Creating Markets For Biotechnology

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INTRODUCTION

Much recent literature on biotechnology has focused on the supply side. Discussions have concentrated either on technological opportunities and applications, which include genetically engineered crops and drugs, diagnostic kits, new search methods in R&D or new approaches to waste treatment; or on organisational change in the firms commercialising biotechnology - merger, demerger, acquisition, divestment, collaborative alliances and the appearance of new firms (Walsh, Ramirez and Tampubolon 2000; Walsh and Lodorfos 2002).

In the face of the new technology and increased globalisation, the chemical and related products industry[1] might be said to have reinvented itself in two stages. First it changed its boundaries and formed two industries: one based on traditional chemicals and synthetic materials and the other based on life sciences, including agrofood and pharmaceutical products. The demerger and divestment of life sciences activities from traditional chemical activities was been followed by a new wave of merger and acquisition within each of the two new groupings, to consolidate market share and move into new markets. The second stage, still underway, has been a futher separation of the life sciences sector into pharmaceuticals and agro-food, via a further round of demerger, divestment, merger and acquisition.

Rather less has been written in the social sciences about the demand side of biotechnology innovation, although the mass media has given considerable attention recently to the opposition of consumers in Europe (though far less so in North America) to genetically modified food (Gee 2000), and the opposition of farmers in poorer countries to genetically modified and especially sterile seeds (Vidal 1999), which this paper discusses later. I have accordingly focused more on the demand side of biotechnology, and in particular on the creation of markets and of demand for agro-biotechnology in the late 1990s.

In neo-classical or standard economics, markets and market signals play a primary role in the allocation of resources and in decisions made about technological change. Neo-Schumpeterian or evolutionary economics, in contrast, places more emphasis on supply-side factors such as entrepreneurship and firm capabilities. It stresses the role of the firm, as an actor which will take risks, which goes through a learning process, and which develops strategies based not solely on 'objective' knowledge, but also influenced by its own culture, ethos and guiding philosophy, rather than one which is able to take profit-maximising decisions based on knowledge of (future) prices of inputs and outputs.

This paper is certainly in agreement with the latter approach rather than the former, but takes the view, firstly, that evolutionary economics tends to neglect the demand side, and in particular the environment in which products succeed or fail. The neo-Schumpeterian tradition (Nelson & Winter 1982) has a name for this - the Selection Environment - but research within its framework has tended to focus more on the study of supply side factors. In re-focusing on the demand side this paper does not in any way embrace a neo-classical perspective, but seeks to develop a better understanding of the concept of the selection environment.

Secondly, the analysis presented here explores a *rapprochement* between economics and other social science disciplines, notably sociology and anthropology. In a sense the concept of the selection environment does this already, since a selection environment includes not only markets but also non-market factors (e.g. government regulation, government and industry standards, and professional recommendation), which may determine the nature and extent of a market, or indeed whether or not a market will exist; factors which have been particularly important in biotechnology. Such an expanded concept of the demand side may be said to incorporate into economics ideas about behaviour and culture (the province of sociology and anthropology) and motivation (the province of psychology).

My purpose in this paper is to explore the evolutionary economics concept of the selection environment, from a perspective informed by ideas from the disciplines of sociology and anthropology, as a framework within which to analyse and understand markets, users and the demand side, and their influence on innovations in biotechnology as they continue to

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unfold and diffuse. I have drawn in what follows on interviews conducted at various times with specialist biotechnology firms and chemical and agro-food multinationals and discussed at greater length elsewhere[2]

THE TAKE-OFF OF BIOTECHNOLOGY

The commercialisation of biotechnology by a wave of new firms created to exploit advances in (mainly) public sector research has been widely reported. So, indeed, has the fact that, despite its revolutionary scientific foundation, biotechnology has been gradually assimilated by the dominant firms rather than leading to one or several waves of significant numbers of new entrants growing to large firms as in information technology (Chesnais & Walsh 1998), while new firms continue to be created to commercialise new waves of discovery in biotechnology.

The established chemical firms might, in principle, have been pushed aside by these new entrants commercialising an entirely new technology in the established firms' traditional markets and destroying their competencies. But many of the chemical firms have been around a very long time[3] and have survived successive waves of innovation as they did in this case, and indeed have been responsible for some of them. This time, when innovation came from elsewhere, the chemical firms established alliances with the independent firms, providing the complementary assets and skills needed by the small firms to exploit their technological knowledge commercially. At the same time the established chemical firms used the collaborative work as a means to develop their own competencies in the new technology.

For their part, the small firms were willing to enter these alliances for two reasons: (1) they lacked skills and experience in manufacturing, clinical trials, regulatory compliance, promotion and distribution, and (2) many of the expected commercial opportunities were a long time in coming to fruition as demand remained only a potential for much longer than anticipated, *and markets had to be created*, the main theme of this paper.

The established firms' investments in the life sciences increased in the 1970s and 1980s. By the late 1980s the firms which had developed biotechnology competencies in pharmaceuticals, health diagnostics and enzymes, consolidated their positions with major investments in those areas and began to gain regulatory approval for, and market, the resulting products. Diagnostics were the first biotechnology products to reach the market, requiring less stringent regulatory approval, followed by genetically engineered human hormones (such as insulin and human growth hormone) used for medical purposes. Meanwhile the firms which had pursued agricultural opportunities came to the conclusion that commercialisation in this area was longer term and more risky. Many of them (e.g. Bayer & Hoechst) reduced their biotechnology investments to maintaining 'windows on opportunity' by alliances with specialist firms, and reinforced their positions in traditional agrochemicals.

A few agrochemicals firms, however, had diversified downstream into seeds and had acquired a position in the seeds market, and skills in traditional plant breeding as well as in genetic engineering. The 1980 decision by the US Supreme Court in *Diamond v Chakrabarty* that "a live, human made microorganism is patentable subject matter" as long as it meets the criteria of novelty, utility and non-obviousness, and as long as it is a product not of nature but of human manufacture (Kloppenburg 1988: 261-2) paved the way for the patenting of genetically engineered plants. This decision was the result of General Electric's appeal against the US Patent and Trademark Office's rejection of an application for a patent on an oil-degrading micro-organism developed by GE scientist Ananda Chakrabarty.

