competitive domestic base gave the Japanese producers good clout to negotiate with the international cartel from a position of some strength.

Notes:

[1] Nakamura, *Prewar Economic Growth*, Chapter 7, pp.194-203, and Sato, "Senkanki No Makuro Keizai" are just two of the many studies discussing the concentration of the Japanese economy during the interwar period.

[2] Hayami and Yamada, *Agricultural Development*, p. 72; for a detailed analysis of the impact of fertilizers on Japanese agriculture in the prewar period, see the discussion in Chapter 5, pp. 159-74 and Hayami, *Nihon Nogyo*, pp. 112-15.

[3] Sodium nitrate tended to break down under wet conditions producing poisonous nitrites without being able to provide the needed nutrient to the soil. See, Molony, *Technology and Investment*, pp. 53-54.

[4] ibid., p. 54.

[5] The major breakthrough in production technology, referred to in the previous paragraph, occurred in 1913 when technology to synthesise ammonia from atmospheric nitrogen was invented in Germany. This invention greatly reduced costs of production while increasing fixed cost requirements.

[6] Molony, *Technology and Investment*, pp. 54-55.

[7] Haber, *Chemical Industry: 1900-1930*, pp. 91-92.

[8] ibid., pp. 100-01, and Molony, *Technology and Investment*, Table 9, p. 56.

[9] It involved production of ammonia gas by passing the gases generated in the process of reformation of coal into an air cooled condensation chamber brought to near normal temperature. The condensate included, in part, ammonia contained in the original feed gas dissolved in water. This was recovered in the form of liquid ammonia. Ammonia water was then led successively into a water cooled chamber and then a washing chamber where its ammonia content was concentrated to about 20 per cent through water scrubbing. Liquid ammonia was then gasified and absorbed into sulphuric acid to get ammonium sulphate. See Ishikawa, *Kagaku Hiryo*, p. 92.

[10] Molony, *Technology and Investment*, p. 57.

[11] Shibamura, *Nihon Kagaku Kogyo*, p. 219.

[12] ibid., p. 222.

[13] Molony, *Technology and Investment*, Table 10, p. 58.

[14] Haber, *Chemical Industry: 1900-1930*, pp. 85-88; Ishikawa, *Kagaku Hiryo*, pp. 241-42.

[15] Haber, *Chemical Industry: 1900-1930*. Calcium cyanamide by itself could be used as a nitrogenous fertilizer (lime nitrogenous fertilizer). However, to increase its acceptability in the Japanese market, it was converted to ammonium sulphate, a product with which the Japanese farmers were more familiar. See Molony, *Technology and Investment*, p. 77.

[16] Haber, *Chemical Industry: 1900-1930*, p. 219. This process of fixing nitrogen was commercialised in Italy in 1906 to produce lime nitrogenous fertilizer.

[17] For interesting details about the process of searching and obtaining the technology as well as the teething troubles faced by the firm in producing and bringing the product to market, see Molony, *Technology and Investment*, pp. 71-81.

[18] Fujino, *Keiki Junkan*, pp. 444-47.

[19] Shimotani, *Nihon Kagaku Kogyo*, pp. 75-82. Noguchi was an active player in the electricity generation business. His Sogi Denki (est. 1906) had surplus capacity encouraging him to set up carbide production. The carbide production needed more electricity than was available and hence generation capacity was increased. For some details of this cycle of expansion, see Molony, *Technology and Investment*, pp. 65-71.

[20] In 1913, Japan was importing about 112,000 tons of ammonium sulphate. In 1918, only 2,000 tons was imported. See Norinsho, ed., *Hiryo Yoran* for statistics.

[21] The Minamata plant, set up in 1910, was small and was discarded in favour of a new plant at the same site with a capacity of 40,000 tons per year in 1915. The new plant was completed in 1918, raising Nihon Chisso's capacity to 90,000 tons per year. See Nihon Chisso Hiryo (KK), ed., *Jigyo Taikan*, pp. 451-55.

[22] In 1912, the price of domestically produced ammonium sulphate was about ¥113/ton. Till 1929, the domestic product was selling at about ¥128/ton. Thereafter the prices declined to under ¥100/ton and stayed there. The calculations are based on the value and quantity data from Norinsho, ed., *Hiryo Yoran* used for calculations in Table 1.

