Science and Public Policy, volume 29, number 4, August 2002, pages 297–306, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Agro-food and employment

Agro-biotechnology, innovation and employment

Anthony Arundel

Several data sources are used to estimate the potential impact of innovation in agro-biotechnology on employment in the European agro-food chain. In the late 1990s, approximately 50,000 jobs were directly due to biotechnology. The indirect employment effects are likely to be much larger. Four of the five main innovation strategies for new plant varieties are likely to reduce indirect employment, but the fifth, improved quality traits (such as enhanced oil content), could increase employment by creating higher value-added crops, although there will be job losses in industrial processing. Field test data for Europe and the United States show, however, that there has been no detectable shift in agro-biotechnology innovation towards quality traits. It could be worthwhile for government policy to increase funding for public research into these traits.

Anthony Arundel is at the Maastricht Economic Research Institute on Innovation and Technology, PO Box 616, 6200 MD Maastricht, The Netherlands; Tel: +31 43 388 3702; Fax: +31 43 388 4905; Email: A.Arundel@merit.unimaas.nl.

AN ESSENTIAL FEATURE of technologies that are major economic drivers, such as information and communication technology (ICT), is that they are pervasive, influencing investment and employment across many economic sectors (Freeman and Perez, 1988). Although nowhere near as pervasive as ICT, biotechnology has possible applications in human and animal health, industrial processing, and in almost all natural resource-based sectors, such as agriculture, forestry, aquaculture, and mining (Arundel and Rose, 1999; PEW, 2001). The range of applications suggests that biotechnology could have a substantial impact on competitiveness, economic growth, and employment. These potential economic benefits are one of the reasons why governments in Europe and elsewhere support biotechnology through a range of subsidies (EC, 2001).

The pharmaceutical applications of biotechnology have attracted the lion's share of venture capital (Sechler, 2001) and public and private R&D, but these applications are unlikely to have a substantial impact on employment because of the relatively small size of the pharmaceutical sector. In 1999, the sector had 536,000 employees in the European Union (EU) (EFPIA, 2001), which is slightly less than 0.4% of total employment.

This provides an upper estimate of the possible impact of biotechnology on pharmaceutical employment if every new drug was a biopharmaceutical, instead of 16% of new drugs introduced onto the world market since 1997 (Ashton, 2001). In contrast, according to Burke and Thomas (1997), the greatest economic and employment impacts of biotechnology are likely to occur in the agro-food production chain, which accounts for the majority of the 450 billion

 0302-3427/02/040297-10 US$08.00

Anthony Arundel is a Senior Researcher at MERIT in the Netherlands, which specializes in the economic and social evaluation of innovation and new technology. Most of his research involves the design, implementation and analysis of surveys on the innovative activities of firms and public research organizations. His main research interests include the economic impacts and public benefits of biotechnology, the value and strategic use of intellectual property rights, and knowledge flows between public research organizations and firms.

Euro of gross value-added and the nine million jobs in the EU that could, potentially, be influenced by biotechnology (EC, 2001).

This article traces the possible effects of innovation in agricultural biotechnology on employment in the European agro-food chain. The employment effects are defined by the fact that agro-biotechnology is predominantly a process innovation that faces competition from alternative technologies for achieving the same end. The analysis assumes that European farmers are free to grow approved genetically modified (GM) crops and that there is minimal public opposition to GM foods. Although these assumptions are currently unrealistic, some of the employment effects of agro-biotechnology will be due to GM crops grown for animal feed or industrial feed-stocks, both of which might be better accepted in the near future by the European public if they offer environmental advantages over alternatives.

The employment estimates draw on several data sources, including previous surveys in Europe and Canada, interviews with Europe's largest seed firms, a 1999 survey of European seed firms, and an analysis of the European and American field release data for GM organisms.

Employment drivers in agro-food

New technology can have both direct and indirect effects on employment. The direct effects are limited to changes in employment within the firm that develops and commercialises the technology. In agro-biotechnology, the direct employment effects occur in firms that develop and sell new GM crop varieties. The indirect employment effects occur elsewhere in the agro-food production chain, which runs from the suppliers of agricultural inputs to the final consumers of agricultural products, as shown in Figure 1. These indirect employment effects of agro-biotechnology are likely to be much greater than the direct employment effects (Watanabe, 1985; Wörner and Reiss, 2001).

Economic research on the employment effects of product and process innovation shows that product innovation generally increases employment, but process innovation reduces it, unless the new process improves quality, increases exports, or consumers respond to a process-induced fall in prices with a proportionately greater increase in demand (OECD, 1996; Smolny, 1998; Wörner and Reiss, 2001). As a process technology, it is anticipated that agro-biotechnology will increase productivity by reducing inputs, which in turn will reduce employment. For example, GM crop varieties that resist fungal, nematode, and insect pests have the potential to decrease demand for chemical pesticides, and therefore employment in firms that manufacture pesticides. However, the actual impact of agro-biotechnology innovation on employment will be influenced by five other factors.

