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Abstract
Internationalisation is a useful strategy to gain firm specific advantages during periods of technological discontinuity. The pharmaceutical industry offers us two such episodes as examples: when the antibiotics revolution was beginning and when the possibilities of genetic routes to new drug discovery were realised. This paper compares the strategies adopted by laggard U.S. firms scrambling to gain capabilities in antibiotics, and Indian firms equally eager to acquire positions in new biotechnology based drugs and shows that both groups used internationalisation strategies to gain technological advantages and build up their firm specific advantages.

Key words: Technological leapfrogging, Internationalisation Strategies, Indian Pharmaceutical industry, Antibiotics revolution, US Pharmaceuticals.
JEL codes: F2, L2, L6,N8, O3

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Internationalising to create Firm Specific Advantages:

Leapfrogging strategies of U.S. Pharmaceutical firms in the 1930s and 1940s & Indian Pharmaceutical firms in the 1990s and 2000s.

The global pharmaceuticals industry is more dependent upon commercializing new scientific innovations than any other sector and has grown in a non-linear fashion, following the cycles of particular paths of scientific discovery. The early alkaloids (plant-based therapies) of the late nineteenth century gave rise to many products and companies of varying levels of scientific veracity and efficacy. From the 1890s scientific discoveries in antitoxins and sera enabled new firms to emerge that acquired capabilities here. By the 1920s new therapies were emerging through synthetic chemistry, but the truly revolutionary change came in the 1930s and 1940s, when the early sulphas and anti-infectives first emerged. Antibiotics required new science and different manufacturing techniques, enabling a window of opportunity for new entrants to grow and acquire market share rapidly. Pfizer, for example, the world's leading producer of penicillin from the end of World War 2 through to the 1960s, had not even had any presence in pharmaceuticals before 1942.

In more recent times, the potential of biotechnology to produce novel drugs and therapies also represents a Kuhnian shift from one paradigm of pharmaceuticals production to a new one, allowing new entrants into global pharmaceuticals. Combined with advances in information technology which have allowed the use of genomic databases and simulated trial and error stages (Gambardella 1989), the use of rDNA methods to discover new remedies and therapies has fundamentally shifted the scientific base of pharmaceutical production from a knowledge of chemistry alone to a more nuanced understanding of the

interaction between chemistry and biology. The emergence of genomics has thus once again opened a new technological trajectory allowing new entrants the opportunity to challenge the market shares of established firms, as was the case with antibiotics in the 1940s. A small number of Indian pharmaceuticals firms with existing capabilities in the bulk manufacturing of generic drugs have attempted to upgrade their research capabilities in attempts to discover and commercialise New Chemical Entities (NCEs) and so compete directly with the world's major pharmaceuticals firms for the most profitable segment of the sector (Athreye, Kale and Ramani, 2008). Such aggressive attempts by these few firms have attracted considerable attention although the jury is still out on whether they will register any success.

The role of technological discontinuities in creative destruction and the emergence of new leaders in the pharmaceutical sector is well researched and documented, however little attention has hitherto focussed on the critical issue of if and how internationalisation can help firms to achieve leadership during moments of technological discontinuity. Exploiting the two crucial moments of technological discontinuity in the pharmaceutical sector (viz. the antibiotics revolution and the emerging potential of biotechnology in new drug discovery), this paper seeks to identify the leapfrogging strategies used by U.S. pharmaceuticals firms in the late 1930s and 1940s to overcome their disadvantages in the early years of the antibiotics era and then systematically compare and contrast these to the leapfrogging strategies used by Indian firms since 1990. Our focus is on identifying which internationalisation strategies have played a role and how they were used for the building of technological capability and lasting competitive advantages by US firms in the 1930s and Indian firms in the 1990s.

The remainder of the paper is organised in the following way: Section 1 briefly reviews the literature technological discontinuity and role of internationalisation in technological leapfrogging; Section 2 sets out the similarities and differences in the market conditions of the pharmaceutical industry in the 1930s and in the 1990s. These sections set the stage for a more detailed comparison of the patterns of internationalisation and knowledge acquisition among U.S. firms in the late 1930s and 1940s and Indian firms in the 1990s in sections 3 and 4. Section 5 concludes with some implications for host economies of such internationalisation behaviour.

1. Technological discontinuity, Internationalisation and Technological leapfrogging

The idea that technological discontinuities could be moments when new entrepreneurs could take over leadership in markets is at the heart of the Schumpeterian 'creative destruction' thesis. There is some debate on whether new firms are the harbingers of radical technologies (the original Schumpeterian thesis challenged by Arrow 1975) or simply better positioned to exploit new technologies, as the innovation management literature suggests (Tushman and Andersen, 1986). The reasoning here is that radical innovations require managerial, organisational and marketing competences, which take time to build. Incumbent firms would thus, prefer to adopt innovations that enhance existing competences rather than radical innovations, which are likely to need new competences or destroy the value from existing ones. In contrast, new entrants would have had no such baggage from the past and were more likely to adopt radical technologies. Other work in this tradition has qualified the early optimism. Market knowledge (Abernathy and Clark, 1985), the important role of system architectures (Henderson and Clark 1990) and the role played by the ownership of complementary assets (Teece, 1985) –

have all been identified as factors favouring incumbent firms in the adoption of radically new technologies.

The idea that laggard nations could better exploit new technologies from around the world during periods of technological discontinuity was first suggested in a prescient paper by Soete (1985). In the context of the newly emerging microelectronics revolution, he argued that globalisation permitted newly industrialising countries to 'leapfrog' into newer technologies and higher rates of growth. The idea is that globalisation presents firms in a technologically laggard nation with the opportunity to gain competitive advantage over incumbent firms in technologically dominant nations through the rapid adoption of superior new technologies. The East Asian success story in semiconductors and microelectronics certainly appeared to confirm his intuition, though studies on successful leapfrogging in East Asia (Kim 1997, Hobday 1995, Amsden 1989) also highlighted the role of domestic absorptive capacity and firm capabilities. However, until relatively recently, the East Asian success was thought to rest on one form of internationalisation viz. large export markets which provided the production scale on the basis of which domestic firms built their capabilities.

More recent work has significantly altered our perception of the role of internationalisation in the leapfrogging strategies of Korean firms. Sachwald (2001) used empirical tests and case studies, to show that Korean groups had invested in developed countries not only to jump over trade barriers, but also to source advanced technology and marketing capabilities throughout the 1990s. Moreover, their ambitious strategies were often stimulated by oligopolistic rivalry among the chaebols. Matthews (2002) in his book *Dragon Multinationals* argues that firms from East Asia invested abroad to make linkages, leverage

capabilities and also learn from their overseas investments. This last aspect was not new of course since at least two empirical studies by Cantwell (1995) and Kummermele (1999) had already argued that in a globalised world where technological spillovers of any kind were present, firms would go abroad not only to exploit their firm specific assets but also to augment their (technological) asset base. However, their work was based on empirical data from developed country MNEs that were thought to possess sufficient resources (managerial and financial) to manage such complex international operations.

Korean firms without too many firm specific advantages to start with, nevertheless went abroad quite early in their life to countries that were in cultural terms very 'distant' from them. An influential strand of International Business theory since the 1970s has seen the possession of some kind of proprietary firm assets (brands, trademarks, patents etc.) as necessary condition for going abroad since going abroad entails various kinds of organisational and transactional costs, costs that increase as the cultural or psychic distance grows. Yet Korean firms had embraced such large risks and further their international investments had been instrumental in creating the global competitiveness and brands of the firms that did go abroad. This suggested the emergence of a different kind of firm with a global mindset - which used both global and local resources to develop their competitive strengths.

Despite the important role played by internationalisation strategies in the development of Korean firms, the literature on leapfrogging does not accord a large role to the study of internationalisation in the successful leapfrogging by laggard firms. A recent review of the empirical literature on ICTs and the possibilities for leapfrogging by developing countries

by Steinmueller (2001) identifies four pre-requisites for successful leapfrogging by developing country firms:

1. Developing absorptive capacity in the technology which enables the firm to use and embed the technology in innovative products and services,
2. Access to know-how and equipment relating to the new technology
3. The need for complementary capabilities in other aspects of systemic integration of ICT based modules- this might mean developing capabilities in modular interfaces and adopting product and quality standards
4. Achieving downstream integration capabilities such as in product design, marketing ability and the ability to create "own brands".

Although developed in the context of the ICT sector this framework presents a coherent way of thinking about the requirements for technological leapfrogging more generally. It incorporates the lessons learnt from the East Asian experiences and also reflects the two properties that Teece (1985) had predicted would be important to explain who would profit the most from new innovations, viz. the influence of appropriability regimes and the possession of complementary assets. The first two preconditions define the important influences on the appropriability regimes facing the innovator. The ability to use and embed the new technology in complex products and processes and the ease with which the innovator could access new developments in the technology were absolutely crucial to defining how inimitable the technological product would be. The last two factors highlight the importance of complementary knowledge and resources in being able to effectively commercialise the products of the new technology.

It is worth noting that internationalisation strategies, in the form of strategic alliances, international licensing or international investments, can help firms to achieve preconditions 2, 3, and 4. Thus in the context of strong IPR international licensing and alliances are alternative methods to access technological know-how and both downstream and complementary assets such as distribution networks, regulatory knowledge can be usefully acquired by setting up own subsidiaries or by acquiring other firms that have regulatory approval and established market shares.

The framework proposed by Steinmueller (2001) only needs small modifications in order to apply it to a study of leapfrogging in the pharmaceutical sector. Precondition 2 is quite different in the case of pharmaceuticals when compared to the ICT sector because the widespread use of defensive patenting may have restricted the scope of technological know-how accessible to firms through licensing.[1] However, as innovation in pharmaceuticals has become more complex and inter-disciplinary, it has over time created more elaborate divisions of labour between the various actors involved in it. Regulatory authorities and quality standards play an important role in coordinating aspects of the systemic integration.