[23] Initial capacity of the plant was 40,000 ton per year which increased to 250,000 ton per year by the end of 1915. See Haber, *Chemical Industry: 1900-1930*, p. 95.

[24] In chemical notation, it can be represented as follows:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3 \qquad \text{(subject to low temperature, high pressure)}$$

[25] For details of synthetic ammonia process, see Greenberg, Hill, and Newburger, *Regulation*, pp. 73-104, and Haber, *Chemical Industry: 1900-1930*, pp. 90-98.

[26] Some information about these inventions is presented in Table 3, discussed later.

[27] See discussions in Nihon Chisso Hiryo (KK), ed., *Jigyo Taikan* and Oshio, "Nihon Chisso Hiryo".

[28] Initially, Daiichi Chisso succeeded in setting up a pilot plant with 5 tons per day capacity. However, it failed to expand production beyond 15 tons per day and went bankrupt in 1927. It was later taken over by Mitsui Group in 1929. See discussion in Hashimoto, "Ryuan Dokusentai".

[29] The wholesale price of the domestic product price fell from ¥361 per ton in 1919 to ¥186 in 1921 and stayed above this level till 1925. Same is true for unit price (value/quantity) which declined to ¥165 in 1921 and stayed above this level till 1925. See Norinsho, ed., *Hiryo Yoran*, p. 51 for wholesale prices and pp. 2-8 for data to calculate unit prices.

[30] Many of the old Zaibatsu groups (family controlled conglomerates in prewar Japan) entered the ammonia and ammonium sulphate industry during late 1920s and early 1930s. Since some of these zaibatsu had insufficient sources of electric power, they tried to find ways to use their coal resources for part of the production. For example, Mitsui substituted hydrogen produced in coke oven in the Claude process and used an improved Claude method (modified by Dupont) for its second plant, the Toyo Koatsu. The NEC process adopted by Sumitomo was also a coal based process. See Molony, *Technology and Investment*, pp. 286-305.

[31] For details of the original agreement and its renegotiation, see Ibid., pp. 179-83.

[32] For a discussion of the formation and role of the Ammonium Sulphate Distribution Agency in setting cartel prices and the resulting price stability, see Ibid., pp. 183-85 and Kondo, *Ryuan*, pp. 177-79.

[33] Steel and the non-ferrous metals industries expanded substantially during this period. See, for example, Ohkawa and Shinohara, eds., *Patterns*, Table 5.2.

[34] The superiority of Nichitsu in the terms of access to electric power is evident from the fact that both its plants, at Minamata and Kagami, had their own power supply and the firm was producing almost 50,000 KW of electricity by 1918 (See, for example, Nihon Chisso Hiryo (KK), ed., *Jigyo Taikan*, p. 454). As against this, Denka began construction of its first electric power station only after it faced difficulties in maintaining power supply. The power station, however, was completed only in 1925 (See, Denki Kagaku Kogyo (KK), ed., *Yonjugonen*). As regards the high cost of purchased electricity, see Sato, *Hiryo Mondai*, pp. 62-63 and Molony,

Technology and Investment, p. 65.

[35] According to Pollitt's calculations as reported in Haber, *Chemical Industry: 1900-1930*, p. 97, ammonia synthesis required only 6.3 to 7.3 tons of coal worth of energy per ton of nitrogen fixed as against 12.7 tons for calcium cyanamide process.

[36] Nichitsu's capacity in early 1920s was probably 90,000 tons per year (see note 21 above) and its production was about 55 to 60 thousand tons per year for a capacity utilization rate of about 60%. In 1929, its capacity had increased to 110,000 tons and production to 109,000 tons for a capacity utilization rate of nearly 100%.

[37] During 1922-26, on an average, 181,000 tons of ammonium sulphate was being imported into Japan every year. During 1927-32, this average rose to 293,000 tons per year, a 62 percent increase (Norinsho, ed., *Hiryo Yoran*).

[38] This is a conjecture and probably needs further investigation a topic that we plan to look into next.

[39] The share of Nichitsu fell sharply. The decline would be much steeper if the production from its subsidiary, Korean Chisso, was not included in the figures from 1930 onwards.

[40] On this point, besides the literature cited in footnote 32 above, also see Shibamura, *Nihon Kagaku Kogyo*, pp. 354-55 for the negotiating stance of this agency with the International Nitrogen Convention on level of imports and prices etc.