The first factor is a long-term decline within Europe, as in other developed countries, in the share

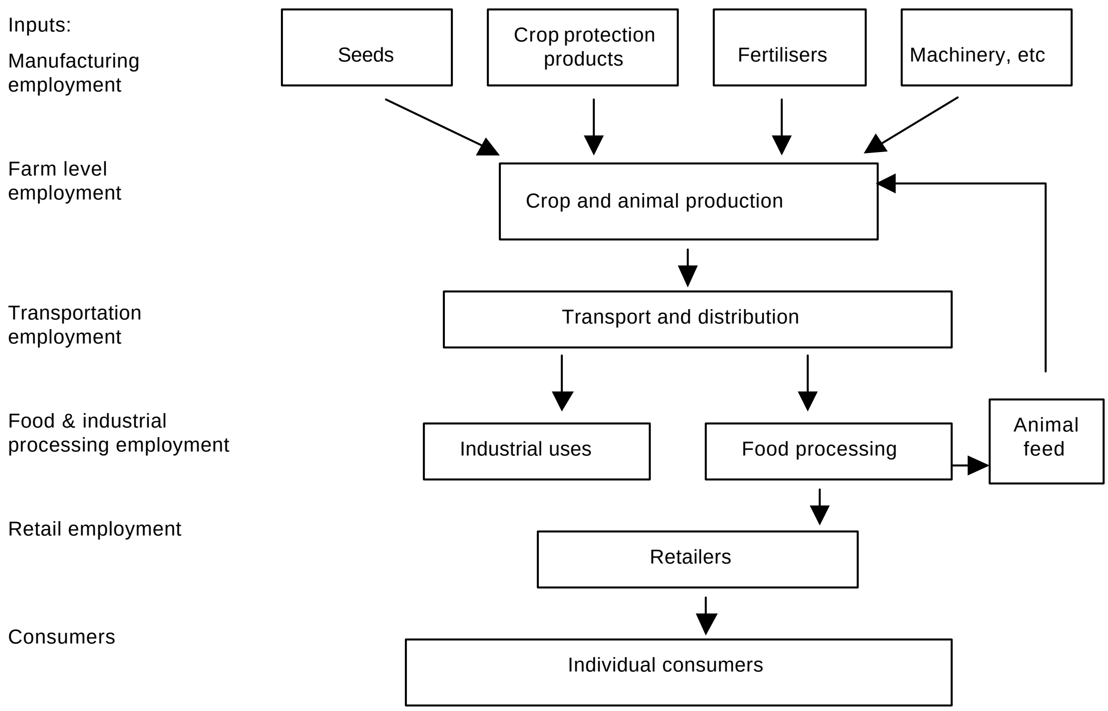

Figure 1. Agro-food chain

of the workforce that is employed in both agriculture and manufacturing, as a result of labour-saving innovation and a relative fall in demand for agricultural and industrial products compared to services. Between 1985 and 1997, the share of the workforce in agriculture declined in all member states of the EU by an average of 35.3%. The fastest rate of decline was 54.1% in Spain, and the slowest rate a still substantial 17.4% in the UK (OECD, 1999). Slow population growth within the EU also places a major constraint on the growth of the European market for food crops.

Second, the main innovation strategy of downstream customers in the agro-food chain is to reduce costs. Feed and food processors are the largest customers of agricultural products. Innovation surveys consistently show that these firms stress cost-reduction strategies. For example, the 1993 Community Innovation Survey of almost 14,000 innovative European firms evaluated the importance of several goals of innovation. Two-thirds of food-processing firms rated reducing material and energy inputs as a 'very important' or 'crucial' goal (Tait *et al*, 2001). The desire of food processors to reduce costs will feed back through the agro-food chain, limiting the prices that seed firms can charge for GM seeds.

The third factor, the existence of alternative technologies combined with low switching costs, acts to reinforce the downward pressure on costs in the agro-food chain (Arundel, 2001). GM crop varieties must compete with other technologies, both on the farm and throughout the agro-food chain. These alternatives include non-GM crop varieties, different types of GM technology, and non-agricultural substitutes.

For example, phosphorous pollution in waterways from pig and chicken manure can be reduced through GM feed crops that contain phytase (an enzyme that would allow these species to digest phytates in their feed). An alternative is to genetically engineer pigs and chickens to secrete phytase in their saliva. Another solution that is not dependent on agro-biotechnology is to add manufactured phytase to feed. Which option is chosen will depend on the relative costs and benefits.

In some cases, GM crops may never offer the most cost-effective solution, because of the cost of identity preservation to prevent a GM variety with a specific, valuable trait from being mixed with other varieties of the same crop. Similar factors could also influence the competitiveness of GM 'functional foods', such as broccoli with high levels of calcium or other desirable properties. Food processors can either purchase calcium-enhanced GM broccoli or add calcium from other sources to their products.