Ciba, Sandoz (since merged to form Novartis) and ICI (subsequently Zeneca Agrochemicals and then Syngenta[4]) are the major firms which strongly invested in this area, although in the early 1990s they were still expressing caution, for example saying in interviews that they were not planning the commercial launch of any genetically modified crops for the time being. However, in practice, the first field trials of a GM crop (virus resistant tobacco) had started to be held in 1986, in the USA and France (Tampubolon 2000). Monsanto is arguably the best known producer of GM crops as a result of its advertising campaign of the late 1990s and subsequent media coverage (discussed below); however, despite its investment in a research programme in agrobiotechnology in the 1980s, Monsanto did not follow the path taken by ICI, Sandoz and Ciba by moving into seeds and plant breeding, either in terms of organic growth of research or acquisition of firms with the desired competences and markets, until the 1990s. Its patents in agrobiotechnology did not begin to take off until the early-mid 1990s, and indeed its move out of traditional chemicals into higher value-added products took place initially via a move into pharmaceuticals, like that of the majority of chemical firms (Walsh & Lodorfos 2002: 279, 281 & 295).

From the late 1980s, events began to move fast, so that all the leading agrochemicals producers, Bayer, Novartis, Du Pont, Hoechst (now Aventis)[5], Monsanto, Rhône-Poulenc (now Aventis) and Zeneca (with 60% of the world market between them) were producing genetically engineered crops by the mid-1990s (Nottingham 1998), and in three years, the amount of acreage planted with them went from negligible to an area the size of Britain (*New Scientist* 1998). The inflection point in the graph (see Fig 1), or takeoff year, of the number of field trials world-wide occurred in 1992 (Tampubolon 2002). In the same year China planted more than 2 million acres of virus resistant tobacco. In 1994 Calgene (since bought owned by Monsanto) launched the Flav^{r}Sav^r ™ tomato. By 1998 more than 5000 field trials were being held involving 60 GM crops, more than 60 countries and about 75 million acres (*Ibid.*). The introduction in the USA in 1993 (and elsewhere soon after) of a fast track system for granting release permits for planting GM crops, considerably speeded up the process of takeoff of innovation in GM crops.

The main features genetically engineered into crops include resistance to herbicides (often but not always the firms' own), resistance to insect pests, and enhanced nutritional properties (e.g. high polyunsaturated oil content) or properties which increase shelf life, automatic handling and value to weight ratio (e.g. low water content). Table 1 lists these in more detail. Another new market has been created for neutraceuticals: these are foods with beneficial health effects, such as grapes which help to reduce heart disease, tomatoes that help control prostate problems, broccoli which helps protect against cancer, and alfafa to resist tooth decay (Radford 1997).

Table 1 Examples of Properties Genetically Engineered into Crops
to 1998 inclusive

Agronomic properties	**Product Quality**
49 categories including	**79 categories including**
Altered maturing	Altered amino acid composition
Cold tolerant	Bruising reduced
Drought tolerant	Antioxidant enzyme increased
Fiber quality altered	Delayed softening
Growth rate altered	Dry matter content increased
Modified growth characteristics	Fiber quality altered
Nicotine levels reduced	Fruit firmness increased
Yield increased	Fruit ripening altered
Stress tolerant	Fruit sweetness increased
	Fruit solids increased
Bacterial resistance	Nutritional quality altered
12 categories	Oil quality altered
	Prolonged shelf life
Fungal resistance	Protein quality altered
42 categories	Seed size increased
	Rust resistant
Herbicide tolerance	Yield increased
11 categories	
	Other
Insect resistance	**29 categories including**
21 categories	
	Altered plant hormone levels
Marker gene	Antibiotic produced
12 categories	Industrial enzyme produced
	Novel antigen produced
Nematode resistant	Novel protein produced
5 categories	Polymer produced

Source: Gindo Tampubolon, (2002)

A convergence of biotechnology and information technology has produced a raft of new techniques, including combinatorial chemistry, rapid throughput screening, and computer-aided molecular design, which have automated parts of the R&D process and enabled the design of molecules for specific end-uses. Initially applied in the pharmaceutical industry, often as a result of the collaboration between small specialist firms (e.g. Affymax in the USA[6] and Cambridge Combinatorial in the UK[7]) and large drug companies, the new search processes have since been applied to the discovery of new agrochemicals (see for example AstraZeneca 2000) designed to kill specified pests and new catalysts designed to generate polymers with specific properties. Genetic engineering for the production of chemicals, building materials, plastics, fibres and new sources of energy from renewable resources has been forecast for years (e.g. OECD 1989; Rifkin 1998); but since the mid 1990s firms have actively developed, for example, a genetically engineered cotton plant that can produce polycotton fibres while Monsanto's Blue Jeans project obtained blue lint from cotton plants (Nottingham 1998).

THE SELECTION ENVIRONMENT FOR BIOTECHNOLOGY DEMAND

In turning now to the selection environment for GM crops, which determines whether or not they will succeed commercially, I start by considering the nature of demand for this area of innovative activity. In everyday English innovation is taken to mean a novelty or a new way of doing something. In the social studies of science and technology it is usually used in the sense given to it by economists Joseph Schumpeter (1912) and Christopher Freeman and Luc Soete (1997: 6), that is an invention[8] which has been launched on the market and has been the object of a commercial transaction, or has been adopted into the social fabric in some other way (e.g. a new medical technique which has been adopted without a commercial transaction necessarily having taken place). In other words, the idea of an innovation captures two notions, technological novelty, and commercial transaction (or other adoption into practice) - contributions of both the supply and demand sides[9]. It also allows for the possibility that innovations may be failures as well as successes. (This paper uses the term 'innovation' to mean 'technological innovation'; other kinds of innovation are qualified, as in 'organisational innovation'.)

