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Current Contribution of Four Biotechnologies to New Zealand's Primary Sector

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This article presents research estimating the economic contribution made by the uptake of biotechnology in the primary sector of New Zealand. It focuses on the impact of four biotechnologies: clonal propagation/cell manipulation, bio-control agents, enzyme manipulations, and marker-assisted selection. Interviews with 59 key informants and secondary economic data were incorporated into a cost-benefit analysis to produce an estimated overall net impact of NZ$266 million per annum. This impact is spread unevenly through the primary sector and across biotechnologies.

Key words: bio-control agents, biotechnology, marker-assisted selection, New Zealand, primary sector.

Introduction

Biotechnology was one of three industries selected by the New Zealand government for particular policy attention in its *Growth and Innovation Framework* (GIF) for economic development. The government set out its vision and direction for the industry in its *New Zealand Biotechnology Strategy*, released in May 2003. The strategy noted that 'biotechnology is an industry in itself, but it is much more than that; it is a sector generating biological knowledge, skills, and technology that can contribute in numerous ways to achieving our economic, social and environmental aspirations' (New Zealand Government, 2003, p. 1). The strategy included a large section on applying biotechnology to other industries since 'application of modern biotechnology research can add value to the products and processes of many New Zealand industries, including agriculture, forestry, marine, environmental and pest management, and human and animal healthcare' (New Zealand Government, 2003, p. 21). This article presents results from research to estimate the economic contribution made by the commercialized application of four key biotechnologies to the primary sector in New Zealand (Kaye-Blake, Saunders, Emanuelsson, Dalziel, & Wreford, 2005). That research is the first comprehensive baseline measurement of the benefits of biotechnology innovations in New Zealand. The primary sector was chosen because this sector remains a core contributor to the country's position in the global marketplace, contributing about 68% of New Zealand's merchandise exports (New Zealand Government, 2003). The research was restricted to commercialized applications in order to focus on realized gains rather than on projected gains from current research and development.

The article proceeds as follows. The next section describes international research measuring the impact of technological development on agricultural production. The next two sections set out the four biotechnologies and the methods used in the New Zealand study, followed by a section reporting the main results assuming New Zealand is a price-taker on world markets (additional research has examined the impact of relaxing this assumption [Kaye-Blake & Saunders, 2006]). Finally, the article ends with a brief conclusion.

Measuring Technology Benefits in the Primary Sector

The impact of technological development on agricultural production has received much attention. A particular focus has been the contribution of improved germplasm to agricultural output. Agronomic research on staple crops led to important increases in production in the second half of the 20th Century, with measurable economic impacts (Evenson & Gollin, 2003). Abeledo, Calderini, and Slafer (2002) summarize research on genetic gains in barley, for example, which have been estimated with some variation to be 0.3 to 0.4% per year for the whole 20th Century. The same paper records that genetic gains from wheat have been slightly higher, at about 0.5% per year. Duvick, Cooper, and Smith (2004) demonstrate a clear linear trend in yields per hectare of maize since 1930. Interestingly, potential yield per plant has not increased from 1930 to the mid-1990s. Instead, newer varieties perform better for harvest index and under stress and crop density, leading to increased yields per hectare over time. However, the yield increases appear to have declined over time (Evenson & Gollin, 2003; Traxler, Falck-Zepeda, Ortiz-Monasterio, & Sayre, 1995). This suggests that the 'easy gains' from traditional breeding techniques have been achieved, so that further gains require more powerful technologies (Bajaj, 1990).

One technology receiving much attention is genetic modification (GM). The current generation of GM technologies tends to affect how crops are produced, particularly searching for potential increases in yield and/or reductions in costs (Caswell, Fuglie, & Klotz, 1998; Fernandez-Cornejo & McBride, 2000, 2002; Organisation for Economic Cooperation and Development [OECD], 2000). The two objectives are not always achieved together. University varietal trials (Benbrook, 1999) and field trials (Marra, Pardey, & Alston, 2002) of herbicide-tolerant (Ht) soybeans, for example, indicate lower yields in 1997 and 1998, while the USDA found only small yield *increases* (Fernandez-Cornejo & McBride, 2002). Ht soybeans are generally associated with higher use of glyphosate herbicide (Roundup) but lower use of other herbicides (Commission of European Communities [CEC], 2000; Duffy, 2001; Fernandez-Cornejo & McBride, 2000; Shoemaker et al., 2001). Management and labor effort are lower for Ht crops because they make weed management easier. Farmers can use fewer pesticides and have a wider window for their use than with other weed management programs (Benbrook, 2001; CEC, 2000; Duffy, 2001; Fernandez-Cornejo & McBride, 2002; Gianessi, Silvers, Sankula, & Carpenter, 2002). Overall, the impact of Ht soybeans on net returns is uncertain, as research has found reduced returns (Benbrook, 1999), increased returns (Shoemaker et al., 2001), and no effect (Duffy, 2001; Fernandez-Cornejo & McBride, 2000, 2002).