2. The historical similarities: U.S. Pharmaceuticals during the antibiotics revolution and India in the biotechnology era

The introduction of antibiotics totally transformed the world pharmaceuticals sector. Before antibiotics the world's leading source for scientific innovation was not the United States but Germany. German scientists were the pioneers of modern chemistry and the leaders in synthetic chemistry. In the late 1930s it was German industry that was the father of the

modern sulphas (Bud 2007). Indeed U.S. scientific capabilities ranked behind Swiss, French and British as well as German in pharmaceuticals research until the 1940s. Even then the leading U.S. scientists remained in public institutes and universities, not in commercial research organisations (Swann 1988). Research capabilities among U.S. pharmaceuticals firms in the mid-1930s were very scarce indeed. Eli Lilly and Merck were the sector's two pioneers of building U.S. industrial research capabilities in the 1930s, but together they employed less than 500 scientists researching ethical pharmaceuticals by 1935, far fewer than the leading German producers. The U.S. pharmaceuticals industry was dominated by heavily advertised, branded consumer products, with low scientific content. But the German firms failed to develop antibiotics.

By the early 1950s there were around fifteen U.S. firms that had rapidly gained leading positions in the global pharmaceuticals industry on the back of enormous investments in R&D and developing new, patented antibiotics and derivative products. These firms then went on to occupy significant positions in the global pharmaceuticals sector through to the 1960s. It represents a classic case of technological leapfrogging and much of the credit for this remarkable transformation of the U.S. pharmaceuticals industry is usually given to the U.S. wartime government for subsidizing the crash programme to build capabilities in mass producing penicillin for military purposes - as well as for destroying the German competition – although as we shall see, internationalisation strategies were also key (Temin 1979, Bud 2007).

Like the U.S. firms in the 1930s, Indian firms in the early 1990s held very few pharmaceutical patents. Most of the patents in this sector were held by European and American firms and most genomics patents were held by U.S. firms. Indian pharmaceutical

R&D investments in the 1980s and even 1990s had been mostly in reverse engineering and large scale manufacture of chemical drugs - the old rather than the new technology in pharmaceuticals. The role of Indian government policies (such as weak IPR laws that recognised only process patents) is widely lauded as having been chiefly responsible for the emergence of manufacturing and reverse engineering capability among a small subset of Indian firms, that are leading firms in the manufacture of generics today. (Lanjouw 1998, Ramani and Venkataramani, 2001, Gehl-Sampat, 2006).

Another similarity resides in the creation of an international market for pharmaceutical products created mainly by the actions of national governments. The antibiotics revolution transformed the scale of the potential international market, leading to a global industry for the first time, dominated by the leading multinational producers. The spur to the U.S. development was the wartime needs to combat infection among the allied forces. But after 1945 many countries tried to develop their own pharmaceutical sectors. There was a two way division of the world market -- between advanced economies, where producers were regulated on quality and governed by the requirements of health systems, and the developing world, where the overwhelming regulation on pharmaceutical producers was in terms of prices.

As the costs of drugs for public health systems in the West became larger and larger from the mid 1980s, something similar to the war-time antibiotics demand took place once again. Cheaper drugs were sought to be 'procured' by US and European governments in order to bring down medical costs for the population, most of which regards access to health services as a fundamental right to be provided by the State. Since generic drugs sell at roughly 1/3 the price of a branded drug, one way to bring down costs of the medical bill to

the public sector was through generics substitution. In 2002 generics held 47% by volume of the prescription drug market in the USA, more than twice the 22% share of 1985 (Maris et al, 2003; WTO 1999). Laws were passed by national governments[2] to encourage the manufacture of generics and to bring down the costs of new entry into this market, which was also fast becoming a highly internationalised market. Many Indian firms today are funding their acquisition of skills in biotechnology and new drug discovery from their strong positions in the generics market.

It is this similarity in the starting points and in the potential opportunities facing the two cases that constitutes the rationale for our comparison of US firms in the 1930s with Indian firms from the 1990s. Of course, no two periods of history are completely alike and in the sections that follow we outline the two histories. Section 5 then discusses the similarities and differences in the role that internationalisation played in the leapfrogging strategies adopted by Indian and US firms.

3. Origins and Development of the U.S. Pharmaceuticals industry.

The nascent U.S. pharmaceuticals sector from the 1900s to World War One consisted of firms that were either wholesalers or distributors of German imported fine chemicals and drugs (Sharp and Dohme and Squibb, for instance), or subsidiaries of German parents (Merck, Schering and several others), or had begun to develop their own competing products, like Mulford and Parke Davis in antitoxins and sera, for example.[3]

But the vast majority of firms producing medicines in the U.S. focused on non-prescription products, typically building market share through aggressive marketing strategies, intensive

advertising, and large sales forces that promoted these branded over-the-counter (OTC) products to the nation's pharmacists and other retailers. These producers of laxatives, 'healing' creams, antiseptics, sedatives, analgesics, and other medicinal products of varying degrees of efficacy, also produced and sold a variety of toilet goods, including toothpaste, shaving cream, cosmetics and hair lotion. In 1929 the wholesale value of ethical prescription medicines sold in the U.S. was just over $55 million. This was dwarfed by the $149 million sales of OTC products, which in turn was much smaller than the $300 million in branded toilet goods and cosmetics (Church and Tansey, 2007, p.411). Ethical pharmaceuticals was only a little over one-tenth the size of the market for OTC medicinal products and toilet goods.[4] The dominant group of firms in the U.S. pharmaceuticals industry – focusing on OTC and toilet goods - actually bore greater resemblance to Heinz or Proctor and Gamble than to the research-led pharmaceuticals sector of the 1950s and 1960s, with their competitive advantage derived from superior marketing capabilities than either research or manufacturing. Research in the U.S. pharmaceuticals sector in the early 1930s was devoted to developing improvements to basic consumer products, not path-breaking science in drug discovery.[5]

It follows that by the mid 1930s even those firms formerly involved in prescription medicines in the U.S. were increasingly diversifying away from science-intensive therapies towards OTC medicines and toilet goods. For instance, Sterling and Upjohn had both begun as producer of alkaloid pain relief products, but in the early 1920s moved into OTC products: Sterling into toothpaste, laxative and shaving cream brands; Upjohn into multivitamins. Sharp and Dohme still retained its fine chemicals distributorship, but after the successful launch of its Sucrets throat lozenges in 1931, the firm moved to augment its marketing capabilities. The number of examples could easily be multiplied.

Only a small number of conservatively managed producers of prescription medicines focused on retaining and building their capabilities in drug manufacturing, specialised product knowledge and on developing internal research capabilities. But competition here was largely on price. There were very few branded, patented products that were able to attract a price premium. So those U.S. pharmaceutical companies not focused on OTC products were essentially generics producers in the 1930s (Temin 1979, Huck 2006). They had little incentive to invest in R&D. In sum, the U.S. pharmaceuticals industry of the 1930s was not only far behind its competitors in Europe in ethical pharmaceuticals, but its underlying science base was dropping further behind German and Swiss scientific capabilities (Kobrak 2002). Yet in less than twenty years the U.S. sector was dominant in global pharmaceuticals, as world sales exploded of U.S. invented products that had not been known in 1939 (Bud 2007, p.110, Greene 2005). This was technological leapfrogging of the first-order.

This survey of the developments of the U.S. pharmaceuticals sector cannot hope to be comprehensive. Instead the focus is very much on how the U.S. sector was able to switch so dramatically from being dominated by low-tech OTC products to acquire technological leadership so quickly, and on the internationalisation strategies used to acquire the know-how essential to such a transition. The U.S. pharmaceuticals sector internationalised relatively early and extensively. But that internationalisation was almost exclusively the preserve of market-seeking FDI among OTC and toilet goods producers.

As with many sectors, the opening of initial overseas sales agencies and then branch plants was in Canada, the ease of transit to there making it relatively easy to invest and so

overcome tariff barriers (Wilkins 1970). A far more important market, yet geographically more distant, was Britain. Moreover the UK was also one of the leading sources of international expertise in pharmaceuticals. While expertise in synthetic chemistry was concentrated in Germany (and to a lesser extent in Switzerland and France), clinical research was pre-eminent in Britain. Moreover London was the centre for international trade in raw drugs (Corley, p. 9). It followed that the leading British hospitals had acquired a reputation for clinical trials, and British drug houses for sourcing the finest quality materials. Britain was, in other words, both an important source of demand for consumer products and an important source of scientific knowledge for the pharmaceuticals sector. Import restrictions meant that producers had an incentive to invest, but (and in contrast to Germany) Britain was also relatively open to inward direct investment. So not only did several U.S. pharmaceuticals producers open branch plants in Canada, but several also did in the UK. That is important because, unlike for Canada, fairly comprehensive data for the historic population of entrants into British manufacturing exist, and so it is possible to assess the broad trends in internationalisation of the U.S. pharmaceuticals industry by using U.S. FDI into British pharmaceuticals manufacturing as indicative of wider trends.

Chart 1 therefore compares the population of all overseas entrants into British pharmaceuticals manufacturing for the periods of 1920 to 1940 and from 1945 to 1959. In the earlier, slightly longer period the total population was twenty-three entrants, in the later period seventeen; the annual rate of entry was therefore broadly similar across the two periods. In both periods U.S. parents dominate, with 18 U.S. entrants in the inter-war and 16 in the post-war periods.[6] The striking contrast between the two periods, however, is when these British subsidiaries are classified according to whether they were producing prescription medicines (P) or OTC goods. In the interwar period fourteen out of eighteen

U.S. entrants were to pursue opportunities in the British market for OTC products, only four for prescription medicines. That is a striking contrast with the dominance of prescription product entrants after World War Two. It was, in other words, FDI by toothpaste, cosmetics and antiseptic oil producers (like Lehn & Fink, Kolynos, Mentholatum, American Home Products, Lambert, Warner, Pepsodent, Ponds, Bristol Myers and Tangee, for example) rather than prescription medicine producers that characterised the U.S. inward investment into British pharmaceuticals before 1940. Those entrants concerned with the market for prescription products were restricted to Mulford (which entered the UK in 1928, but was by then a failing producer of biologicals and succumbed to acquisition in 1929), Abbott (exploiting its sodium pentothal anaesthetic, which became the most successful anaesthetic product in the world – entered the UK in 1937), Lilly (a leader in insulin production – entered the UK in 1939) and Gelatin Products (a producer of gelatine capsules for pills – entered the UK in 1938).