Early debate in the innovation literature about the relative importance of demand-pull and discovery-push forces in stimulating innovation (e.g. Walsh 1984) resolved itself around a consensus that innovation is in fact a coupling process between technical possibilities or opportunities and market demands or opportunities[10], though at different times in the life-cycle of a technology or industry one or other might be the prime mover. Radical innovation, in particular, is more likely to be initiated by the supply rather than demand side. But if any innovation is to be a success, radical or otherwise, there must be customers who are willing and able to do so.

A potential innovator might be expected to find out who are likely to be customers of their innovation, and how the innovation might best be adapted to meet their needs. Some social science research suggests, however, that managers and innovators often believe they intuitively know what their customers want (e.g. Akrich (1995). In any case, radical innovations may be so different from potential customers' experiences that they do not necessarily realise that they have needs which the innovation might meet (Miles 1993; Miles, Cawson & Haddon 1992).

At the same time innovators may not have a very clear idea about which the most promising markets will turn out to be. Traditional market research is not very helpful where a new product or process departs substantially from what is reasonably familiar to potential customers. Marketing becomes 'existential' (Littler and Leverick) and innovators take what anthropologist Lucy Suchman (1987) and others call 'situated actions', that is, actions which have to be adapted to the unforseeable contingencies of particular situations. The innovator is unable to shape or adapt the product or process to the needs of a target customer. Where innovations are radical, a market in the usual sense may not exist, but may have to be *created.* Michel Callon (1987), a sociologist with an engineering background, writes about 'engineer-sociologists', that is engineers acting as sociologists (or economists), who not only make inventions but invent social and economic environments in which they can be successful, and then continuously seek to mould their (real) environment accordingly, rather than just introduce new artefacts into a pre-existing environment on which they then have some impact.

In the early days, there was no market for the various applications of biotechnology, though *potential* demand existed in the form of a variety of problems in need of solutions that the developers of biotechnology believed they could provide. The existence of various illnesses and medical conditions, for example, may represent a potential demand for drugs to treat them - although in practice the solution may not be a drug at all, but the reduction of pollution or provision of clean water. In any case such a potential demand is not the same as a market signal, though it may be a motivation for key actors.

The gap between the belief that the existence of a medical condition was an indication of a potential demand for treatment, and the actual demand that materialised when a product or service becomes available, was illustrated by Ken Green (1992) in the creation of markets for diagnostics by the active intervention of the innovators. World hunger could be said to represent even less a demand for genetically modified foods, even though Monsanto was quoted in the late 1990s as saying 'ask how you're going to feed the world' in reply to public opposition to GM foods (Vidal & Milner 1997). It certainly is not a market signal for them, since poverty is a major factor in lack of adequate food. The entrepreneurs and investors who first tried to commercialise biotechnology discovered that they had grossly misjudged the time scale within which returns could be realised and the conditions underwhich demand would be sufficient for commercial viability.

USERS AND CONSUMERS

Having discussed the concept of 'demand', let us now turn to the users and consumers of innovations, and especially of innovations in agro-biotechnology. Von Hippel and colleagues (e.g. von Hippel 1988; von Hippel and Tyre 1995) have written about users as prime movers in the innovation process, and Lundvall (1988; 1995) has argued the key role of user-supplier interaction in the success of innovation. Collaboration in the development stage between a producer of an innovation and its lead users can be very important. Indeed, users may be as innovative as producers of innovations since they may have to adapt a new product, or adapt their own procedures. Some innovators create markets, customer loyalty and 'lock-in' by providing technical services and training to customers of radically new products[11]. In biotechnology, collaboration between suppliers and users of the technological knowledge, or of innovative, biotechnology-based tools and diagnostics, has been important in commercial success of innovations and the survival of new firms. So has interaction between innovators and experts who test biotechnology-based products and subsequently recommend them to end-users.

Any technology which has or is seen to have moral or ethical implications can generate public concern, and aspects of the demand side of biotechnology can be highly politicised. Consumer reaction against genetically modified foods, the lobbying of government bodies by multinationals, and concern about the ethics of aspects of human reproductive technology, are all examples. Campaigning and pressure groups (such as Greenpeace, Friends of the Earth, consumer organisations, 'right to life' and 'right to choice' groups) are in a position to play a significant role, while the media not only reflect but also influence public opinion, and hence play their part in market shaping.

Monsanto adopted a strategy of first commercially launching GM crops which were bulk commodities and would blend seamlessly with traditional varieties as they entered the processing and export pipeline (Morse 1996). Multinationals in general expected that the application of genetic engineering to food would be welcomed by the public for their beneficial effects for crop production and the environment. US consumers accepted the new technology fairly readily, but firms were surprised to learn that many consumers in Europe regarded GM food as contaminated. Firms thought that all that would be necessary would be to provide the public with facts and logic to convince them otherwise (Nottingham 1998) and Monsanto, in particular, launched an advertising campaign in the summer of 1998. Advertising is a traditional method of creating markets, but this particular promotional activity proved to have the opposite effect: it increased resistance to the new technology as it increased awareness of it.

Promotional material claimed that the new technologies were environmentally friendly, and would lead to health benefits, an end to world hunger and reduced use of pesticides. Monsanto's advertising campaign, for example, said that GM foods meant higher yields and lower chemical treatments. They found, however, that 'people's concerns are not based on science or economics. They're based on a gut feeling that there's something dodgy about these foods.' (Greenberg 1998a)[12].

Monsanto commissioned a survey of public opinion in Britain and Germany before and after their advertising campaign, focusing on several different groups: the general public, social classes A and B, the press, retailers, and MPs and Civil Servants. In Britain, the public were found to be skeptical of science (*ibid*). They were generally without confidence in the food chain, in scientists, in government, and in British or European regulatory authorities, primarily as a result of 'mad cow disease' ('stating that seed had been approved by British food safety agencies *reduced* support for our products' [*ibid*, emphasis added]). The media were sceptical or even hostile. And the name Monsanto was well known to the public and explicitly associated with the unwanted products ('those dreadful people with that f---ing long name, whatever it's called, Monsanto' and 'they used bullying tactics, really. Used their might to bulldoze it through.') (*ibid*).