Low or negligible switching costs from one input to another ensure that a small increase in the price of a GM versus a non-GM input will reduce the demand, and hence the price, for the GM input. A food processor who purchases GM soybeans today will incur few, if any, additional production costs by switching to a different protein source tomorrow in response to a cost advantage (Kane, 2001). Similarly, feed manufacturers need to include lysine in poultry feed. If the price of GM corn containing lysine is too high, they can add lysine from industrial fermentation (Coaldrake, 1999).

Fourth, current levels of employment in the European agro-food chain are not sustainable without subsidies, as shown by a 10.7% decline in the gross value-added of European agricultural output (at market prices) between 1990 and 1997. One cause of the decline was an increase in the cost of inputs such as fertilizers, pesticides, equipment maintenance, and animal feed. The increase in input costs was largely met by a 2.3-fold increase in agricultural subsidies. A fall in subsidies as a result of reform of the European Common Agricultural Policy would alter both employment and the types of crops that are grown in Europe (OECD, 2000).

Fifth, the large number of mergers in both the seed and agro-chemical sectors in the last decade will also reduce employment. As an example, the 1999 merger of Rhone-Poulenc and AgrEvo to form Aventis reduced employment by 3000–4000 jobs, with the closure of an R&D centre in the UK and a European agro-chemical manufacturing plant. A new round of job losses is possible after the purchase of Aventis by Bayer.

Direct employment impacts

There is no accurate information on the number of direct jobs in agricultural biotechnology in Europe. The best option is to estimate direct biotechnology employment in the agro-food chain by combining different survey estimates. Data from Ernst and Young (1997) suggest that there were 5,625 jobs in Europe in small agro-biotechnology firms in 1996 (more recent Ernst and Young surveys did not provide separate estimates for agro-biotechnology). Two surveys by Statistics Canada in 1996 and 1997 estimate that approximately 1% of food processing employees were involved with biotechnology in some way (Arundel and Rose, 1998). The same rate applied to the 3.3 million food processing jobs in Europe predicts 33,000 biotechnology jobs.

A 1999 survey of European seed and agro-chemical firms determined the percentage of R&D expenditure on genetic engineering and the application of these technologies to enhance conventional plant breeding (Arundel, 2001). These rates, applied to the total number of employees in seed and agro-chemical firms, estimate an additional 8,500 biotechnology jobs. After rounding up to account for employment growth (which may not be realistic given recent mergers), the final estimate is approximately 50,000 direct biotechnology jobs in the European agro-food chain in the late 1990s. This is a very small percentage of total employment.

Indirect employment effects

Direct biotechnology employment in the agro-food chain in Europe is likely to be severely depressed by the current regulatory situation, which prevents commercial farming of GM varieties. Furthermore, agro-biotechnology is in its infancy, with only a few major GM varieties available, such as Bt cotton and corn, and herbicide-tolerant corn, soybeans, and rapeseed. All these varieties have had only very small or no effects on farmer incomes in the United States (Nelson, 2001), which limits their employment impact, and almost no effect on downstream processing. Because of these constraints, there is no point in estimating current indirect employment effects from agro-biotechnology.

There are five possible options for innovation in plant breeding, each with its own effect on indirect employment: increased yield per hectare; increased yield per unit inputs; reduced risk to farmer; input switching; and enhanced quality characteristics

Instead, I provide a qualitative assessment of the possible employment effects of different innovation strategies in the seed sector. The estimates assume no increase in exports and no change in current agricultural subsidy levels. European demand for agricultural products is assumed to be price inelastic. For example, a large decline in the price of wheat would only result in a small increase in demand, since most markets for wheat are already saturated. The exception is for some quality characteristics.

There are five possible options for innovation in plant breeding (DG Agriculture, 2000a). Each will have a different effect on indirect employment. Table 1 outlines each option and gives a qualitative assessment of the expected employment effects through the agro-food chain (with the exception of retailers, for whom no employment effects are expected).

The first option of an increase in yield per hectare should result in farmers producing more at a given price, leading to a fall in crop prices (in the absence of an increase in European demand, exports, or subsidies). Without an increase in subsidies, this should result in a decline in farm-level employment.

The second option of an increase in yield per unit of inputs could have no effect on farm-level employment if yield per hectare is left unchanged, but it should decrease employment among input suppliers. An example is protective seed dressings or coatings that reduce the need for fungicides and other pesticides. This innovation should reduce costs for farmers (thereby increasing farmer incomes), but decrease employment among competing pesticide firms.

Risk-reducing innovations could have no effect on total yields, but reduce the risk experienced by each individual farmer. An example is Bt cotton, which should reduce the risk of crop loss from insect pests that are susceptible to Bt. The estimated gain to farmers from Bt maize compared to conventional maize is an increase of US$44.5 per acre with high infestation levels and a loss of US$4.5 under low infestation levels (OECD, 2000, page 102).