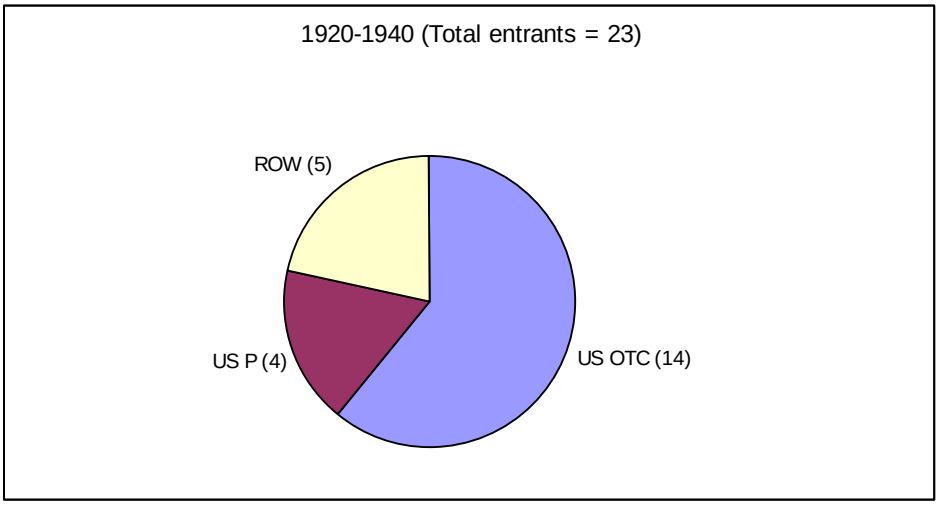
The U.S. pharmaceuticals sector also had many links with other nations, Canada most obviously (where Lilly had acquired its insulin technology from, for example), but also with German firms. Moreover, there were other types of alliances with the British market apart from FDI, as will be emphasised below. But the data for inward investment into British manufacturing effectively capture what branch of the U.S. pharmaceuticals industry was most internationalised before 1940. Underlining what was taking place in the domestic U.S. market, it was the OTC producers that dominated outward FDI, exploiting FSAs in marketing, not science-based research and production.

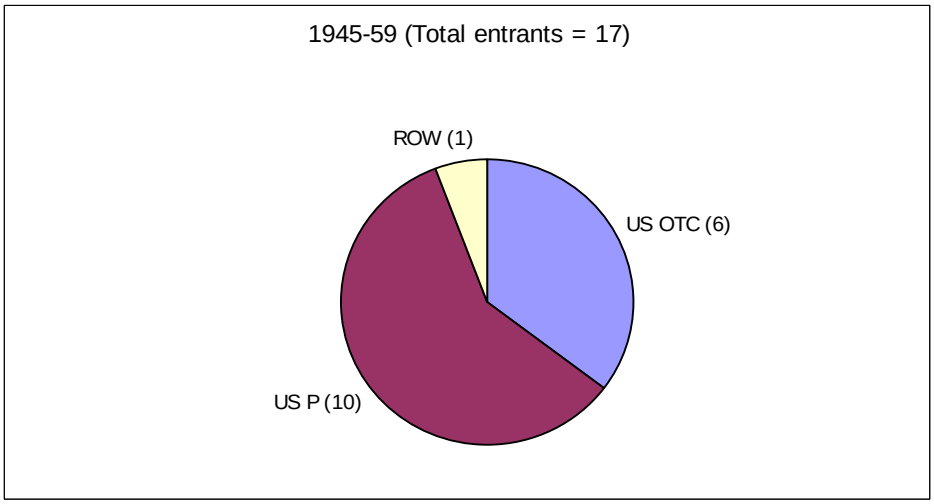
In stark contrast, the second chart shows that during the period 1945 to 1959 it was prescription medicine producers that were the overwhelming majority of entrants into the

UK – with ten out of the sixteen U.S. entrants, six of which arrived specifically to manufacture antibiotics and related products for the large British market.

The science base of the U.S. pharmaceuticals industry was transformed during the war with the revolution in penicillin production capabilities. The discovery of the 'first successful chemical attack' (Bud 2007, p. 17) on bacteria, the sulphanomides, or the predecessor to antibiotics, was in the Bayer laboratories, part of IG Farben, in Germany between 1932 and 1935. The news of the first of the sulphanomides spread through medical journals, prompting pharmaceuticals producers elsewhere to begin experimenting with attempts at manufacturing them. The critical competencies required for the commercial production of sulpha drugs were, first and foremost, the ability to be able to screen many, many (sometimes thousands) of samples of spores growing on organic matter (typically soil), laboratory testing (typically on mice) of each potential product, and then designing a manufacturing process that would enable the exact dosage to be delivered in a stable form to patients large distances away from the manufacturing plant (Bud 2007, Church and Tansey 2007). With the IG Farben discovery process published, it was only a matter of time before others copied the scientific method of discovery. French, Swiss and British producers all had success between 1936 and 1939 with what were highly advanced manufacturing techniques. It was notable, however, that Squibb and Merck, the two leading U.S. producers of fine chemicals, were initially unable to manufacture sulphas. U.S. difficulties were compounded when S.E. Massengill, a small Tennessee producer, incompetently killed over 100 people with its sulpha product in 1937. (Bud 2007, pp. 37, 110). The OTC-dominated population of U.S. pharmaceuticals companies lagged behind European and Canadian scientific capabilities and were falling further back. But penicillin and war changed all that.

Chart 1. U.S. and Other Foreign Entrants into British Pharmaceuticals Manufacturing, 1920-40, and 1945-59 (Prescription [P] and OTC producers).





Source: Godley 2000 and Bostock and Jones 1994. The chart includes the entire subset of entrants in pharmaceuticals - SIC 257 (using UK SIC 1980 three digit codes, following Bostock and Jones 1994).

The story of penicillin and its role in the Allied war effort is well known. What is important for the purposes here is to note how news of penicillin's therapeutic efficacy disseminated from Britain to the U.S. and so led to a transformation in manufacturing and research capabilities there. Alexander Fleming first discovered the mould and its properties while working at St Mary's Hospital, London, in 1928. His attempts to generate interest in it were thwarted until war broke out. Then the Oxford scientists, Howard Florey, Ernst Chain, and Norman Heatley, devised a technique for penicillin's extraction and manufacture. Manufacturing required, however, considerable industrial experimentation, and in 1941 Florey was convinced that British firms were unable to divert scarce resources in wartime to invest in experimental techniques for mould growing. In the summer of 1941 Florey and Heatley went to the U.S. and Canada. The crucial exchange was with scientists at the U.S. government's northern regional research laboratory at Peoria, who had developed expertise in fermentation techniques for moulds. Before Florey and Heatley returned, both Merck and Squibb agreed to experiment with production techniques, working with the Peoria laboratory and the Federal War Production Board. The net result was that by 1942 two U.S. and six British pharmaceuticals firms were trying to develop mass production techniques for penicillin (Bud 2007, ch. 2, Liebenau 1987a). It was not, however, until the intervention of Pfizer from late 1942 that the U.S. industry was able to generate any kind of obvious technological lead. Pfizer, a manufacturer of citric acid, had long experience with fermentation techniques, and John McKeen, Pfizer's then Superintendant of its Brooklyn plant (and from 1949 its President and then Chairman), worked out a technique for the deep fermentation of penicillin. This provided the step-change in productivity required for the effective mass production of this 'wonder drug' (Weber 1979).

With the U.S. government co-ordinating efforts, bids were solicited from as many producers as possible, and by early 1944 twenty firms were manufacturing penicillin in the U.S., the four leading producers (Pfizer, Merck, Squibb and the Commercial Solvents Corporation, which was to exit production shortly after the war), and almost all the other manufacturers of prescription pharmaceuticals, as well as just two OTC producers, Bristol Myers and American Home Products, that had been able to develop sufficient expertise in drug manufacture to produce credible bids by 1943. By the end of the war the leading producers dominated output. The top five producers had 88 percent of total penicillin output in 1945 (Temin 1979, p. 435). But the U.S. government's deliberate diffusion of manufacturing expertise meant that there was a very competitive environment in the immediate post war period. By 1950 the top five producers only had 48 percent of the penicillin market, with several of what had been the second-tier producers in the war carving out important niches. Lederle and Parke Davis developed novel and patentable antibiotics, Upjohn and Bristol Myers variations of Pfizer's penicillin. Abbott, Lilly, Hayden and American Home Products all enjoyed significant shares of the market. By 1950 42% of AHP's sales came from its pharmaceuticals division, dominated by antibiotics, for instance.

The net effect was that the U.S. government had subsidised the entry into the penicillin market in 1943, broadening the population of manufacturers. This prompted a dramatic increase in output, subsequent price falls and a much reduced profitability in the early 1950s (Bud 2007, p. 106). By 1955 what Temin describes as the 'broad-spectrum antibiotic cartel' (of Pfizer, Squibb, Lederle, Bristol and Parke Davis) had emerged. In a break from industry practice, they enforced their patent rights and higher prices, so causing a shake-out of penicillin production.[7] In 1955 the leading four producers were responsible for 86

percent of total output (Temin 1979, p. 435). But those firms exiting penicillin production did not exit prescription medicines; rather they were then responsible for drug discovery in a range of derivative products. Lilly, Abbott and Merck discovered different antibiotics, Sharp and Dohme novel sulphonamides, Merck an important diuretic and an anti-parasite animal health product, and Upjohn an important anti-diabetes product, all from similar methods and source materials as the original IG Farben sulphonamide process. American Home Products, Upjohn, and Smith Kline and French also all developed new products (Temin 1979).

Only one pre-war pharmaceutical producer that had not been involved in the U.S. Government's crash programme of penicillin production went on to prosper in the 1950s - Smith, Kline and French. Conversely the overwhelming majority of the OTC producers of the 1930s were not involved in penicillin production during the war. Almost invariably they then failed to develop strong prescription medicine-based pharmaceuticals businesses afterwards. Plough, Warner-Hudnet, Lambert and many, many others came into this category.[8] Government intervention during the war therefore not only subsidised the creation of the core competence of the U.S. penicillin producers – the deep fermentation technique – but also effectively decided the composition of the population of the post-war industry through its 1943 tender process. It then becomes important to understand how those firms whose bids the U.S. government accepted in 1943 were able to demonstrate credible penicillin manufacturing capabilities, in particular given that only five or six years earlier even Merck and Squibb were struggling to develop anti-infective manufacturing facilities. It is here that the importance of internationalisation strategies to acquire important know-how becomes clear.