Customers for innovative foods are not only the end consumers who eat it, but also the retailers who decide what to stock and what to promote to the public, and consequently make a crucial contribution to market demand. The retail sector's stance was not so much about safety as about consumer demand (Wrong 1999a). They were particularly critical of Monsanto whom they saw as having 'foisted [GM foods] upon us', having left retailers to reassure the public, and having removed the possibility of giving consumers a choice. 'They didn't care, didn't want to help' (*ibid)*. In 1986, both European food retailers and Greenpeace began to campaign against non-labelled imports, and consumer organisations were advising caution towards GM foods, fearing that scientific, ethical and social concerns were being swept aside. They were all critical of the fact that decisions were being made on behalf of consumers with minimal public debate. EuroCommerce, which represents the wholesalers and retailers, urged US grain companies to segregate GM from non-GM products. At that time Monsanto claimed this to be physically and economically impossible (Maitland 1996), and in general it continued to shrug off protests at this time.

Whereas in the USA the more highly educated and upper socio-economic groups 'helped forge the way for biotechnology', in the UK they were found to be even more hostile than the general public. Seventy percent of Members of Parliament and civil servants, while themselves reacting positively to GM foods, showed a strong negative reaction to the way in which Monsanto introduced them ('absolutely appalling' and 'arrogant' were among the comments quoted by Stan Greenberg [1998a]). In summary, the Monsanto advertising campaign, which had cost the firm £1 million, 'was overwhelmed by the society-wide collapse of support for genetic engineering in foods' in 1998 (*ibid*). That year saw a major upsurge of hostile public opinion in Europe to genetically modified products in food.

Firms we interviewed in the USA in the same year were not yet faced with similar concerns from the American public, and commented that Europe's move towards requiring the labelling of genetically modified foods 'could really disrupt trade' or indeed that firms in European biotechnology markets could be facing 'a major trading disaster'. The reports to Monsanto discussed above were leaked onto the internet by Greenpeace in November 1998, revealing the 'extreme hostility' and 'collapse of public support for biotechnology and genetically modified foods' (Greenberg 1998 a & b), in both Britain and Germany. The hostility towards GM foods was even greater in Germany than in Britain.

Meanwhile other firms in the business, such as Zeneca and Novartis, were busy distancing themselves from Monsanto's strategies, both in GM food promotion (to which they attributed the consumer backlash (Coughlan 1998)) and in limiting the sales of Roundup Ready™ crops to users of their herbicide Roundup™, although these crops are also resistant to other herbicides. There was also opposition to Ciba's corn-borer resistant maize, but tomato paste using Zeneca GM tomatoes had been sold for a few years in UK supermarkets, clearly labelled and apparently without opposition (Maitland 1996)[13]. UK supermarkets Sainsbury and Safeway labelled tomato pastes made with Zeneca tomatoes, so shoppers knew what they were buying and could choose something else (though tomato paste containing GM tomatoes appears to have since been withdrawn). Monsanto's advertising campaign, however, *alerted* the public to the fact that they in fact had no choice - and possibly no knowledge - about the inclusion of GM soya and other products in all manner of unlabelled foods, and to add insult to injury the firm was telling them it was a good thing.

Europe's early opposition - compared with the USA - to GM foods has been attributed to the public's inability to trust what politicians, scientists or representatives of the food industry said about food safety, in the light of misleading statements during a succession of food safety scares, such as those about salmonella in eggs and chickens, listeria in cook-chill meals, and above all BSE in beef (Nottingham 1998; Gee 2000). Environmental concern, for example about 'gene hopping' has also been expressed and this, too, seems to be more an issue in Europe than the USA. Smaller farms, smaller fields, closer to each other, and high population density in Europe may have contributed to this. Opposition to 'meddling with the processes of life' has also been present, though no more so in Europe than in the USA. The latter concern seems to have been overcome in relation to the development of drugs for saving life or alleviating serious chronic medical conditions (Maitland 1996), although other medical treatments where ethical issues are more to the fore, such as those concerning human reproductive technology, are still the subject of widespread public unease, and this is at least as much the case in the USA as in Europe.

This section has considered the role of consumers and users as actors in the demand for agro-biotechnology products and services, arguing that there are a number of different actors along the value chain, and that these actors not only send (or do not send) market signals in the conventionally accepted way, but also contribute to the creation and shaping of markets in various ways. As discussed earlier, evolutionary economics has expanded the concept of the market into that of the selection environment, which includes the system which regulates what may or may not be marketed, and intermediaries who prescribe and recommend products on the market. These will now be explored in the next section.

THE REGULATORY ENVIRONMENT AND INTERMEDIARIES

The non-market parts of the selection environment are particularly relevant in understanding the success and failure of biotechnology-based products and services. Regulations covering drug and food safety and environmental protection affect the market for biotechnology, while professional experts in the field of medicine, nutrition, agriculture and ecology carry out trials and prescribe or recommend products. Firms consider it necessary - and worthwhile - to lobby law and policy-makers and to direct promotional material at the professionals and experts.

In the early 1990s, for example, the Council of the Chemical Industries in Europe (CEFIC[14]) had a Senior Advisory Group on Biotechnology (SAGB), made up of representatives of all the large firms in the industry with biotechnology interests. This group had the task of producing information and lobbying the European Parliament and other decision makers to encourage them to take decisions that were as close to the interests of the industry as possible, especially concerning environmental, product safety, intellectual property and other regulations governing biotechnology based products, processes and services (e.g. SAGB 1990). The 'fast track' for notification of releases of GMOs in field trials and commercial planting, a consequence of public policy in this area, has also affected the rate of growth of the market for the products.