The trade-off for the farmer is higher initial seed costs that are recovered when insect infestation is heavy but not when insect infestation is low. Over the medium-term, this could have no effect on average prices and costs. However, the extra cost of risk-reducing varieties must be paid for in some manner, either through an overall increase in yields (resulting in declines in farm-level employment) or through

Table 1. Employment effects of innovation in the seed sector

Option	Employment effects in the agro-food chain					
	Input suppliers	Farm level	Transport and distribution	Food processors	Industrial processors	Overall
1. Increased yield per hectare	--	⬇	--	--	--	⇩
2. Increased yield per unit inputs	⬇	--	--	--	--	⇩
3. Reduced risk to farmer	⬆	--/⇩	--	--	--	--
4. Input switching (no yield effect)	⇧/⇩	--	--	--	--	--
5. Enhanced quality characteristics	⬆/⬇	⇧	⬆	--/⇩	--/⇩	⇧/⬆

Key:
⬆ = relatively strong positive increase
⇧ = weak increase
⬇ = strong decline
⇩ = weak decline
--/⇩ = no effect to weak decline
-- = no effect
⇧/⇩ = substitution effects

higher seed prices and lower farm incomes. Either way, this could translate into lower farm-level employment.

Input switching innovations could have no effect on farm-level employment, unless they also increase yields, but they should shift employment among the input suppliers. For example, the use of imazetaphyr declined from 44% of US soybean acres in 1995 to 17% in 1998, while Roundup use increased from 10% of acres in 1990 to 45% in 1998 (DG Agriculture, 2000a). These changes in herbicide use patterns should have shifted employment from competing herbicide manufacturers to Monsanto, the producer of Roundup Ready GM soybean varieties and the herbicide Roundup.

The employment effects of each of the first four innovation options are largely confined to input suppliers and to the farm level. The predicted employment effects are either negative or neutral. In contrast, quality enhancement is likely to have far more complex effects on employment, with shifts in employment from one part of the agro-food chain to another. Furthermore, quality enhancement is the only type of agro-biotechnology innovation that could increase total employment in the agro-food chain. This would occur by increasing the value-added component of agricultural products. Quality traits with industrial applications, such as the use of plant oils for lubricants or improved biomass crops for energy production, will also increase agro-food employment, although these increases could be matched by a decline in employment in industry.

Quality traits require identity preservation, which will increase employment in transport and distribution. Quality traits will also require an increase in crop prices in order to cover the cost of identity preservation, which is estimated, based on US experience, to cost between 6% and 17% of the farm-gate price, depending on the crop (DG Agriculture, 2000a). Farm-level employment could also increase slightly if the price paid for improved crops increases and if farmers can capture part of the price increase.

One aspect of quality traits could have a net positive effect on European employment. This is when domestic European production replaces imports. Examples include high lauric acid rapeseed to replace imported coconut and palm oil in lubricants and detergents (OECD, 2000) or bioethanol production from GM grasses to replace imported petroleum. Another example, although a step removed from traditional agriculture, is GM bacteria to produce natural vanilla and other aromatic botanicals that are currently imported (Acharya, 1995).

Potential markets for GM crops

The size of possible changes in employment patterns as a result of new GM seed varieties depends on the market value of GM crops. Interviews with the managers of seed firms in Europe (see the other articles in this issue), plus an analysis of the European field test data for GM crops, show that these firms are concentrating their GM plant breeding programmes on major crops such as maize, sugar beets, oilseeds and potatoes where large market sizes increase the potential profits and provide an opportunity to recoup high R&D costs.

Table 2. Value of agricultural crops in the European Union

	1997 crop values	
	million Ecu	**%**
Main GM target crops	17,110	16.3
Maize	*4,128*	*3.9*
Potatoes	*4,227*	*4.0*
Sugar beets	*5,657*	*5.4*
Oilseeds	*3,098*	*3.0*
Other cereals (excluding maize)	17,143	16.3
Vegetables, fruits, and vine crops	55,110	52.5
Other crops	15,567	14.8
Total	104,930	100.0

Sources: OECD (1999); DG Agriculture (2000b)

Therefore, a limiting factor on the potential employment effects of GM seeds is the share of these crops out of total crop values in Europe. As shown in Table 2, the main GM target crops for Europe accounted for only 16.3% of the total crop value in 1997 (the most recent year available).

The effect of GM crops on employment in the agro-food chain is likely to be comparatively small until GM techniques can be applied to other cereals (mostly wheat) that account for another 16.3% of crop values, and to vegetables, fruits, and vines. Monsanto is close to marketing GM wheat that is resistant to proprietary herbicides, after over a hundred field trials of this trait in the United States. The remaining crops account for over half the total value, but many of them have very small markets.

The employment effect of advanced biotechnology will therefore depend on the ability of seed firms to apply genetic engineering to small-market crops. To date, small-market food crops (excluding tomatoes) account for only 6.5% of all GM plant field trials in the United States and 7.3% of field trials in Europe since the late 1980s. A future increase in GM research on small-market crops will depend on the cost of using GM techniques. As with many technologies, these costs should fall over time.