[41] We calculate the profit rate on paid-up capital and data were obtained from Asahi Shimbunsha, ed., *Keizai Tokei* for the period 1914-28 and Mitsubishi Keizai Kenkyujo, ed., *Jigyo Seiseki Bunseki* for the period thereafter.

[42] Bain, *Barriers*.

[43] Use of this process by Denka resulted in a lengthy litigation between Nichitsu and Denka. See, Denki Kagaku Kogyo (KK), ed., *Yonjugonen*, pp. 196-201.

[44] Tokyo Industrial Experimental Laboratory process was very similar to the Haber-Bosch process except for the catalyst used.

[45] This is starkly brought out by Molony, *Technology and Investment* (p. 136) when she states that "Noguchi had hoped to use Japanese-made machinery and regretted that the still low level of technology in the Japanese machinery industry forced him to buy compressors and other heavy equipment from Italy and elsewhere."

[46] Hashimoto, "Ryuan Dokusentai", pp. 49-50.

[47] Molony, *Technology and Investment*, p. 268.

[48] For further details on the Eastern Nitrogen Association and the search for synthetic ammonia technology, see ibid,, pp. 269-272.

[49] It was only in the later half of the 1920s, 1927 to be precise, that British Imperial Chemical Industries was able to set up its own synthetic ammonia process plant. See, Reader, *Imperial Chemical Industries*, pp. 353-60 for details.

[50] Hashimoto, "Ryuan Dokusentai", p. 56.

[51] Nihon Chisso Hiryo (KK), ed., *Jigyo Taikan*, p. 5.

[52] The pilot plant had a capacity of 5tons/day. See Hashimoto, "Ryuan Dokusentai" and Molony, *Technology and Investment*, p. 125 for some more details.

[53] Morikawa, *Zaibatsu*, pp. 293-94.

[54] Hashimoto, "Ryuan Dokusentai", pp. 52-53.

[55] ibid., p. 51.

[56] This was, perhaps the only major government help given to this industry during the interwar period.

[57] Hashimoto, "Ryuan Dokusentai", pp. 53-54.

[58] See Table 3. Molony, *Technology and Investment*, p. 269, cites Nihon Ryuan Kogyo Kyokai's calculations to indicate that the fixed costs would have made it too expensive, given the falling prices, to produce using the Haber-Bosch technology.

[59] Hashimoto, "Ryuan Dokusentai".

[60] ibid., p. 52.

[61] ibid., p. 51.

[62] Layard and Walters, *Microeconomic Theory*, pp. 165-66.

[63] See pp. 2-9.

[64] See Table 10, p. 164.

[65] Cropped area under improved rice seed varieties and the total cropped area for the East and West Japan were added for the available years and intervening values interpolated assuming a constant compound rate of growth. See Hayami and Yamada, "Agricultural Productivity", Tables A-I-1 and A-I-2.

[66] All references to percentages in this paragraph are approximate.

[67] The actual numbers depend on which estimate of elasticity is used – the estimates from equation (a) or equation (b) in Table 4.

[68] An investigation into the conduct and performance of the ammonium sulphate producers during the 1920s can shed further light on this issue.

[69] See, for example, Teranishi, "Sannyu Boshi".

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Table 1: Growth of Domestic Production of Ammonium Sulphate

Year	Average Annual Production Volume [a]		Average Annual Value of Production [a]		Average Annual Consumption [c]	
	(Yen '000)	Growth Rate [b]	('000 tons)	Growth Rate [b]	('000 tons)	Growth Rate [b]
1912-1913	975	-	7	-	106	
1914-1918	7,624	50.88	36	38.60	66	- 9.07
1919-1923	19,514	20.68	90	20.30	185	23.04
1924-1928	23,622	3.90	159	12.01	360	14.22
1929-1933	31,339	5.82	365	18.08	559	9.23
1934-1939	75,217	15.71	839	14.89	957	9.36

a. Relates to Production in Japan proper.

b. Rates of growth are average annual compound rates over the previous period.

c. Consumption is calculated as production + imports - exports.

Source: Norinsho, *Hiryo Yoran*, pp. 2-11.