We have reported elsewhere (Walsh, Ramirez & Tampubolon 2000) that the building of international inter-firm / inter-organisational alliances, in relation to pharmaceuticals, has been motivated by firms' need to tap into and embed themselves in the different national systems of innovation, not only for supply-side reasons (e..g. best utilisation of the science and technology infrastructure, tax breaks and other favourable government policies), but also for demand-side reasons. By becoming recognised as an established part (and 'good citizens') of the countries in which they sell their products, firms may shape and influence their selection environment, notably by influencing the policies of governments that affect markets, prices and regulatory régimes, as well as carrying out the more traditional activities of establishing links with lead users and complying with regulatory requirements that necessitated local trials. The drive to commercialise genetically engineered foodstuffs, in particular, has involved heavy lobbying of trade organisations, regulatory bodies, law makers, the media and consumers (Vidal & Milner 1997).

The intense lobbying and advertising by the agrofood industry has, however, rebounded on it, as discussed above, and although governments in Europe have generally been more willing than their citizens to accept GM foods - the EU approved US imports of soyabeans containing GM varieties in April 1996, for example - public pressure has had its effect. EU policy in the late 1990s was influenced by two main concerns - lack of consumer choice, generating calls for labelling and the separation of GM from non-GM foods; and environmental safety as expressed in the danger of creating weeds resistant to pests and herbicides, or the harm to beneficial predators of crop pests.

Even the US government began to feel the pressure. The British press had been critical, as noted in the previous section, but until the spring of 1999, food biotechnology still had broad support in the USA. A special report by *The Guardian,* serialised over several days at the end of 1997, had reported a 'revolving door between the US government and the biotechnology industry'; 'heavy lobbying', and 'use of the world's leading PR firms' to 'massage debate' and 'rewrite world food safety standards' in favour of biotechnology; 'legal contracts locking farmers into corporate control of production'; 'consumers being given no effective choice of foods'; and 'use of world organisations to challenge governments opposing GM crops'. Both 'Wall Street and the White House' were said to favour Monsanto (Vidal 1999), whose income had grown 28% since the previous year, and whose CEO was saying that the launch of GM crops was the most successful of any technology, ever. This was the year *after* the very negative report on public acceptability discussed above - clearly Monsanto were hoping to ride the storm, having dismissed social and ethical criticisms from environment, church and consumer groups (*ibid*).

But less than two years after *The Guardian's* special report, *The Wall Street Journal* wrote in April 1999 that the GM controversy was beginning to be felt in the USA. By May 1999, even the US Secretary of Agriculture warned 'of profound consequences' and suggested voluntary labelling. The US grain industry reported that it had nearly stopped shipping to Europe: by the summer corn exports had gone down by 96% and the first GM crops in the USA were being destroyed by environmental activists.

INTERACTION WITH THE SUPPLY SIDE

Economic analysis does not really allow for an interaction between the supply and demand sides, other than in the market place. However, some degree of selection may be made by managers and R&D staff in the innovating firm (normally considered to be part of the 'supply side'), on the basis of what is likely to work, or to be accepted by customers. Thus a degree of interaction or even blurring of boundaries exists between the supply and demand side (Chesnais and Walsh 1994). This is an area more within the scope of sociology of innovation, and some sociologists working in the framework of actor-network theory (e.g. Akrich 1995, Mangematin & Callon 1995) have suggested that there is a simultaneous construction of a product or a technology and the market for it. For example, a prototype is tried out with lead users, who adapt it to better meet their own needs and provide feedback to the innovator who makes the necessary adjustments. At the same time the lead users may also adapt their own practices, relationships and related products to make better use of the prototype, while enlisting new potential users by a demonstration effect. In this way they create and shape the market at the same time as modifying the technology, and there is a blurring of the distinction between 'early adopters' and 'late designers'.

Table 2

Elements of the Selection Environment for Biotechnology	The role they play
Pharmaceuticals & diagnostics	
Health care providers (organisations)	Recommend drugs, use diagnostics
State or private health insurance	Pay for drugs, diagnostics; may influence which products are sold by determining which will be paid for
Pharmacists	Sell over the counter drugs & diagnostics; stock others for supplying to a prescription
Medical profession	Conduct clinical trials; write prescriptions; use diagnostics; advise regulatory bodies
Government regulatory system	Determines whether a new medicine is safe, efficacious and represents an advance in treatment over existing products
Patients	Consume products
New methods for design and discovery of new molecules	
Researchers, laboratories	May buy in, develop themselves or acquire via collaborative alliance with firm developing the techniques
Genetically modified crops	
Farmers	Buy seeds, grow crops
Food processing firms	Buy foods and additives as raw materials for canning, freeze drying, freezing and preparing ready-to-heat meals; preparation of 'processed' foods and products such as TVP, Quorn. Buy diagnostics and testing devices for unwanted micro-organisms.
Supermarkets	Buy from food processing firms, farmers and markets; decide what to stock and hence what consumers may buy; what to permit in 'own brands'; important pressure group for lobbying e.g. over labelling
Greenpeace, consumer organisations and other public interest groups	Campaign on consumer choice, public health and safety, environmental protection, labelling, openness in decision-making and government regulations; provide information; may carry out independent tests of products & services
People who buy and eat food	The end user – consumes the products; may or may not have made an informed choice
Citizens	Vote for representatives who support particular policies; campaign on all manner of issues; may demand more openness in decision-making
Government regulatory bodies	Examine evidence that new products meet product and environmental safety standards; may carry out tests themselves; negotiate with firms to establish the tests that they need to carry out or other actions required for regulatory compliance
Agricultural research establishments	Carry out research; recommend products and techniques
Nutritionists	May carry out research; recommend products
Research Foundations	Fund research; inform the public; influence many of the main actors
IPR regime	Allows market to exist; allows monopoly profits to be made (possibly for a temporary period); encourages innovators to innovate

This kind of adjustment between the demand side and the supply side, however, works better with an innovative product or system where lead users can actually work with, and adjust, a prototype - for example, a road guidance system (the case study used by Mangematin & Callon), or a telecommunications system (Akrich's example). Users of biotechnology tend to have a different relationship to the innovation and to the innovator than is the case with such mechanical and electronic examples, and do not modify the product to suit their needs in the same way. Various users and stakeholders along the supply chain (such as supermarkets, farmers, agricultural research institutes, health care services, food processing firms, doctors, regulatory bodies, pharmacists, waste treatment organisations, final consumers and public interest campaign groups, see Table 2) have a role in shaping the products and services that biotechnology supplies, typically by making demands on the supplier, rather than playing the part of 'lead users' in the way that users of IT products and services, for example, might do. They also shape markets by their own acceptance, recommendation, opposition, reassurance, raising concerns or campaigning, as the case may be.