Is there a shift to quality traits?

Other than an extension of agro-biotechnology from large to small-market crops, the main employment effect of agro-biotechnology will be a result of quality traits. These are of great interest as they are the only innovation type that could increase employment.

In the late 1990s, both Monsanto's Chief Executive Officer, Robert Shapiro, and Cargill Agricultural Division President, Fritz Corrigan, predicted that a quarter of all grain production would be devoted to quality or output traits within a decade (Morrison and Giovannetti, 1999). Interviews with the European managers of seed firms also found that several of them are moving to an innovation strategy based on quality or output traits such as functional foods or neutraceuticals (physiologically beneficial products isolated from foods) (Tait, 2001; Chataway, 2001).

Yet, GM crops with quality traits constitute only a miniscule percentage of all GM plantings so far. Only 0.1% of 41.5 million hectares of GM crops in Canada and the United States in 1999 were for quality traits, primarily high oleic oilseed (DG Agriculture, 2000b). A major shift in firm strategies to quality traits would require a significant number of new GM crop varieties to come onto the market over the next five to ten years.

Depending on the species and the desired traits, eight to twelve years are needed to develop most new crop varieties, which means that the timing of employment effects from quality traits depends on when seed firms began to research these traits. An essential step in the development process is to field test the variety to ensure the consistent expression of the desired traits. Field trials can begin two to three years into an R&D project to develop a new seed variety and can run almost until the variety is ready for commercialisation. Therefore there is a lag between field trials and market-readiness of one to ten years, although the average is probably around five or six years from the first field trials.

In the 1970s and 1980s, concerns about the safety of GM varieties among scientists and the general public led governments in both the United States and Europe to establish field trial registration systems. These provide valuable data on the direction of research investment in agricultural biotechnology. Field trial data is similar to patent data in providing a record of the types of research projects conducted by firms.

In the 70s and 80s, concerns about the safety of GM varieties led US and European governments to establish field trial registration systems, which provide valuable data on the direction of research investment in agricultural biotechnology

This data has one advantage over patents, in that firms are unlikely to conduct field trials unless they are relatively confident that the variety can be commercialised. Patents are a poorer indicator of innovations because not all innovations are patented (while all GM crops to be grown outdoors must be field tested).

The main disadvantage of the field trial data is similar to that of patents. Although both provide a measure of investment in particular lines of research, there is no direct correlation between the number of field trials (or patents) and the number of commercialised GM plant varieties (or patented innovations). As an example, several hundred field trials were conducted in the United States to test tomato varieties that ripened without becoming soft. In contrast, only 15 field trials were required to develop a viral-resistant variety of papaya.

At the time of writing, the most recent database for field trials in the EU includes all field trials up until April 2001 (JRC, 2001), while the US database includes all field trial applications and notifications up until January 2002 (maintained by APHIS of the USDA (US Department of Agriculture)). Both databases include the name of the applicant, the purpose of the field test, the application year, and the species. In addition, APHIS assigns each field test to one or more of ten categories based on the trait under investigation: herbicide tolerance; agronomic characteristics; marker genes; product quality; an 'other' category; and five types of pest resistance — bacteria, fungi, insect, nematode, and viruses. For example, a field test for both insect and viral resistance is included in both the insect and viral resistance categories. Approximately 7% of the US trials for pest resistance are for more than one type of resistance.

For analysis, I assigned the purpose of each EU and US field trial to one of five broadly comparable trait categories: herbicide tolerance; pest resistance; other agronomic characteristics such as yield and stress resistance; product quality; and a technical category that includes male sterility, research on gene markers and other types of trials. To improve comparability with the US data, EU field trials in more than one category are counted more than once, as are EU field trials for more than one type of pest resistance.

The main problem for analysis is to identify all trials for product quality traits, which include both industrial applications and food processing characteristics. These trials are assigned in the US APHIS database to either the 'other' or 'product quality' categories, but APHIS also includes additional information on the enzyme target and on the purpose of the trial. The EU database contains a much shorter description of the purpose of the trial, although the enzyme targets are often mentioned. I used this information to create a more detailed classification of industrial and food processing uses.

However, about 2% of the trials could not be classified with a high degree of confidence because the

Table 3. Distribution of EU and US field trials by trait

	USA			EU		
	Number	**%**	**Public sector share** (%)	**Number**	**%**	**Public sector share** (%)
Herbicide tolerance	2,509	27.5	4.9	980	48.0	9.5
Pest resistance	3,800	41.7	16.3	477	23.4	18.7
Other agronomic	394	4.3	25.3	86	4.2	61.6
Technical	669	7.3	47.3	238	11.7	14.7
Product quality	1,750	19.2	15.6	259	12.7	29.0
Total	9,122	100.0	15.0	2,040	100.0	16.9

enzyme target could either serve multiple functions or its purpose was unknown. If plausible, these trials were assigned to one of the main trait categories, but otherwise I assigned them either to the technical category or to an 'other' group within the product quality category. The latter also includes American trials that were classified by APHIS under product quality, but which lacked additional information on the purpose of the trial because of business confidentiality.