Internationalisation and its role in technological leapfrogging

The traditional understanding of parent-subsidiary relationship is one where the parent develops some sort of FSA, and then exploits it in some overseas market (Vernon 1966 and 1979, Dunning 1992). But recent analysis of FDI in knowledge-intensive sectors suggests that internationalisation may be as much about technology-enhancing as technology-exploiting strategies, with deliberate attempts to acquire know-how from overseas (Cantwell 1995, Cantwell and Mudambi 2005). There is also considerable evidence of similar know-how acquisition strategies being pursued with greater or lesser degrees of deliberation among those wartime penicillin producers. Some clearly pursued a conventional product-cycle strategy, some sought overseas technology through a variety of alliances and overseas investments, and some who did both.

Some of the U.S. producers had developed their own technology and engaged in FDI in the classic product-cycle manner. Abbott, as mentioned above, in anaesthetics, followed what Parke Davis had done thirty years earlier (and then in anti-toxins) in establishing a British branch plant. But, as the earlier part of this paper has made clear, the U.S. industry typically did not possess the key scientific technology in pharmaceuticals – Abbott, with its path-breaking anaesthetics, was very much an exception. Rather U.S. producers mostly had to source essential know-how from Europe and Canada. This was done either through what can be described as a legacy effect, or through informal alliances and formal joint ventures, or, rarely, through acquisition.

Merck, Squibb and Lilly are perhaps the best examples of successful U.S. antibiotics producers benefiting from long-established channels to foreign sources of superior

technology. Merck was originally established as the subsidiary of a leading German producer of pharmaceuticals. Uniquely after the World War One sequestrations, the newly independent U.S. Merck remained in the hands of the same family. One of the conditions was that the two companies should no longer collaborate commercially. However, the two firms continued to collaborate on technical matters, largely as they had before the war. Unlike its U.S. peers, Merck therefore gained privileged access to new developments in German pharmaceuticals during the 1930s giving them crucial knowledge in sulpha production (Merck Archives).

Lilly had established a close commercial relationship with the leading Canadian research laboratory, Connaught Laboratories of Toronto University, when they agreed to commercialise the Canadian innovation of semi-synthetic insulin in 1923. Close links continued between Lilly and Toronto. When Florey and Heatley broadcast their hopes for penicillin in 1941, the Canadian scientists were not slow in developing it. Lilly, as the longstanding commercial partners of the Connaught group, benefited from early exposure to penicillin laboratory production techniques pioneered abroad. Less is known about Squibb, but the firm's entrepreneurial CEO from 1904 was a German immigrant and former leading employee of E. Merck & Co, who also retained research links with Germany.

But proximity to foreign science and technology was not sufficient for the subsequent development of technological competences. Of all the firms in the U.S. pharmaceuticals sector in the 1920s and 1930s, Sterling was the closest to the world's leading source of technological advancement, yet did absolutely nothing about it.

Sterling bought Bayer's U.S. subsidiary, after the U.S. Government had sequestrated the firm in World War One. Sterling then marketed worldwide Bayer's innovative synthetic analgesic as 'Bayer's Aspirin', prompting threats of litigation from the former German parent. In 1923 agreement was reached which prompted the creation of the Winthrop subsidiary as a fifty-fifty Sterling-Bayer (now I.G. Farben) venture. In return for ceding half its claims on 'Bayer's Aspirin' back to the German company, Sterling acquired access to and the rights to commercialise in North America all of Bayer/ IG Farben's research in ethical pharmaceuticals from then on. This surely was the ultimate opportunity to leverage marketing capabilities to acquire scarce research capabilities. Yet despite all the privileged access to new medicinal compounds (and recall that Bayer was *the* leader in the discovery of the new sulphas), Sterling retained its focus on marketing 'Bayer's Aspirin' and other branded OTC products. Sterling enjoyed easier access to advanced pharmaceutical knowledge than any other U.S. firm, yet chose to remain locked-in to its OTC product range and its marketing capabilities. It only entered research for ethical pharmaceuticals in the 1970s.

Perhaps more interesting examples, at least for this paper's purposes, are those U.S. producers that deliberately used their overseas' subsidiaries or alliances to acquire important know-how. The best examples here would include Parke Davis' use of its long established British subsidiary, the alliance between Pfizer and the British firm Kemball Bishop, and Bristol's joint venture with Boots.

Parke Davis had established a British subsidiary as early as 1902 to develop the British market for its advanced anti toxins. But it quickly developed an important relationship with St Mary's Hospital, acquiring the rights to market innovative vaccines and sera developed

by St Mary's staff. The Parke Davis British subsidiary was, in other words, increasingly concerned with knowledge acquisition rather than the overseas exploitation of its parent company's proprietary knowledge. It was a very successful relationship (Church and Tansey 2007, p. 222). It also meant that Parke Davis had privileged exposure to the earliest of discussions about penicillin in Fleming's laboratory at St Mary's and the mechanisms to be able to communicate that potential back to its parent.

Pfizer had established an informal alliance with the British manufacturers of citric acid, Kemball Bishop, sharing technology and manufacturing processes. In 1936 Kemball Bishop licensed a new manufacturing process from Pfizer and John McKeen was seconded to London to design and build the new plant. On his return to New York in 1938 he then designed and oversaw the construction first of the firm's Brooklyn plant, and then, in late 1941, the construction of a pilot plant for the laboratory production of penicillin, the first step towards Pfizer's deep-fermentation process techniques. McKeen's critical innovation undoubtedly took place in New York, but the year and a half spent designing the new Kemball and Bishop factory gave him many of the foundations for the what was the revolutionary innovation in the chemical engineering of penicillin production, first in the laboratory plant in late 1941, then in a pilot plant in 1942, before scaling-up for mass production in 1943 onwards (Weber 1979).

Bristol also benefited from an earlier established alliance. As a constituent member of Drug Inc., Bristol had a commercial relationship with Boots in the UK, after Boots had been acquired by the U.S. firm in 1920. After the demise of Drug Inc. in 1933, Bristol continued the relationship through a formal joint venture for the British company to manufacture and distribute its products. Bristol was, of course, dominated by its range of OTC products, its

key strengths were in marketing. Boots was known for its nationwide chain of chemists and druggist stores. But during the 1920s and 1930s, Boots deliberately invested in its scientific capabilities, increasing its research and development base. In the 1930s its chief scientist experimented with one of Fleming's penicillin mould samples. In the end, perhaps unluckily, it led Boots to develop a commercially unsuccessful version (Bud 2007). But it also gave Bristol access to detailed knowledge about how to manufacture penicillin, knowledge that gave it the possibility of acquiring sufficient credibility to have its bid for penicillin production accepted by the War Production Board in 1943, despite its OTC background.

Like Bristol, American Home Products, or AHP (now Wyeth), was a producer of OTC products in the late 1930s not prescription medicines. It was a 1926 merger of several producers of OTC products like toothpaste and laxatives and then expanded rapidly overseas. It acquired the moribund Wyeth from Harvard University in 1931 and its Anacin (Anadin in the UK) analgesic, which it promoted aggressively with great success, so funding an acquisition spree. This led to diversification into prescription medicines, including a license agreement for an anti-arthritis vaccine in 1936 and acquiring the British firm Boyle Pharmaceutical Products in 1938. AHP also acquired an interest in the Chester County Mushroom Company in 1942, which was successful in developing techniques for surface culture production of penicillin mould. While this technology was shortly to be superceded by events at Pfizer, AHP at least was able to acquire its initial manufacturing capabilities in penicillin. Then shortly after the U.S. entry into war, it also acquired the Canadian pharmaceutical company Ayerst, McKenna and Harrison. This Montreal-based producer of hormones had earlier collaborated with Glaxo, but, after Florey and Heatley's tour, it had also developed techniques to produce penicillin. In 1942 it had been contracted

to provide the antibiotic to the Canadian military. Through these acquisitions, AHP was therefore a strong contender for one of the contracts for penicillin production.

Whether it was through exploiting the privileged legacy of historical relationships with superior sources of know-how, or whether it was through the mutual gains in formal or informal alliances and joint ventures, or, as with AHP, through acquisition, all these leading U.S. companies were able to utilise internationalisation strategies to leapfrog over European competitors during and after the war. Clearly the effect of U.S. government policy during the war was of far greater importance in creating the industry, both in stimulating knowledge sharing and promoting competition, as well as in partially destroying the most important source of foreign competition. But the examples here suggest that those firms that were able to acquire sufficient technical competence to be able to be considered by the U.S. government during the critical bidding process in late 1943 had all used a variety of strategies to acquire superior knowledge from overseas.[9] The American examples of successful technological leapfrogging during the antibiotics era suggests that that the Indian generics companies of recent years may indeed successfully be able to move into genomics. It is to this group of firms that section 4 now turns.

4. Indian Generics Producers and the attempts to integrate biotechnology

In India, the Patent Act of 1970 and government investment in the drug industry is widely acknowledged as having infused life into the Indian pharmaceutical industry. Increasing drug prices in a sector dominated by western multinationals presented a national healthcare problem. Indian policy makers responded by weakening the patent law to recognise only process patents and instituted price control over essential drugs. The 1970s and 80s saw the

entry of a number of indigenous manufacturers, who set up production units of different sizes. Thus, in 1970, the Indian market was clearly dominated by multinational firms: eight of the top ten firms were MNCs. After two decades following the 1970 Patent Act, the Indian market was dominated by domestic firms.[10] The availability of trained manpower, comparative ease of imitation and a strong chemistry base among Indian research institutes supported these manufacturers. By 1996, only 4 of the top ten firms were foreign multinationals. Domestic firms dominated and their share of the domestic market climbed from a mere 10% in 1970 to 70% by 1989.

Price controls on drugs meant that the domestic market was never the most profitable one for Indian firms. Estimates suggest that while India accounts for 8% of the drugs market by volume, it only accounts for 1% of the value of this market. By the mid 1980s market leaders such as Ranbaxy had already begun to explore export markets in Asia and Africa. Much of this activity was centred around the export of pharmaceutical ingredients, though export of formulations (what are known more generally as generics) also started rising. Through the 1990s the export of bulk drugs grew at rates of 15% per annum, while the export of formulations grew faster at 20% per annum.