Meanwhile, as we have seen in the case of GM foods, suppliers have also been rather more active in trying to create a market for the new products than is often the case, and have resorted to lobbying and propaganda as well as advertising and market research. Innovators, even established firms with a great deal of experience, can sometimes wildly misjudge potential markets. In an area where ethical issues are important it is even easier to misjudge public opinion, and the agrofood industry, especially Monsanto, seems to have succeeded in the late 1990s in what would normally be a nearly-impossible task: it unified (in opposition) the various stakeholders or elements of the selection environment. End users, farmers, retailers, wholesalers, government bodies, consumer organisations, environmental organisations and the press were all drawn, to a greater or lesser extent and some only temporarily, into the network of opposition to the new technology.

DEVELOPING COUNTRIES

The case of GM crops in economically less advanced countries further develops some of the points already made about demand, the creation of markets, and the politicisation of the whole process. Genetic engineering is a highly competitive business and the focus of biotechnology companies has been on developed country markets where potential sales are large, patents are well protected and the risks are lower. However, agrofood firms frequently legitimate genetic engineering of food by asserting that they provide the means to overcome world hunger and malnutrition, through provision of the technology for breeding pest-resistant crops. This social need, however, is not likely to translate itself into market demand, since vast numbers of poor farmers are in no position to buy the new patented seeds, unless United Nations or charitable organisations are able to subsidise them or the biotechnology firms reduce their prices. Otherwise GM crops could add to, not solve, world hunger as millions of small farmers who are without access either to the technologies or to global markets, would be unable to compete.

GM crops are produced more widely throughout the world than other biotechnology products (drugs, for example). Table 3 shows that Argentina and China are among the top 10 growers of transgenic seeds. In the USA transgenic soya and maize represent 40% of total plantings; in Argentina 70% of soya is transgenic. But this is not necessarily going to eradicate hunger. Brazil is the world's second largest producer of soya, but resisted GM crops for a long time. Monsanto invested $550 million in 1998 to build a factory in Brazil to make their herbicide Roundup, and Roundup Ready soyabeans became the first genetically engineered crop to be approved by the Brazilian government. But the vast numbers of rural Brazilians who are subsistence farmers do not grow soya: that is grown by the big landowners, and is used to feed beef cattle for export (Mack 1998). The growth in demand for non-GM soya in the wake of public opposition to the transgenic version might have offered a market opportunity to Brazil, as a large producer which had not gone very far towards embracing the new technology. But this would not necessarily help the poor either, if it is the large landowners who grow soya.

Table 3

Country	Cumulative No of Field Trials 1986-1995
USA	1,952
Canada	486
France	253
UK	133
The Netherlands	113
Belgium	97
Argentina	78
Italy	69
China	60
Germany	49

Source: Gindo Tampubolon, 2002

The claim that biotechnology will enable the third world to feed itself has to take into account the complex social and economic factors that contribute to hunger. Is it due to not enough food being produced, or to the exclusion of some of the hungry from access to the food that is produced? Feeding the world is a complex question that is largely outside the scope of this paper or the competencies of this author. I shall therefore limit myself to asking some questions. For example, exactly which properties are in practice being bred into crops using the new technology, directed at which markets and in whose interests? How many staple foods are being bred to withstand adverse soil, climate and other conditions in poor countries, compared to the breeding of 'exotic' foods that may be grown in industrial countries? Or compared to the breeding of crops for automated farming practices, increased value to weight ratio or otherwise to satisfy farmers or food processors in the richer countries? Is biotechnology, in the form of cell culture or tissue culture, currently being used to propagate crops native to developing countries outside those countries, rather than to enable those countries to grow food for themselves?

The experience of the terminator gene and Monsanto does rather suggest that feeding the third world was not that firm's primary goal in developing biotechnology. The company invited Gordon Conway, president of the Rockefeller Foundation and an agricultural ecologist, to address a meeting with Monsanto board of directors on July 14th 1999. This was part of a commitment they had made to consult more widely, following the GM furore in Europe the previous year. Conway is a supporter of the view that biotechnological techniques are necessary to feed the world, especially in 20 or more years' time, and believes that health concerns may be overstated[15], although he is concerned that the agrobiotechnology multinationals will monopolise patents so that the poor cannot afford them. (He proposes public-private partnerships, if developing countries are to benefit [Conway 1997]). However, the Rockefeller Foundation had invested more than $100million in GM crop research & Monsanto expected Conway to be more of an ally than otherwise. But in his speech he deplored the company's style and global strategy. He said that they had alienated millions and threatened trade war and long term damage to the prospects of the poor. That the firm had a reputation for arrogance and secrecy, and was seen as responsible for meltdown in confidence in science and big business, and for a backlash against US agriculture (Vidal 1999).

He referred in particular to the terminator gene, which makes crops produce sterile seeds. It was heralded as the solution to environmental fears since crops with the terminator gene could not reproduce. But poor farmers would be in no position to keep buying seed every year - typically they save some from the harvest each year for re-planting. The significance of this speech, and especially the fact that the Rockefeller Foundation had issued a press release containing its main points, so that it became public very quickly, was that a monolithic corporation was being held up to public accountability by someone with far more authority with Monsanto or the industry than Greenpeace or the Consumers' Association, and who could not be accused of opposition to biotechnology or to big business in general. However, the various campaigns and actions of Greenpeace, the Consumers' Association and other such groups, not to mention consumers themselves and poor farmers in some of the developing countries where GM crops were being planted or planned, laid the basis on which the Rockefeller Foundation's criticism could have meaning and impact. Within three months, Monsanto finally admitted (in a speech by satellite link by CEO Robert Schapiro to the Greenpeace conference in London) that it had lost the public relations war by appearing arrogant and condescending (Wrong 1999b). US executives of the company held talks with Greenpeace and other environmental groups, and finally made the formal pledge not to commercialise terminator technology. The following year, in a further move towards improved public relations, Monsanto placed in the public domain the data it had assembled on the rice genome (Monsanto 2000).