I used the information on the applicant in both the EU and US databases to determine if the applicant was a private firm or from the public sector, such as a university or publicly-funded research institution. The US APHIS data only list one applicant, but the EU data list multiple applicants where relevant. A small proportion (1.7%) of the EU field tests include an applicant from both the public and private sectors. These field tests are assigned to the public sector.

The results given here are limited to field trial applications for higher plant species. Note that all results are given for trial–trait combinations. For example, a trial that includes a trait for herbicide tolerance and one for pest resistance is counted in each of these two categories. After excluding non-plant species, there are 2,040 European and 9,122 American trial–trait combinations.

Results for product quality field trials

Table 3 gives the number of EU and US field trial–trait combinations within each of the five main trait categories, plus the percentage of trials conducted by the public sector. In absolute terms, the USA is more active than Europe in product quality trials, with 1,750 field trials compared to 259 in Europe. In addition, a higher percentage of all US trials are for product quality (19.2%) compared to Europe (12.7%). In contrast, the European public sector accounts for almost double the proportion of product quality trials (29.0% versus 19.2%). In both regions, two traits, herbicide tolerance and pest resistance, account for the majority of trials — 69.2% of the total in the USA and 71.4% of the total in Europe.

Table 4 provides a detailed breakdown of the purpose of product quality trials in the USA and the EU. Most are for food quality characteristics, such as oil content, the types of starches, sugars and protein in the crop, and the ripening characteristics of fruit. Many of these traits should improve the efficiency of food processing, which would decrease processing employment while possibly increasing employment further down the agro-food chain.

The industrial and environmental traits include low phytase animal feed, fibre inputs, and the use of plants as industrial feedstocks for lubricants, polymers, pharmaceuticals, and enzymes. Many of these traits could shift some employment from industry to agriculture. Although the net employment effect could still be negative as a result of more efficient production, the same characteristic offers substantial environmental benefits through cleaner production processes.

A main question of interest is whether the share of product quality traits has been increasing over time, perhaps because of a shift in the innovation strategies of seed firms. Relevant results are given in Figure 2 for industrial and food processing traits in the USA and for all European product quality traits combined (there are too few trials for industrial traits in Europe to provide separate results, while the 'other' group for the USA is included under food

Table 4. Breakdown of product quality trials

	USA		EU	
	Number	**%**	**Number**	**%**
Industrial/ environmental	201	11.5	61	23.6
Food quality				
Oils	214	12.2	16	6.2
Starches and sugars	394	22.5	123	47.5
Proteins	496	28.4	12	4.6
Fruit ripening	251	14.4	20	7.7
Other	194	11.1	27	10.4
Total	1750	100.0	259	100.0

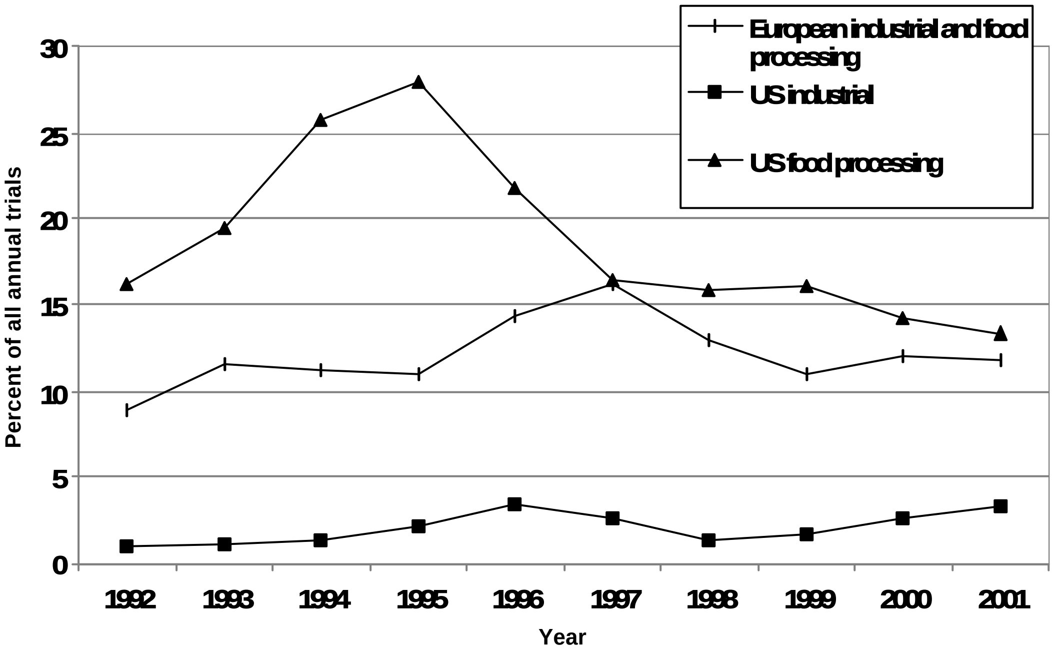

Figure 2. Distribution of US and EU field trials for product quality (two-year running average)

processing). The results for 1992 include all trials before this date.