Athreye, Kale and Ramani (2008) note that another strategy induced by price controls in the domestic market was the quest for ever cheaper processes to manufacture known and patented drugs. A handful of Indian firms had invested in R&D to manufacture 'copycats', reverse engineer the processes, bring down costs, and then patent any new process innovation. These were typically then licensed back to MNEs operating in the country. The profits from the process innovation were thus shared between the innovating Indian firms and the MNE firm that marketed the 'brand'. Ranbaxy, in particular was also

investing large amounts in new process R&D[11] under the direction of Dr. Parminder Singh, who had been educated in the US. Bhandari (2005) notes that Parminder Singh pursued this program despite reservations from the Board of Directors at Ranbaxy and that in doing so he had his eye on the lucrative generics market in the US.

The passage of the Hatch-Waxman Act in 1984 [12] had reduced entry costs into the US generics market for all manufacturers of generic drugs. This was a lucrative business opportunity for the Indian firms who enjoyed a low cost advantage of about 30% relative to other manufcturers. Bower and Sulej (2005) estimate that the main cost advantages of Indian firms lay in cheap active pharmaceutical ingredients (which form about 50% of the cost of a drug) followed by lower costs of scientific labour. The opportunity also arose to reinvest some of the money made from the generics business to gain technological advantages in discovering new biotechnology products/ therapeutics and thus leapfrog into the big league.

In 1991, the pioneering R&D attempts at Ranbaxy bore fruit and they successfully patented a non-infringing process patent for Cefaclor (a drug sold by Eli Lilly) resulting in a jpoint venture with Eli-Lilly for the new process. But soon other Indian firms such as Dr. Reddy's labs, Lupin laboratories, Sun Pharmaceuticals, Wockhardt and Cipla joined the race to find cheaper processes for drugs that were due to go off-patent. Many Indian firms saw the opportunity to plough back the profits from their generics exports into research aimed at finding new molecules using the new techniques associated with biotechnology to make and test drugs and vaccines.

As is well known, the 1990s also saw a transformation in the Indian domestic environment. In 1991, the economy was liberalised and the pharmaceutical sector was de-licensed, with most drugs removed from price control. By 2004 only 76 drugs (26%) remained under price control. India's entry to the WTO prompted both strengthened patent protection and a significantly increased life of a patent from seven years to twenty years. Ramani and Venkatramani (2001) identify a large variety of strategies used by Indian pharmaceutical producers post-1995, where some firms explicitly targeted the development and integration of biotechnology capabilities. They identify the following specific objectives for firms that invested in competence widening measures:

(i) Process improvements to produce 'me too' products, concentrating on near to expiry patents but with an eye on including biotechnology when these type of patents are no longer available. (e.g. Dr. Reddy's, Cipla, Wockhardt)

(ii) To create easy to make diagnostic kits based on biotechnology methods as a simple way to learn about the technology (e.g. Ranbaxy)

(iii) To create new chemical entities and speciality chemicals (e.g. Dr. Reddy's, Malladi Drugs)

(iv) To create therapeutics for other developing countries (e.g. Kopran and its R&D into waterborne diseases)

(v) Invest in biotechnology through diversification into non-healthcare biotechnology (e.g. Cadilla's alliance with a Dutch firm for tissue culture and aquaculture products)

While all these strategies represent different developmental paths, it is too early to say which of these will definitely translate into long lasting competitive advantage for an Indian pharmaceutical firm. In contrast to the US firms by the 1950s, the Indian situation is still open-ended, but nevertheless Indian firms have been able to develop an important

presence in global pharmaceuticals. Bower and Sulej (2005) also observe that the leading Indian firms steadily increased their cash generative capability and profitability before attempting to develop a “discovery” capability and argue that this strategy contrasts sharply with those of Western biotechnology companies, which typically started with some “discovery” capability before attracting finance and complementary expertise through strategic alliances with pharmaceutical firms, venture capital and public equity finance.

Indian technological capabilities may have befitted from advantageous financial terms, but recent events suggest that those capabilities are likely to continue to improve. The established Indian strengths in reverse engineering and in generics may become increasingly important as biotechnology drugs increasingly come off patent. From 2002 to 2004 20 biotechnology drugs lost their patent. But in 2005 the patents of 13 US biotechnology products expired. The numbers of expiring patents will continue to grow.

The Indian firms’ abilities to push their strengths in the bio-generics and vaccine market and penetrate the European and American markets in the future are likely also to be dependent on the degree to which they adhere to international standards of good manufacturing and clinical standards. But the biotechnology industry associations are well aware of this (Athreye and Chaturvedi 2006). There is, in other words, substantial evidence of technological convergence in during the 1990s and increasingly since 2000 of the beginnings of Indian leapfrogging in some processes. Much of the key know-how was acquired from overseas.

Internationalisation and its role in technological leapfrogging

Internationalisation in the form of increasing outward investments has been an important aspect of the leapfrogging strategies adopted by Indian pharma firms. Outward investment from Indian Pharmaceutical firms increased dramatically after 1990. Using outward foreign investments approvals data, Pradhan and Alakshendra (2006) show that the number of outward investing firms increased from 11 in the pre-1990 period to 55 in the 1990-99 period. The firms with the most outward FDI approvals were the leading generics manufacturers viz. Ajanta Pharmaceuticals (17 projects) followed by Ranbaxy Laboratories (13), Core Healthcare, Dabur and Sun Pharmaceuticals with 7 projects each.

Second,they show that the direction of outward investment changed from being concentrated on Asia and Africa to encompass developed countries of the West, with the US and UK emerging as leading destinations for such investments.[13] Third, the purpose of investment in developed and developing countries differed significantly as Table 1 below shows. Investments directed towards developed countries are for marketing and trading purposes, while those targeted at developing countries are for establishing manufacturing subsidiaries. This indicates a clear strategy of exploiting and leveraging global location advantages. Developing countries are more attractive places to start local production because they can enhance their cost advantages of the Indian firms and the firms also benefit from the soft patent regimes prevalent in these countries. By contrast, their investments in developed countries as Table 1 indicates are mainly to build their distribution networks in the more regulated western markets.

Table 1: Nature of Outward Greenfield Projects over Developed and Developing Countries, 1990–1999

Nature of Projects	Developed Countries		Developing Countries	
	Number	Per cent	Number	Per cent
Manufacturing	16	36.4	35	52.2
Manufacturing and marketing	3	6.8	5	7.5
Marketing and Trading	25	56.8	27	40.3
Total	44	100	67	100

Source: Pradhan, JP and Alakshendra A (2006), Table 7.

Pradhan and Alakshendra (2006) also point to changes in the mode of entry that has characterised internationalisation of firms from this sector. While Joint Ventures were the predominant form of outward investment by Indian Pharma firms prior to 1990, between 1990-99 both joint ventures and wholly owned subsidiaries were equally preferred modes of entry.[14] Since 2000 acquisitions have become the most preferred form of entry into foreign markets. The popularity of acquisitions can be overstated. Policy regulations created many restrictions for the free outward flow of foreign exchange prior to full capital market liberalisation of the economy. So the new popularity of acquisitions in international outward investment probably merely reflects the relaxed policy towards outflows of foreign exchange from the Indian economy. Acquisitions have probably also been helped by strong financial positions in international markets enjoyed by the large Indian generics producers noted earlier.

Prominent countries where companies have been acquired are: USA (14), UK(8), Germany (5) , Brazil and China (3 each) and Belgium, France and Italy with 2 acquisitions each. Only 8 firms have accounted for about 70% of all acquisitions viz, Ranbaxy Laboratories (9), Sun Pharmaceuticals and Glenmark Pharmaceuticals (5 acquisitions each), Dr. Reddy's and Jubilant Organosys (4 acqusitions each), Nicholas Piramal, Wockhardt and Aurobindo Pharma (2 acqusitions each).

Analysing the purpose of acquisitions shows three reasons dominate: the need to acquire manufacturing facilities and market share in particular locations and the desire for technological and brand assets.[15] Whilst technological and brand assets clearly reflect a 'buying' in of firm specific advantage using relatively strong financial market positions, the acquisition for manufacturing facilities represents better positioning with regard to complementary assets. Not only will the possession of such facilities give Indian firms an advantage in manufacturing generic versions of expired biotechnology and other patents, they are also fungible assets in the sense that any new product developed through the firms own R&D efforts can also be pushed through these distribution networks. A closer inspection of the sequence of acquisition also reveals that the first international acquisitions made by Indian firms were for laboratories and brand assets. Later investments for each firm were to acquire distribution networks and generics market share.[16] A number of contract manufacturing agreements have also been signed by many of the internationalising firms with western MNES with varying degrees of technological collaboration built into the contracts.[17] Nicholas Piramal, for example, has cemented its relationships with many of the former parent companies of the Indian subsidiaries, which Nicholas Piramal has acquired in the course of its growth.

As was the case with the U.S. firms earlier, a variety of internationalisation strategies were deployed by Indian firms to acquire core assets to enhance their competences in the global generics market. Acquiring new biotechnology-based NCE discovery capabilities needed systematic investments in own R&D, but this has had to be complemented with internationalisation strategies of various kinds in the late 1990s and since 2000. In each case, the proximate reasons that dictated the form of internationalisation was a bit different.