Other specific biotechnologies have not received the same attention, and there has been little work on valuing the impacts on agricultural production associated with the four biotechnologies considered in this article. However, the GM research does suggest that a new biotechnology may affect two different dimensions of agricultural production (Caswell et al., 1998; Shoemaker et al., 2001). The first dimension is product quality, or the extent to which the primary product is altered by biotechnology. Such changes may affect demand for the product, perhaps allowing product differentiation in the market and a competitive advantage for adopters (Porter, 1991). The second dimension considers production systems with and without the new biotechnology. Some innovations are simply input substitutes; they replace non-biotech inputs. Other biotechnology applications may lead to more radical changes. Any change may be expected to affect the cost per unit of output through changes in inputs and yield. They may also affect the configuration of input factors (Barney, 1986) and/or the activity structure (Porter, 1991) of production.

Four Important Biotechnologies in New Zealand

The first task of the research project was to determine the most important biotechnologies that have been adopted by the primary sector in New Zealand. After widespread consultation with experts, four biotechnologies were identified.

Clonal propagation/cell manipulation

In vitro cell and tissue cultures have many direct and indirect commercial applications, including:

- clonal propagation using meristem and shoot culture to produce large numbers of identical individuals;
- removal of viruses by heat treatment and propagation from meristematic tissues;
- doubling chromosome numbers of cells to enable wide crosses, attain homozygous lines more rapidly in breeding programs, or produce polyploid plants for sale;
- crossing distantly related species, rescuing the embryo and regeneration of the novel hybrid;
- screening cells, rather than plants, for advantageous characters; and
- growing plant cells in liquid culture as a source of secondary products.

Bio-Control Agents

Classical bio-control seeks control of a pest at the ecosystem level and is therefore of general benefit to all primary sector producers (Auld, 1998). This was not included in the New Zealand study, which focused instead on the adoption of modern bio-control agents derived from organisms, such as insecticides based on the bacterium *Bacillus thuringiensis* (Bt). Biotechnological techniques, particularly isolation and multiplication under sterile conditions, are important in producing quantities of some bio-control agents: for example, using fungal formulations for weed control and using viruses and nematodes for insect control.

Enzyme Manipulations

Enzymes are proteins that can catalyze reactions at low concentrations. They are the basis of biological reactions and are ubiquitous in nature. Basic studies in cell biology have improved knowledge of enzyme properties so that now their activity can be harnessed to perform a number of functions, including some that were previously undertaken using harsh chemicals. Enzymes are used across a wide range of activities including feed quality, waste management, food processing, textile manufacture, and bleaching of wood pulp.

Marker-Assisted Selection

Selection to improve the performance of economically valuable species of animals and plants has been carried out for centuries on the basis of the phenotype of individuals. This has been effective for traits controlled by major genes, such as dwarfing in wheat, flower color, absence of horns, and resistance to some diseases. It has been less successful for quantitative traits, such as yield or quality, that are usually controlled by many genes, which are termed quantitative trait loci (QTL). Genetic linkage maps can be used to locate genes, including those affecting quantitative traits of economic importance in plants or animals. By using molecular markers closely linked to particular genes, or located within one or more QTL, information at the DNA-level can be used for early selection. This allows selection at the genotype level in a similar fashion for genes of major phenotypic effect. The potential benefits of marker-assisted selection (MAS) are greatest for traits that are difficult, time-consuming or expensive to measure, or can only be measured after reproduction has been completed. Mapping and MAS tend to be used mainly in species of high economic value and have most potential in clonal breeding programs, where additional genetic gains can be rapidly multiplied.

Methodology of the New Zealand Research

The project's research design involved the following elements:

- *Identification of production impacts.* This included market and non-market impacts. A key consideration was the counterfactual, the situation that would have prevailed in the absence of each of the four biotechnologies, against which the impact of the biotechnology was estimated.
- *Identification of economic impacts.* Information regarding the production impacts formed the basis for calculations of costs and benefits of the technology. The research was restricted to commercialized biotechnology innovations, so that estimates of the potential impact of current scientific research were not considered.
- *Analysis of net benefits to producers.* The calculation of net benefits involved two elements. The first was to ensure that the calculation included additional costs involved in adopting the new biotechnology. The second was to estimate what would have been the return to producers using the (non-biotechnological) next best alternative method of production, and to subtract this return from the calculated gross returns after adoption.
- *Review of study and assumptions.* This study and its underlying assumptions were extensively reviewed by the research team and by a wide range of biotechnology stakeholders in New Zealand.