There has been little change over time in the share of product quality traits in Europe or industrial traits in the USA. The share of trials for food processing traits reached a peak of 28% of all US trials in 1994/95 before falling to 16.4% in 1996/97 and to 13.3% in 2000/01. Part of the 1994/95 peak was a result of trials for ripening in the tomato. Excluding this one trait reduces the 1994/95 peak to 23%. However, almost all types of food processing trials reached a peak between 1994 and 1996 and declined afterwards.

This suggests that seed firms in the USA lost interest in developing GM crops with improved quality characteristics, compared to other types of traits. The main shift was towards technical and agronomic traits, for which the share of all GM trials increased steadily after 1994 (results not shown). The absolute number of trials for food processing traits in the USA has fluctuated since the 192 trials in 1994, but there is no detectable trend. Conversely, the number of trials for industrial traits increased from 10 in 1994 to 42 in 2001.

The share of trials for product quality traits would have declined even further except for an increase in trials by the public sector. In the USA, the public-sector share of product quality traits (industrial and food processing combined) increased from a low of 5% of these trials in 1994 to approximately 25% between 1999 and 2001. In Europe, the public-sector share of product quality trials also increased, although not as dramatically, from 18% of these trials up to 1994 to 43% in 1998 and 39% in 1999.

It is possible that most of the research by private firms on product quality traits has not yet reached the field trial stage, with most testing still occurring in the laboratory or greenhouse, where a field trial application or notification is not required. If true, a substantial shift to higher value-added quality traits is probably over five years away, given the time required to field test a GM trait. This also means that any possible employment impacts from GM traits for product quality are equally distant in time.

Conclusions

Policy documents in Europe and in other countries such as Australia and Canada have frequently stressed the potential economic benefits of biotechnology, including increased employment, although in the late 1990s the discussion of employment changed from an emphasis on new jobs to one on high-skilled jobs. The various types of evidence assembled in this article show that most of the employment effects of biotechnology are likely to be a result of indirect employment effects in the agro-food chain, plus those in industrial firms that adopt agricultural inputs.

Wörner and Reiss (2001), in a study of the German biotechnology industry, also estimate that the indirect employment effects of biotechnology are likely to be much larger than the direct effects. Furthermore, most types of agro-biotechnology innovation will reduce employment. This will have major economic benefits by increasing productivity, competitiveness, and living standards, but an increase in employment is not one of them.

Although agro-biotechnology is unlikely to increase the number of jobs, it could increase the number of higher-skilled jobs that are traditionally better paid than lower-skilled jobs in manufacturing and agriculture. In a 1997 Statistics Canada survey of agro-food firms, 43.2% of these firms (after employment-weighting) reported that the adoption of biotechnology increased skill requirements, compared to only 1% that reported a decrease (Arundel and Rose, 1999). This is encouraging, although the increased skill demands could be relatively minor and might not translate into greater productivity and higher wages.

Any increase in demand for very high-skilled jobs in the agro-food chain is likely to be relatively small. For example, the results of the 1999 survey of European seed firms suggest that employment in seed research and development would increase by about 7.4% between 1999 and 2002, which is equivalent to about 400 new jobs (Arundel, 2001). Many of these expected gains in high-skilled jobs could be lost through mergers.

Of the five innovation options available to seed firms, quality traits have the greatest potential to increase employment in the agro-food chain. The interviews with seed firm managers and published statements from seed firm chief executive officers suggest that quality traits should play a growing role in the innovation strategies of these firms. This could have a positive impact on employment in the agro–food chain, or at least delay the rate of job losses.

Surprisingly, there is little evidence from the field test data to support a marked shift towards quality traits. There are several possible explanations. The first is technical. Many of these traits could be developed using non-GM breeding methods, or it could be technically more difficult to develop quality traits via GM methods than originally thought. Second, research on quality traits could still be in the laboratory or greenhouse stage and therefore undetectable using the field trial data for Europe and the USA.

Although conjectural, there is also a third possible reason. The economic obstacles against quality traits could be reducing the private enthusiasm among seed firms for these traits, compared to their public statements and advertisements (such as for golden rice) in support of quality traits. The obstacles include the cost of identity preservation, competitive alternatives, and low switching costs for farmers and for food and industrial processors. This could be one reason why the share of field trials for product quality traits declined in the USA after the mid-1990s.