Table 2 : Share of Top Companies in National Production 1914-1936 (Units: %)

Year	1[a]	2	3	4	5	6	7	T2	T3
1914	47.2						52.8		
1915	53.8	9.4					36.8	63.2	
1916	55.4	16.1					28.5	71.5	
1917	51.3	24.6					24.1	75.9	
1918	65.5	20.8					13.7	86.3	
1919	66.7	22.8					10.5	89.5	
1920	64.1	23.7					12.2	87.8	
1921	57.7	17.9					24.4	75.6	
1922	57.1	20.4					22.5	77.5	
1923	53.6	20.3					26.1	73.9	
1924	56.2	28.1					15.7	84.3	
1925	46.8	29.4					23.8	76.2	
1926	46.3	28.8					24.9	75.1	
1927	47.8	28.2					24.0	76.0	
1928	46.7	27.6	6.8				18.9	74.3	81.1
1929	41.0	27.5	10.4				21.1	68.5	78.9
1930	58.8	15.8	11.9				13.5	74.6	86.5
1931	56.1	12.0	8.0	11.0	4.7	0.9	7.3	68.1	79.1
1932	46.9	10.7	7.0	20.1	4.8	4.4	6.2	67.0	77.7
1933	45.6	7.7	6.3	21.3	7.3	3.5	8.3	66.9	74.6
1934	44.5	6.7	6.1	19.4	10.0	4.3	9.0	63.9	74.9
1935	41.8	6.4	5.7	17.2	7.7	9.0	12.2	59.0	68.0
1936	36.0	5.8	4.6	14.3	10.0	16.1	13.2	52.1	66.4

Notes:

1- Nihon Chisso, 2- Denki Kagaku, 3- Daiichi Nihon Jinzo, 4- Showa Hiryo, 5- Sumitomo, 6- Miike, Toyo Koatsu (Mitsui), 7- Others, T2- Share of top 2-firms, T3- Share of top 3-firms.

[a] Nihon Chisso includes production by its subsidiary, Korean Chisso from 1930 onwards.

Source: Suzuki, ‘Senkanki Nihon Kagaku Kogyo’, Table 6, pp.128-29.

Table 3: Licensing and Cost of Adopting Technology in the1920s

Process	Invented		Japanese Company Involved	Adoption	Costs Construction (c) Equipment (e)		Licensing fee		Royalty	Capacity
	Year	Country			Total (¥ m)	¥/ton	Total ¥m.	¥/ton	¥/ton	tons/year
1. Haber-Bosch	1913	Germany	Eastern Nitrogen Association (Including Mitsui, Sumitomo, Mitsubishi)	Considered only (1919-1920)	50 (c+e)	500	5	50	25	100,000
2. Cassale	1916	Italy	Nihon Chisso	1924			1	17		60,000
			(KoreanChisso)	(1930)						
3. Claude	1919	France	Daiichi Chisso	1924	10 (c+e)	200	5	100	40	50,000
			Miike (take over)	1929	Taken over at ¥1.5 m	200	1.5	15	13	50,000
4. Woody (Mont-cenis)	1927-1928	Germany	Showa Hiryo	Considered	8 (e)	80				100,000
5. Fauser	1923	Italy	Dai Nihon Jinzo	1928	7.5 (c+e)	150			2.5	50,000
			Showa Hiryo	Considered	2-3 (e)	20-30	0.8	8	2.5% of price	100,000
6. NEC	1928	America	Sumitomo Chemicals	1931	7.8 (c+e)	195	0.45	11		40,000
7. Tokyo Industrial Experimental Laboratories	1928	Japan	Showa Hiryo	1931	16.8	112	NIL		very soft	150,000

Source: Constructed from various company Histories and, Hashimoto, ‘Ryuan Dokusentai’. For Claude process and its take over price, see, Morikawa. ‘Senkanki ni Okeru’.

Table 4: Estimation of the Demand Function

Parameter	Coefficient Value		Standard Error		t-value	
	(a)	(b)	(a)	(b)	(a)	(b)
Constant	3.384^{***}	3.439^{***}	0.199	0.155	16.978	22.252
b_1	-1.588^{***}	-1.482^{***}	0.284	0.157	-5.595	-9.422
b_2	0.274		0.611		0.448	
b_3	2.032^{*}	2.360^{***}	0.878	0.478	2.313	4.934
Adjusted R^2	0.917	0.920				
DW		1.50				
n	28	28				

(a) includes relative price of the substitute while (b) excludes it.

* significant at 5% level. *** significant at 1% level.

For data sources, see text.