Interviews with firms like Ranbaxy, Dr. Reddy's Foundation and Wockhardt - all of whom have plans to develop biotechnology capabilities suggest that their major constraint to doing so is the lack of adequately trained biologists in India. Historically the Indian science base has developed good doctors and good chemists but very few dedicated centres of research in biology. Kale et al (2006) show that several Indian firms tried to attract and employ returning scientists who had worked in US or European MNEs as a way to boost the firms' skill set and technological competence in these deficient areas. However, this strategy met with only limited success, since many returnees at the senior level had concerns about the working environment in India, while post-doctoral researchers were often too specialised to fit into a firm at an early stage of discovery capability.[18]

The drive to fill skill gaps led to a very early internationalisation of R&D in the case of Dr. Reddy's. Kale et al (2006) note that after establishing discovery research in Hyderabad, Dr. Reddy's wanted to introduce modern skills such as drug discovery based on genomics and proteomics and using rational drug design but struggled. They quote the former R&D president of DRF as saying, "We could not recruit the requisite skills because it's not the one scientist, you need a whole team and we could not do this for the period of three years. We located scientist but 1 or 2 may be willing to come out but they had inhibitions and

they needed lot of time and they were unable to take decisions. Then we decided there is no point in waiting. We can not bring people here; we will move our lab there". Thus in 2000, DRF set up a lab in Atlanta, US dedicated to discovery and design of novel therapeutics using molecular genomics and proteomics approaches. The lab, Reddy US Therapeutics Inc (RUSTI for short) quickly built a team of 12 scientists, and in seven years the organisation has obtained twelve US patents.[19]

Ranbaxy has also systematically used its internationalisation in the US to build its distribution network and to concentrate on the developmental aspects of R&D. Its internationalisation efforts in the US started with the joint venture with Eli Lilly for the manufacture of Cefaclor in 1992. This joint venture was dissolved in 1995 and in return for an early dissolution Ranbaxy obtained brand recognition by buying rights to manufacture all of the products for which Eli Lilly was the only supplier. In 1995, they made their first acquisition in the US (Ohm labs) to benefit from its FDA approved manufacturing facilities. This was followed with the setting up of their own 100% subsidiary in the US for the manufacture of products under the Ranbaxy brand name. However, unlike all the other Indian firms that have used internationalisation to source technology directly from abroad, Ranbaxy has not yet drawn a single patent from its overseas laboratories or acquisitions. It has rather used these investments to gain regulatory and legal expertise for its existing range of products - capabilities recognised as being important to the development stage of a new chemical entity.

Wockhardt placed biotechnology at the heart of its strategy in the early 1990s and spent 20 -30% of its total research budget on biotech R&D. In 1993, the company initiated an international joint venture with a Research Centre (ICGEB) in Trieste, Italy for research on

recombinant products such as Hep-B vaccine, EPO and human insulin. However, the company called the deal off after 3-4 years because of a lack of output. Subsequently, Wockhardt set up its own R&D centre at Aurangabad in 1994 and in 1995, entered into another international joint venture with Rhein Biotech, a German firm, for the development and manufacture of Recombinant Biopharmaceuticals. The venture was funded by equities on the Wockhardt side and resulted in the successful production of the hepatitis B vaccine, Biovac-B in 2001. However, due to a conflict of interest over the rights to this product, the joint venture was dissolved and Wockhardt bought Rhein's shares and took full ownership of the subsidiary. In 2004 Wockhardt acquired the German pharmaceutical company 'Esparma', GmbH to enter Germany, the largest generic drug market in Europe. Esparma has a portfolio of 135 marketing authorisations, of which 67 are in Germany. The company also has nine international patents and 94 trademarks to its name.

Ranbaxy, DRF, Wockhardt, as well as Nicholas Piramal have, unknowingly, mimicked the earlier case of U.S. entrants into penicillin production. First those with the stronger links to overseas know-how developed stronger R&D capabilities in generics. Then, as the potential in genomics became clearer, have been instrumental in acquiring biotechnology capabilities from overseas.

Patent data help us to establish the success of these strategies in building technological strengths. The patents filed by Indian inventors have been on the rise in the USPTO and one analysis[20] of patents filed in biotechnology and related sectors (in classes 210, 264, 424, 435, 514, 530, 536, 549, 800) at the USPTO reveals that 60% of the total 746 patents filed by Indian resident inventors were assigned to government or research institutions (dominated by the Council of Scientific and Industrial Research (CSIR) with 383 patents).

Patents assigned to the generics pharmaceutical company Dr Reddy's constituted the next largest proportion after CSIR (totalling 31 or 4%). Closely following were Dabur Research Foundation, part of the multinational Dabur Group (with 29 patents), and the generics pharmaceutical company Ranbaxy Laboratories (28). Moreover, apart from Ranbaxy, the other Indian companies have also successfully filed patents from their international subsidiaries. More narrow definitions of biotechnology (based for example on classifications developed by Bronwyn Hall) however, reveal that no Indian firm has successfully integrated biotechnology into its range of technological competences. This disagreement is perhaps not surprising given the short amount of time in which Indian firms have been engaged in NCE efforts.

5. Discussion

The Indian strategy of investing to acquire new technological capability from overseas in this most knowledge-intensive of all sectors has been widely commented on, with few believing it to be a recipe for lasting success. But the example of U.S. pharmaceutical leapfrogging European leaders in the 1940s suggests that there may be more legitimacy in the strategy than critics allow. Though our starting point was the similarities between the two cases, the narratives in section 3 and 4 clearly highlight that the environmental contexts in the two periods were very different: the policy environments were clearly different, with world war two dominating the earlier case, perhaps even precipitating it and unlike the US story the Indian story is far from over. In this section we discuss more systematically the similarities and differences in the leapfrogging strategies of the two groups of firms.

First, let us examine the similarities. Indian firms had developed capabilities in particular kinds of manufacturing and reverse engineering. The U.S. firms had mostly developed marketing capabilities during the 1930s, such was the growth of sales in the OTC and toilet goods markets compared with prescription medicines. Only two pharmaceutical firms (Merck and Squibb) and one non-pharmaceutical firm (Pfizer) were augmenting manufacturing strengths. None of these had developed research or knowledge capabilities in what was to be the core science bases before the late 1930s. There was nevertheless sufficient general information in the scientific literature for experimentation to begin. However, critical items of know-how mostly had to come from abroad. Yet, in both cases the study appears to suggest that the firms were aware of weaknesses in their range of assets and were investing in acquiring know-how from overseas in order to compensate.

In both the Indian case and the earlier U.S. case internationalisation in its various forms has played a major role in compensating for the absence of particular kinds of pre-requisites required for leap-frogging. Thus, the strong similarities between the two leapfrogging episodes arise because of the juxtaposition of globalisation with technological discontinuity. In both cases, firms with relatively low technological competences were keen to exploit internationalisation for technology acquisition. The strategies used by partiucalr firms varies although here too there are strong similarities between the two groups. Nicholas Piramal, for example, almost copying Merck in exploiting the legacy of earlier parent-subsidiary relationships. Wockhardt, like Parke Davis, Lilly and Bristol, engaged in alliances and joint ventures with overseas laboratories. Ranbaxy developed its manufacturing capabilities in alliance with Eli Lilly, perhaps in a similar fashion to Pfizer's relationship with Kemball Bishop.

The internationalisation strategies adopted for successful leapfrogging necessarily varied, partly no doubt reflecting the differences in the economic and policy contexts. Thus, U.S. firms were unable to acquire European firms once war had begun there in 1939, for example. Further, in the 1940s the industry's efforts were focused on just one product – penicillin, and solving the problem of its mass production. In contrast, Indian firms found it hard to make acquisitions abroad before 2000 due to domestic foreign exchange related restrictions. Furthermore, breaking into biotechnology-based NCE discovery today is a far more complex business than designing large-scale manufacturing facilities for penicillin based antibiotics.

In the U.S. the combination of an exceptional degree of government intervention, with the windfall gain of basic technology available freely from the Oxford scientists meant that the pharmaceuticals sector was transformed. The firms that became successful in the 1940s were atypical of the U.S. pharmaceutical industry of the 1930s. They were the very small number of conservative, manufacturing pharmaceutical and specialist chemical firms, along with several pharmaceuticals companies that retained manufacturing strengths, even while diversifying into branded OTC lines during the 1930s. Only two, AHP and Bristol, out of all the vast number of OTC and toilet goods producers made the transition into penicillin production by 1943. Explaining how these firms were able to acquire the key manufacturing capabilities to have been considered potentially capable of manufacturing penicillin is only partly generalisable, as they each had different development paths. What we can say definitively is that it was not privileged access to overseas know-how alone which firms became penicillin producers. After all, on paper Sterling was the prime candidate for developing sulphas in the U.S. But even after the potential returns to sulphas

became known in the late-1930s, Sterling was unwilling to erode the value of its marketing capabilities by switching resources into science-based research and production.

Using Steinmueller's four pre-requisites for technological leapfrogging to order the discussion, we can suggest that in the case of the US pharmaceutical industry in 1941, there was clearly sufficient absorptive capacity to produce or use technology among the market leaders of Merck, Squibb and Pfizer, as well as among the follower pharmaceutical producers (like Parke Davis, Lilly, Upjohn, Sharp and Dohme and so on), albeit to a lesser extent (precondition #1). But until the Oxford scientists' tour of summer of 1941 and the critical exchange with the Peoria laboratory that led to the breakthrough on production media, the leading U.S. firms remained significantly behind foreign competitors in their access to key equipment, manufacturing techniques and technological know-how (pre-condition #2). During the war, the U.S. government took over the role of industry co-ordinator (delegating much of this to the Peoria laboratory), making the critical decision about which firms it gave licenses for wartime production. The U.S. government, in other words, subsidised the diffusion of complementary technological capabilities throughout the population of its selected wartime producers (precondition #3). After 1945 the net result was a crowded market, with output soaring, prices falling and a race for product innovation. By 1950 the market share of the original leading firms had more than halved. By 1955, however, five firms had created what was effectively a patent pool, driving out non-patent holders and putting a floor on the price of the new broad-spectrum antibiotics. Temin's (1979) analysis of this concludes that the key to cartel membership was not technological capabilities, but marketing. The winners were those firms with some technological capabilities (acquired through membership of the government wartime

producer group) and those who had developed and integrated either existing or wholly new marketing capabilities (precondition #4).

Internationalisation through outward investment in the U.S. case was therefore mostly a less instrumental route to capturing new knowledge than among the Indian firms today. The U.S. pharmaceuticals firms with manufacturing capabilities (not, in other words, the OTC and toilet goods firms) typically used information from alliances with overseas' laboratories or firms as a way of broadening their understanding of potential new developments: the best examples here being Merck, Parke Davis, and Lilly. The war interrupted, and, after US government intervention, sped up developments. Indeed even among the OTC and toilet goods producers, Bristol and AHP used overseas sources to diversify into acquiring pharmaceuticals manufacturing capabilities during the late 1930s and early 1940s, thus proving to be the exceptions making the rule of OTC firms being unable or unwilling – like Sterling – to move into science based manufacturing. Acquiring know-how from overseas was, in other words, largely the differentiating factor between those firms able to present credible bids to be included in the wartime penicillin production pool and those omitted. Internationalisation and the global search for technological knowledge was mostly the route to inclusion, inclusion largely dictated the population set for the future U.S. pharmaceuticals industry.