Any possible barriers to the development of quality traits should be of concern to governments, not so much because quality traits offer employment gains in some sectors, but because of secondary environmental benefits. Some quality traits could be developed specifically to solve environmental problems, such as phosphate pollution of waterways. Other quality traits that improve food, feed, and industrial processing will also provide environmental benefits by reducing the amount of inputs or processing that is required to achieve a given amount of output (OECD, 2001).

The public sector in both Europe and the USA already focuses on product quality traits with potential benefits for employment and the environment. It may be worthwhile for governments to build on this strength by increasing public-sector funding for research on applications with environmental or other benefits in the public interest. An additional benefit is that research on these types of traits might help overcome what Gaskell and colleagues (2000) describe as the "Achilles heel" of agricultural biotechnology, which is a lack of useful applications that can attract greater public support.

References

Acharya, R (1995), The Impact of New Technologies on Economic Growth and Trade: A Case Study of Biotechnology (Universitaire Pers Maastricht, Maastricht).

Arundel, A (2001), "Agricultural biotechnology in the European Union: alternative technologies and economic outcomes", Technology Analysis and Strategic Management, 13, pages 265–279.

Arundel, A, and A Rose (1998), "Finding the substance behind the smoke: who is using biotechnology?", Nature Biotechnology, 16, pages 596–597.

Arundel, A, and A Rose (1999), "The diffusion of environmental biotechnologies in Canada: adoption strategies and cost offsets', Technovation, 19, pages 551–560.

Ashton, G (2001), "Growing pains for biopharmaceuticals", Nature Biotechnology 19, pages 307–311.

Burke, J F, and S M Thomas (1997), "Agriculture is biotechnology's future in Europe", Nature Biotechnology, 15, pages 695–696.

Chataway, J (2001), "Novartis: new agribusiness strategies", AgBioForum, 4, pages 14–19.

Coaldrake, R (1999), "Trait enthusiasm does not guarantee on-farm profits", AgBioForum, 2, page 118.

DG Agriculture (2000a), Economic Impacts of Genetically Modified Crops on the Agri-Food Sector (Working document, revision 2, Commission of the European Communities, Brussels).

DG Agriculture (2000b), Statistical and Economic Information for Agriculture in the European Union, January (Commission of the European Communities, Brussels).

EC (European Commission) (2001), Towards a Strategic Vision of Life Sciences and Biotechnology: Consultation Document (Commission of the European Communities, Brussels 4.9.2001 COM(2001) 454 final).

EFPIA (European Federation of Pharmaceutical Industries and Associations) (2001), The Pharmaceutical Industry in Figures — 2001 Edition (EFPIA, Brussels).

Ernst and Young (1997), European Biotech 97: A new economy (Ernst and Young International, Stuttgart).

Freeman, C, and C Perez (1988), "Structural crises of adjustment, business cycles and investment behaviour", in G Dosi et al (editors), Technical Change and Economic Theory (Pinter, London).

Gaskell, G, N Allum, M Bauer et al (2000), "Biotechnology and the European public", Nature Biotechnology, 18, pages 935–38.

JRC (Joint Research Council) (2001), Summary Notification Information Format (SNIF) database, European Commission.

Kane, M (2001), "Food industry in safety and labeling of Biotechnology", in G Nelson (editor), Genetically Modified Organisms in Agriculture: Economics and Politics (Academic Press, London).

Morrison, S, and T Giovannetti (1999), Bridging the Gap, 13th Biotechnology Industry Annual Report (Ernst and Young, Palo Alto).

Nelson, G C (editor), Genetically Modified Organisms in Agriculture: Economics and Politics (Academic Press, London).

OECD (1996), Technology, Productivity and Job Creation, Volume 2: Analytical Report (OECD, Paris).

OECD (1999), Economic Accounts for Agriculture (OECD, Paris).

OECD (2000), Agricultural Outlook 2000–2005 (OECD, Paris).

OECD (2001), The Application of Biotechnology to Industrial Sustainability (OECD, Paris).

PEW Initiative on Food and Biotechnology (2001), "Harvest on the horizon: future uses of agricultural biotechnology", available at <http://pewagbiotech.org/research/harvest/>.
Sechler, B (2001), "Food, agriculture miss out on biotech investment boom", Dow Jones Newswires, Monday, 27 August.
Smolny, W (1998), "Innovations, prices and employment", Journal of Industrial Economics, 46, pages 359–381.
Tait, J (2001), "Zeneca agrochemicals", AgBioForum, 4, pages 63–67.
Tait, J, J Chataway and D Wield (2001), Final Report on Policy Influences on Technology for Agriculture: Chemicals, Biotechnology and Seeds, Annex F1, DG Research, Project No. PL 97/1280, European Commission, Brussels.
Watanabe, S (1985), "Employment and the income implications of the 'bio-revolution': a speculative note", International Labour Review, pages 281–297.
Wörner, S, and T Reiss (2001), "The direct and indirect impacts of new technologies on employment: the example of the German biotechnology sector", Science and Public Policy, 28, pages 1–10.