INTELLECTUAL PROPERTY RIGHTS

Intellectual property rights are an important part of the infrastructure for innovation, but would normally be associated with the supply rather than the demand side, as they are designed to encourage inventors by ensuring that they can benefit from their discoveries and their investments. This paper argues, however, that the intellectual property rights (IPR) régime also affects the demand side in an important way. Patent protection, in allowing a firm to have a monopoly and therefore charge monopoly prices (if only temporarily) encourages the establishment of a market for the invention. It may also encourage a market in the patents themselves, in the form of licensing and various cross-licensing arrangements. And freely available technology may not be implemented at all, if a firm cannot protect its ability to generate a revenue from its discoveries, e.g. by patenting them.

There has been an ever-increasing expansion of the definition of what could be considered to be intellectual property, and therefore subject to protection via patents, trademarks and copyrights, especially since the Second World War (discussed for example by Coombe 1998, Hayden 1998 and Cassier 2002). In the last 30 or so years in particular, rapid changes have taken place in what the public expects and accepts in IPRs, and in IPRs covering biotechnology in particular. Patent law has been extended to cover life forms such as novel plants (e.g. US Plant Variety Protection Act 1970), genetically modified organisms (following *Chakrabarty v Diamond* 1980, mentioned earlier), and subsequently genetic sequences, despite opposition especially to the latter. (Callon (1994), for example refers to the controversy over patenting genetic code, particularly in Europe, quoting *Le Monde*'s view that the 'hereditary patrimony of the human race' should be offered to the international community and not retained as private property.)

The distinction between what is classified as 'natural' and what is the product of human ingenuity has been continuously renegotiated (Hayden 1998) so that the US Patent and Trademark Office, for example, now treats a gene as equivalent to a chemical formula for a product (Cassier 2002). New methods of appropriation of resources or knowledge outside the formal IPR system have also been identified by Cassier (*ibid)*, including exclusive-use contracts and private databases covered by the terms of commercial confidentiality. These have been used to appropriate collections of genealogical and medical data, then used to add value to gene sequence information in the development of diagnostics and therapies. Trademark law has similarly evolved from a primary emphasis on protecting consumers from 'fakes' to the protection of manufacturers from competition (Coombe 1998: 53 & 64-66). 'Establishing intellectual property is one way of securing control over the potential life of creative ideas with reference to both their production and their future use,' comments Strathern (1996: 17).

Most IPR systems are based on the assumption that property rights have to be granted to an identifiable inventor or a limited number of inventors, although (as discussed above) invention and innovation are increasingly carried out in networks. Sometimes a vast array of firms, other organisations and individuals each makes a contribution, but cannot all be named on a patent, trademark or copyright. Some economists have addressed the issue of IPR in networks by expressing concern with the optimum IPR system to encourage collaboration, and to promote the commercialisation of public sector research either by collaboration with existing firms or by the researchers concerned establishing new start-up firms (e.g. Mazzonleni & Nelson 1998; Merges & Nelson 1994). On the whole, however, the issue of IPR in networks is not typically problematised in the economics literature. This is more the domain of anthropologists and sociologists. Indeed, Rosemary Coombe (1998) criticises economists for their focus on the incentive structures of IPRs, aimed at producing a socially optimal supply of intellectual creations, and their neglect of the question of what is owned, how rights of possession may be exercised, who else has made a contribution, and others whose lives are affected in some way. Penny Harvey (1998) makes the point that indigenous knowledge about plants, for example, belongs to a whole community rather than to identifiable individuals, and is based on tacit knowledge of complex local ecologies and on subtle skills in selection and breeding. The success of a plant that is then genetically modified relies as much on such knowledge as on the ingenuity and novelty imparted to it by Western science: but it is not recognised when the GM plant is designating as 'property' according to the laws and conventions of patenting.

A related issue is to consider innovation as a cumulative activity, in which new products are made by applying existing knowledge in new ways, in building on, extending and improving existing innovations, and in 'reverse engineering'. Dominique Foray (1995) argued that conventional IPR régimes were experiencing a crisis (especially in biotechnology), because they discouraged this type of innovative activity, especially in the USA and Europe (where the IPR system favours radical innovators), although he suggested that the Japanese IPR system was more favourable to incremental innovation. This, too is an area more discussed by sociologists and anthropologists. While economists' work on Biotechnology and IPR has generally concentrated on ownership by industry or at least ownership within industrial society, anthropologists' work may focus on non-industrial societies and indigenous knowledge. Penny Harvey (1998) argues that a community may use knowledge in a way that is quite different from earlier uses, and that this recontextualisation - as opposed to simple abstraction - is part of the creative process. This point might apply equally to the copyrighting of music as to the patenting of plant products. Michel Callon (1994) takes the view that even 'pure' or 'basic' science is always appropriable to some extent, because it cannot be separated from its context, the specific matter on which it is inscribed (e.g. equipment, papers, the minds of scientists), and from the complementary assets and skills needed to make use of it.

The distributed and cumulative processes by which innovation takes place have particular implications for IPR in the context of GM foods and feeding the world, where it is particularly relevant to the question of the appropriation of indigenous and traditional knowledge and the ownership, possibly collective, of rare species and areas rich in biodiversity, to be found in many poorer countries[16], or indeed poorer regions of richer countries. There is not much evidence that this concern, strongly expressed by some of the poorer countries, has had an impact on multinational firms' practices. Indeed, the World Trade Organisation's agreement on trade-related aspects of IPR in 2000 has led to pressure on some of the poorer countries to introduce legislation that protects outside investment, although it has also given rise to attempts to protect local resources through intellectual and cultural property legislation, such as the model law drafted for the Pacific Region by the World Intellectual Property Organisation and UNESCO[17]. These concerns do, however, seem to have affected the freedom of Western biologists carry out botanical expeditions in developing countries, and has led to demands for the compensation of traditional communities (as well as their governments) for use of their intellectual and material property (Daly 1996).