Internationalisation through outward investment may however, be more crucial to the success of technological leapfrogging in the Indian case. Unlike in the 1940s there are no leading scientists willing to give blueprints about how biotechnology may be used in vaccine or generic drug production. The IPR system was more monopolised in the 1990s than it was in the 1930s. Again using the Steinmueller framework we can see that though

the level of absorptive capacity for organic chemistry in Indian firms is high (due to the weak patent regime of 1970) most firms have little experience of finding new molecules and the interface between biology and chemistry. However, the market leaders, Ranbaxy, Dr. Reddy's, do show some evidence of this capacity in their patenting profile (precondition #1). Access to technical know-how for Indian firms is constrained by the nature of the international patent regime, whereby product patents are strictly enforced. Greater degrees of internationalisation, however, do allow Indian firms to access equipment and manufacturing facilities both through international trade and overseas acquisitions (precondition#2). Internationalisation through overseas acquisition has also been an important in the acquisition of complementary capabilities (through acquisitions and strategic alliances). The role of ensuring the compatibility/ensuring quality of different stages of production has been taken over by international standards settings agencies such as the FDA. It is estimated that India has the largest number of US FDA approved plants outside of the US (precondition#3). Leading Indian firms are investing heavily in downstream capabilities, such as brand development and distribution networks, though capabilities in new product design are still scarce. However, the preferred strategy of the leading firms, viz concentrating on drugs that are likely to go off-patent also obviates the need for better developed marketing abilities, as their target markets are already well defined (precondition#4).

But the differences in strategies pursued for leapfrogging are also illuminating, and the most striking difference is the strong Indian preference since 2000 for internationalising through acquiring target firms in western markets, a little like Korean firms in the 1990s. The acquisition route to acquiring know-how was unusual among the earlier U.S. firms. Only AHP and Bristol (via the legacy of its earlier acquisition) pursuing it. Of course much

of this difference may be explained by how much easier it has been to finance and gain permits to acquire western firms compared with the late 1930s. But it is notable that the only U.S. producers to gain know-how through acquisition were the two that had the least science-based capabilities by the late 1930s, the two specialist OTC producers. This may be suggestive of the acquisition route being particularly optimal for those entrants with relatively weak firm specific advantages in their attempts to leapfrog incumbents. Those U.S. firms with existing firm specific advantages in science-based manufacturing may have been in far better positions to negotiate alliances with British and Canadian partners. Bristol and AHP may simply have been viewed as too unlikely to be able to contribute to a partnership.

At moments of technological discontinuity, when uncertainty over outcomes increases, alliances between strong partners are always likely to be the preferred organisational structure. Both partners have strong *ex ante* claims to the residual rights on the eventual outcome, but the level of uncertainty is too high for this to be reduced to a contractible relationship. Firms with lesser FSAs at the outset, like the U.S. OTC producers and, perhaps, like the Indian firms today, are unable to build alliances (Wockhardt, as we noted failed successively to develop technologies within alliance relationships), and so have to acquire targets instead.

Moreover, it is at moments of technological discontinuity that the spillover of knowledge is at its highest, as that is when firms are least certain of what knowledge to protect. It follows that the spillover gains to locating in the key centres of innovation and participating in the key networks are at their highest during such moments, whether for overseas entrants or domestic incumbents. In this context, the monopolisation of IPRs may also make one form

of internationalisation more preferable to the other. In the 1930s when free licensing of penicillin technologies was the industry convention, strategic alliances may have been enough for technology transfer and there may have been an acceptance of the unintended spillovers. However, monopolisation of IPR in the presence of possible spillovers makes the significance of ownership of residual rights even more important and thus might favour full ownership.

6. Conclusions

No two periods in history are ever completely alike, but this detailed comparison of the variety of strategies adopted by U.S. firms in the 1930s and 1940s with Indian firms more recently does find some supporting evidence for the view that technologically laggard firms (in the US and in India) may attempt to overcome initial disadvantages and develop knowledge capabilities through targeted internationalisation strategies. Far from exploiting firm specific advantages, we show that laggard firms from both countries entered growing markets and through their internationalisation strategies built lasting competitive advantages. In fact almost all of the U.S. firms that were able to create successful pharmaceuticals capabilities in the 1940s, had also exploited a variety of internationalisation strategies to acquire relevant expertise during the late 1930s and early 1940s, suggesting that there may be considerable merit in the more aggressive internationalisation strategies adopted by the Indian generics producers today.

This finding has two important implications. Firm Specific Advantages are believed to be the cause of outward FDI in a large literature- we show outward FDI can sometimes secure FSA. Partly this is because of a long held belief that firms would not incur the manifold

costs of going abroad unless there was some inherent firm specific advantage that they could gain. However, in this paper we show that U.S. firms in the 1930s-40s and Indian firms from 1990 to 2005 did go abroad without many firm specific assets or advantages. Furthermore, among both groups some firms were able to use their internationalisation as a strategy to gain and develop capabilities that would sustain their competitive advantage in the longer term. The particular form of internationalisation strategies that firms may resort to in order to gain long term competitive advantage are not well understood and may depend upon on several contextual features viz. nature of IPR regimes, globalisation of financial markets and the particular policy regimes in place. But it may also be the case that acquisitions are evidence of a party's relative weakness and evidence of it compensating for its exclusion from alliances with stronger partners in the sector.

Clearly much more research remains to be done, but our study also has implications for a broader understanding of the strategies important in technological leapfrogging. In discussions of technological leapfrogging and capability building openness to trade and inward FDI are privileged as the vehicles of technological transfer, but our analysis of the strategies used by firms in two different historical periods shows that outward FDI can be useful as well. This may have implications for the host countries that receive such FDI, but our analysis has shown that it is not without historical precedent in technology intensive sectors such as pharmaceuticals.

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Appendix Tables

Table A1: Inward Direct Investment in the UK Pharmaceuticals Industry, 1919-1959

A. 1919-1940

	Parent	Entry	Home	Purpose	Mode	Notes/ Entry product
1	Lehn & Fink	1920	US	OTC	G	antiseptic (Lysol) & cosmetics
2	Colgate-Palmolive	1922	US	OTC	G?	toothpaste, soap
3	Kolynos	1922	US	OTC	G	toothpaste
4	United Drug	1923	US	OTC	A	toilet goods & proprietary medicines, acquired Boots. Divested 1933.
5	Mentholatum	1924	US	OTC	G	toothpaste
6	American Home Products	1927	US	OTC	A	toilet goods, toothpaste
7	Rhone Poulenc	1927	F	P	A	Acq. May & Baker c.£½m. Fine chemicals, biologicals & early sulfas.
8	Aspro Nicholas	1927	AUS	OTC	G	Novel aspirin, factory in Slough, expanded thru A into toiletries. P post WW2
9	Mulford	1928	US	P	G	Late entry into UK biologicals. Parent acq by Sharp & Dohme 1929
10	Ex Lax	1932	US	OTC	G	Laxatives
11	Lambert	1932	US	OTC	G	Listerine antiseptic, toothpaste, shaving cream
12	Warner	1932	US	OTC	G	toilet goods, cosmetics

13	Pepsodent	1932	US	OTC	?	toothpaste
14	Ponds	1933	US	OTC	G	Ponds Extract 'pain destroying and healing'.
15	Bristol-Myers	1933	US	OTC	JV	Laxative & toothpaste, maf by Boots after United Drug divestment. 1939 fdi.
16	CIBA	1934	CH	P	G+	Fine chemicals, following earlier fdi in chemicals (1911) & R&D (1919)
17	Abbott Laboratories	1937	US	P	G	Anaesthetics
18	Tangee	1938	US	OTC	A	Lipstick.
19	Gelatin Products	1938	US	P	G	Gelatin capsules for pills.
20	Tampax	1938	US	OTC/P	G	surgical tampons as minor sideline
21	Eli Lilly	1939	US	P	G	Antibiotics – entry at instigation of HMG
22	Geigy	1940	CH	P	G+	fine chemicals following earlier fdi in chemicals
23	Organon	1940	NL	P	G+	hormones following earlier fdi in Anglo-Dutch group.

B. 1945 - 1959

	Parent	Entry	Home	Purpose	Mod	Notes/ Entry product
1	American Cyanamid	1945	US	P	G+	Antibiotics from Lederle division, followed earlier fdi in chemicals.
2	Miles Laboratories	1947	US	OTC	G	Alka Seltzer & sedatives. Expanded via acquisition into dental products.
3	Roussel Laboratories	1948	F	P		
4	Squibb	1949	US	P	G	Antibiotics, HMG invited to acquire (ex Distiller's) factory in Liverpool
5	Johnson & Johnson	1949	US	P	G+	Surgical dressings, following earlier fdi in baby products (1928)
6	Foster McLellan	1950	US	OTC	G	medicinal products
7	Riker Laboratories	1951	US	P	?	pharmaceutical chemicals
8	Upjohn	1952	US	P	JV	Entered JV with Boots to manufacture antibiotics.
9	Vicks	1952	US	OTC	G	Vicks Vapo-Rub salve.
10	SB Penick	1952	US	OTC/P	?	Medicinal products (spermicide) and fine chemicals.
11	Pfizer	1952	US	P	G	Penicillin
12	Armour Pharmaceuticals	1954	US	P	G+	Hormones, followed earlier fdi in food and chemicals
13	Stafford Miller	1955	US	OTC	?	Dental fixatives
14	Smith Kline	1956	US	P	A	Fine chemicals & sulphas

15	TIC Gums	1957	US	P	G	Supplier for pill manufacturing
16	Merck	1957	US	P	A+	A Sharp & Dohme in 1953. A Thos Morsons 1957 fine chem. - sulphas
17	Wizard Lightfoot	1959	US	OTC		Corn pads, arch supports etc.

Notes: Parent is parent company name. Entry is year of entry into UK manufacturing (unless otherwise stated); this typically post-dated UK sales agencies. Purpose differentiates between 'P' for prescription medicines or specialised inputs, or 'OTC' for non-prescription medicines, toilet goods, cosmetics and so on. Mode of Entry is Greenfield ('G'), Acquisition ('A'), or Joint Venture ('JV'). Exit is year of divestment. Genuine withdrawals only recorded. Change of parent company within same country not recorded (e.g. Chas. Phillips acquired by United Drug in 1923, but UK subsidiary continued nevertheless). Exits within period recorded only.
The suffix '+' indicates an earlier entry in a non-pharmaceutical sector, thus CIBA entered UK manufacturing with a chemicals plant in 1911, but pharmaceuticals only in 1934 (listed below as G+). Notes mostly state the leading product for the UK market, or elaborate on the main purpose for entry.

Source: Database on historic FDI into UK manufacturing, retailing and banking. See Bostock and Jones (1994), Jones and Bostock (1996), Fletcher and Godley (2000), Godley and Fletcher (2001) and Godley (2003). Supplemented by additional research by author (see Godley and Leslie-Hughes 2007).

TableA2: Acquisitions by Indian Pharma firms: 1995-2006

Month	Year	Acquirer Indian Company	Acquired Company	Amount ($ MILLION)	Headquarter
September	1995	Ranbaxy Laboratories	Ohm Labs		USA
	1997	Sun Pharmaceuticals	Stake of 30 % in Caraco Pharm Labs	8	USA
March	1998	Wockhardt Ltd	Wallis Laboratory	9	UK
April	2000	Ranbaxy Laboratories	Basics, Germany-based generic company of Bayer AG	8	Germany
December	2001	Aurobindo Pharma Limited	60 per cent stake in Shanghai Wide Tex Chemical Co Limited		China
June	2002	Ranbaxy Laboratories	A brand called Veratide from Procter & Gamble Pharmaceuticals	5	Germany
September	2002	Ranbaxy Laboratories	10 per cent equity stake in Nihon Pharmaceutical Industry Co Ltd		Japan
March	2002	Dr Reddy's Laboratories Ltd	BMS Laboratories Ltd and Meridian Healthcare (UK) Ltd	13	UK
April	2002	Unichem	Niche Generics	5	UK
July	2002	Ranbaxy Laboratories	Liquid manufacturing facility from the New York-based Signature Pharmaceuticals Inc		USA
October	2002	Sun Pharmaceutical	Additional stake of 4 per cent in Caraco Pharmaceutical		USA
April	2003	Aurobindo Pharma Limited	The entire 50 per cent stake of Shanxi Tongling Pharmaceuticals Compar	4	China

			Ltd (STPCL) in a Chinese joint venture		
July	2003	Zydus Cadila	The formulation business of Alpharma France	6	France
December	2003	Ranbaxy Laboratories	RPG (Aventis) SA and its subsidiary OPIH SARL	86	France
July	2003	Wockhardt Ltd	CP Pharmaceuticals Ltd	18	UK
May	2003	Suven Pharmaceuticals Ltd	The assets of the New Jersey-based Synthon Chiragenics Corporation		USA
June	2004	Jubilant Organosys Ltd	80 per cent stake in two Belgium-based pharmaceutical companies - Pharmaceutical Services Incorporated NV and PSI Supply NV	16	Belgium
April	2004	Glenmark Pharmaceuticals	Laboratorios Klinger	5	Brazil
May	2004	Wockhardt Ltd	Esparma Gmbh	11	Germany
August	2004	Glenmark Pharmaceuticals	Two FDA approved products from Clonmel Healthcare Ltd		Ireland
December	2004	Nicholas Piramal India Ltd	The global inhalation anaesthetics (IA) business of Rhodia Organique Fir Ltd	14	UK
May	2004	Dr Reddy's Laboratories Ltd	Trigenesis Therapeutics Inc	11	USA
September	2004	Sun Pharmaceutical	Three brands from US-based Women's First Healthcare	5	USA
October	2005	Glenmark Pharmaceuticals	Servycal SA		Argentina
June	2005	Matrix Laboratories Ltd	Docpharma NV	263	Belgium

February	2005	Stides Arcolab	Additional stake of 12.5% in Strides Latina	6	Brazil
March	2005	Glenmark Pharmaceuticals	The hormonal brand, Uno-Ciclo, from Instituto Biochimico Indústria Farmacêutica Ltda	5	Brazil
July	2005	Nicholas Piramal India Ltd	17 per cent stake in BioSyntech, Inc.	7	Canada
September	2005	Matrix Laboratories Ltd	60 per cent stake in the Mchem group		China
June	2005	Torrent Pharmaceuticals Ltd	Heumann Pharma GmbH & Co Generica KG	30	Germany
August	2005	Sun Pharmaceutical	Valeant Pharma's manufacturing operations	10	Hungary
July	2005	Stides Arcolab	70 per cent stake in Beltapharm	2	Italy
November	2005	Dr Reddy's Laboratories Ltd	Roche's API unit	59	Mexico
July	2005	Stides Arcolab	A sterile manufacturing facility	8	Poland
December	2005	Glenmark Pharmaceuticals	Bouwer Barlett		South Africa
June	2005	Ranbaxy Laboratories	Efarmes Sa	18	Spain
April	2005	Dishman Pharmaceuticals & Chemicals Ltd	Synprotec Ltd	4	UK
October	2005	Nicholas Piramal India Ltd	Avecia Pharmaceuticals	17	UK
July	2005	Jubilant Organosys Ltd	Trinity Labs	12	USA

November	2005	Sun Pharmaceutical	Able Labs	23	USA
May	2005	Malladi Drugs and Pharmaceutical	Novus Fine Chemicals	23	USA
July	2005	Jubilant Organosys Ltd	64 per cent equity in Trinity Laboratories Inc and its subsidiary Trigen Laboratories Inc	12	USA
October	2005	Jubilant Organosys Ltd	Target Research Associates Inc	34	USA
June	2005	Stides Arcolab	60 per cent stake in Biopharma	1	Venezuela
March	2006	Marksans Pharma Ltd	Majority stake in Nova Pharmaceuticals		Australia
February	2006	Dr Reddy's Laboratories Ltd	Betapharm Arzneimittel GmbH	582	Germany
February	2006	Kemwell Pvt Ltd	Fizer's manufacturing plant in Sweden		Sweden
February	2006	Dishman Pharmaceuticals & Chemicals Ltd	51 per cent in IO3S Ltd		Switzerland
February	2006	Aurobindo Pharma Limited	Milpharm Ltd		UK
February	2006	Natco Pharma Ltd	NICK's Drug Store		USA
March	2006	Ranbaxy Laboratories	Patents, trademarks and equipmennt of Senetek's autoinjector business		USA
March	2006	Ranbaxy Laboratories	The unbranded generic business of Allen SpA, a division of GlaxoSmithKline		Italy

Source: Pradhan, JP and Alakshendra A (2006) "Overseas Acquisition versus Greenfield Foreign Investment: Which Internationalization Strategy is better for Indian Pharmaceutical Enterprises?", ISID Working Paper, No. WP2006/07.

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Notes:

[1] Pisano (1996) has pointed out that biotechnology process development does not have as rich a theoretical and empirical knowledge base as traditional chemistry-based pharmaceutical process development has. Even the most experienced bioprocess firms have a limited knowledge base to draw on. Thus, the biotech revolution may have made new entry easier and less dependent on existing patent holdings.

[2] For example the Htach-Waxman Act passed in 1985 in the USA.

[3] There was of course some overlap. Both Merck and Powers, Weightman and Rosengarten were subsidiaries of German producers, yet before 1914 had begun to experiment with novel products.

[4] The term ethical pharmaceuticals derives from the strategy of promoting products only to physicians and pharmacists and not direct to the public. The terms ethical and prescription are used interchangeably here.

[5] Hence the frequent references to laboratories in the advertising copy of the early US OTC firms were (perhaps confusingly to a present-day perspective) actually attempts to confer greater legitimacy on their shaving cream or toothpaste etc products.

[6] There was only one non-U.S. entrant – the French firm Roussell Laboratories – in the post-war population, compared with five in the inter-war period – Rhone Poulenc (F), Aspro Nicholas (AUS), CIBA (CH), Geigy (CH) and Organon (NL).

[7] The convention had been that licensees produced unlimited quantities of patented products, paying a standard 2½% royalty fee to the patent holder.

[8] Some of which later were to merge with the major pharmaceuticals firms (Chandler 2005).

[9] Space constraints do not permit similarly detailed discussion of Upjohn, Lederle, Sharp and Dohme and others. But all exploited international links to acquire key knowledge. See Godley 2000.

[10] For more details see Athreye, Kale and Ramani (2008), Table 1. The small scale sector in pharmaceuticals was also actively encouraged.

[11] R&D as a proportion of sales was about 2% for Ranbaxy in the 1990s – modest by world standards but quite large by Indian standards.

[12] Under this new law, manufacturers no longer had to go through a lengthy period of extensive clinical trials in order to market a generic drug - demonstration of bio-equivalence was sufficient to acquire marketing rights on the drug. Procedures were established for the resolution of disputes between branded drug manufacturers and generic manufacturers.

[13] Developed countries accounted for 50 of 142 projects (35%) with the most popular destinations being (# of FDI projects in parentheses): USA (18), Nepal (13), UK (12), Uzbekistan (9), Mauritius (8), Russia (6), China, Ireland, Netherlands and Thailand with 5 projects each.

[14] Out of the 127 greenfield projects between 1990-99, for which they have information on the nature of ownership, 64 are jointly owned and 63 are wholly-owned subsidiaries. Further, about 58 of these projects were for trading and marketing, whilst 53 were for manufacturing and 8 are for both manufacturing and trading.

[15] Appendix Table A2 lists the 52 acquisitions made by Indian companies in the 1995-2006 period.

[16] See Appendix Table A2 for this.

[17] See Pradhan and Alakshendra (2006), Table 13 for details.

[18] For more details based on case study evidence, see Kale et al (2006).

[19] Numbers from USPTO website updated to October 30, 2007.

[20] These estimates are based on research reported by Silico Research at the URL: http://jungle-research.com/analysis/emerging/briefing/biotechasia. [last downloaded 29 October 2007)