This section has argued that establishing intellectual property rights, and extending their scope (geographically and in terms of what constitutes 'property'), is one way of privatising what was once in the public domain, or the property of a community, and of creating markets in those areas.

CONCLUSIONS

At the beginning of the 21st century, especially in English-speaking countries, markets are often emphasised as the best, or even the only efficient way of organising and governing an economic system. However, market organisation may often be far more complex, and with more varied forms, than is suggested by conventional economic theory. At the same time an increasing number of situations exist in which the market is not a very satisfactory way of governing and coordinating behaviour or allocating resources. Regulations and other non-market elements may be necessary to make market governance work, while for many activities it is, or would be, socially more desirable or economically more efficient to use other modes of organisation and governance.

This paper has taken the case of biotechnology, focusing on GM foods in particular, and examined the creation of the selection environment within which the innovation could diffuse. The selection environment is a wider and much more complex and subtle concept than that of the market, which is useful in understanding the many factors at work in determining the success or otherwise of an innovation. It is not enough to have market demand: there are also many other institutional factors that may decisively determine whether or not a market can exist, while demand itself may be created by the actions of those individuals and organisations with an interest in the success of the innovation.

Some of these factors, and their interaction with each other and with demand, are also particularly susceptible to analysis from a sociological or anthropological perspective, or - as I have tried here - a multidisciplinary approach using concepts from several social science disciplines, which provides a richer picture than would be the case using the tools available from only one discipline. Creating a market, for example, may therefore be shown to be not only an economic, but also a social shaping activity. The behaviour and expectations of key actors are as important in the success of an innovation as factors susceptible to purely economic analysis. Intellectual property may be understood from an economic perspective as an incentive system that ensures an optimal supply of inventions, whereas anthropological and other approaches question from whose point of view the supply might be considered 'optimal', and identify social groups (within industrial society, as well as indigenous people) who make important contributions to the generation of intellectual property but are unable to reap the benefits.

The many elements of the selection environment in the case of agro-biotechnology included the market of consumers and potential consumers - a complex supply (or demand) chain illustrated by Table 2. But it also included the regulatory system; retailers; policy makers; environmentalists; consumer organisations; the intellectual property régime; intermediaries which promoted the new products, which informed consumers, and which raised areas of concern; the politicisation of the whole process; and the market creation activities of the main players (one in particular). These latter - normally within the realm of traditional market creating behaviour - in the context of other elements of the selection environment, had a counter effect and generated a learning process in which the companies concerned discovered the merits of opening up a dialogue with these and other elements of the selection environment. They may well have to alter what they offer customers if they are to create a market successfully.

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ENDNOTES

[1] Defined as the complex of industries related to the exploitation of chemical knowledge, or which have grown around a chemical base (Walsh 1997). Thus new materials, food processing, glass, paper processing and waste treatment, which are based substantially on flow processes and chemical reactions, and seeds and confectionary, with ownership as well as technological links with chemicals, were all for a time within the boundaries of the industry according to the above definition.
[2] The biotechnology firms were interviewed for a study reported in Walsh, Niosi and Mustar (1995), the chemical and agrofood firms for a study reported in Walsh (1997 & 1998), and the pharmaceutical firms for a study reported in Walsh, Ramirez and Tampubolon (2000).
[3] Du Pont, the oldest US firm I visited in a recent survey, was established in 1802, while many of the European firms are much older. Merck, for example, took over the Engel Apotheke in Darmstadt in 1668 (E. Merck AG, 1968).
[4] ICI's pharmaceuticals, crop protection and specialities businesses demerged to become Zeneca in 1993; Zeneca merged with Astra in 1999 to form AstraZeneca, the agrofood business keeping the name Zeneca Agrochemicals; the latter then merged with Novartis crop protection business to form Syngenta in 2000.
[5] Hoechst merged with Rhône-Poulenc to form Aventis in 1999
[6] Acquired by Glaxo Wellcome in 1995 and spun off again by GlaxoSmithKline in 2001.
[7] Now called Cambridge Discovery Chemistry & owned by Oxford Molecular Group plc.
[8] An invention in turn is the embodiment of a new idea or concept (or a new application of an old idea or concept) in the form of a sketch, prototype, model or blueprint.
[9] There are one or two exceptions to this. Some sociologists of innovation also study non-technological innovations: for example, Antoine Hennion (1989) has written about innovation in music while Cécile Méadel (1992) has written about radio programmes. *Organisational* innovations are important both to sociologists and evolutionary economists in analysing the take-off of *technological* innovations (e.g. Green *et al* 1999). Design can both be part of the technological innovation process (the embodiment of a new technology in a product) or innovative in the non-technological sense (as in packaging and advertising design) (Walsh 1996).
[10] Faulkner and Senker (1995: 206-211), for example, review recent models of innovation.
[11] Particularly important in the early computer industry and the early diffusion of synthetic materials.
[12] Stan Greenberg was CEO of Greenberg Research, and polling advisor to Tony Blair, Bill Clinton and others.
[13] There seem to have been two factors at work here: one a concern to preserve consumer choice (in this case farmers' choice of herbicide) in the face of monopoly power; the other a concern about openness.
[14] Conseil Européen des Fédérations de l'Industrie Chimique, based in Brussels.
[15] Gordon Conway's views on GM food, the need for careful testing for unwanted effects, the role of the food industry and also its profits, but also the potential of modified crops to save lives, are presented in more detail in his book (Conway 1997), in a speech made at an OECD conference (Conway 2000) and in an article in *The Guardian* (Conway 2001).
[16] For example a seminar, on intellectual property rights in the context of policy discussions over biodiversity protection, took place in 1997 in Port Moresby, Papua New Guinea (Strathern 1999: 179 & 201). A conference on these issues was held at Cambridge University 13-15 December 2001: Property, Transactions and Creations: New Economic Relations in the Pacific, although the context was wider than the Pacific Region.
[17] Discussed at the Cambridge conference mentioned in the previous note.