To identify the production and economic impacts, the Agribusiness and Economics Research Unit (AERU) research team drew up a list from 78 different organizations of 115 key informants who could provide relevant information. These informants were in three broad groups. One group could explain the science involved and how the biotechnology affected physical production. Another group could explain the commercial or economic benefits. The third group could provide context or overall industry information. From this list, 59 individuals agreed to participate in semi-structured interviews, which took place between April and June 2005. Some interviews were face-to-face, others were by telephone. Some informants provided relevant background documents and others answered questions on specific points by email. Informants were specifically asked about adoption patterns, characteristics of markets, upstream and downstream impacts, and the impacts of not having biotechnology.

These interviews allowed identification of all innovations of commercial importance to New Zealand relying on the four biotechnologies. Using primary and secondary data sources, the analysis then estimated the direct economic value of each innovation to primary producers. An example is the growing of potatoes in New Zealand, which has been significantly improved by tissue culture used after heat treatment to propagate the initial generation of plants that are then used to produce seed potatoes. This produces virus-free, uniform seed potatoes and does so more quickly than older methods of propagation. The industry depends to such an extent on tissue culture that one key informant suggested the potato industry would disappear without it, while others suggested that production would fall by two-thirds to three-quarters.

The net benefits of this productivity increase were estimated from farm production budgets reported in Burtt (2004). These suggest that the average gross margins for growing potatoes between 1999 and 2003 were

Table 1. Summary of value of direct impacts of four biotechnologies.

Subsector	Clonal propagation / cell manipulation ($000)	Bio-control agents ($000)	Enzyme manipulations ($000)	Market-assisted selections ($000)	Total ($000)
Dairy	74,914	19,893	3,791	nil	98,598
Beef and veal	20,890	772	nil	nil	21,662
Sheep (meat and wool)	35,287	41,353	nil	770	77,410
Forestry	16,976	nil	nil	nil	16,976
Horticulture/ floriculture	32,995	small value	9,960	nil	42,955
Arable crops	8,220	nil	nil	nil	8,220
Seafood	nil	nil	nil	nil	0
Total	**189,282**	**62,018**	**13,751**	**770**	**265,821**

NZ$1,438 per hectare. Aggregating this to the approximately 10,600 hectares in production (HortResearch, 2003) produced total gross margins of NZ$15.2 million. Drawing on the information from the interviews that without tissue culture biotechnology there would be a smaller industry producing a much smaller crop (75% smaller), the estimated net benefit of this biotechnology to potato producers is calculated to be NZ$11.4 million.

Results

The research analysis was sufficiently detailed to allow results to be disaggregated by commodity. The dairy subsector is the largest for New Zealand, and is centrally organized around one firm (Fonterra). Horticulture, including floriculture, is the second largest and comprises a wide range of products and farm types. Sheep, beef and veal, and forestry subsectors are all largely based on extensive land use practices and tend to be export-focused. The arable subsector is small relative to the others. Finally, seafood is another export-driven area of primary production, and is based on both wild and farmed production.

The information obtained in the semi-structured interviews can be grouped under the following headings:

- *Range of impacts.* The identified technologies affected both the product qualities and production practices. For example, input-oriented innovations appeared to generate the greatest returns for livestock, whereas product quality innovations were more important for horticulture.
- *Nil results.* In some cases participants could identify subsectors where the biotechnologies do not appear to be producing material commercial impacts. Significantly, MAS appeared to be creating little commercial value outside the sheep subsector.
- *Extent of contributions of biotechnology.* The survey revealed the importance of complementary factors, such as natural resources, management effort, human labor, and machinery, in increasing returns from the primary sector.
- *Awareness of the value of innovations.* Commercial considerations seemed to be minor factors in the research and development of many innovations identified.
- *Commercialization of biotechnology.* Many informants distinguished between fundamental science and commercial application. Commercialization resulted from using fundamental science to produce usable, convenient innovations within the context of a production system. Profiting from commercialization required business expertise in addition to technological proficiency.

As described in the previous section, data provided in the interviews on the specific production impacts of a biotechnology could be used with secondary data to provide an estimate of an innovation's direct economic impact. In some cases, proxies were needed to give an estimate of the economic impact (see Kaye-Blake et al., 2005, for a full description of the valuation methods used). For example, informants identified increases in arable crop yields as a benefit of cellular biotechnology, but estimates of the size of the benefit relied on the international literature on crop genetic gains (Abeledo et al., 2002; Bajaj, 1990; Evenson, 2003; Traxler et al., 1995).

The estimated net benefits of the four biotechnology innovations to the primary sector of New Zealand are presented in Table 1. The total direct net benefit (assuming no changes in world prices due to the production effects, and not including any macroeconomic multiplier effects) is estimated to be NZ$266 million per year.

Clonal propagation/cell manipulation represents the largest contributor by virtue of its widespread and relatively long-term use in New Zealand. Bio-control agents and enzyme manipulations had smaller economic impacts. The least-commercialized biotechnology was MAS, contributing less than NZ$1 million.

There are significantly different contributions in the subsectors. Dairy production benefits most, even without accounting for the economic impacts of processing enzymes. This result is largely a function of the economic importance of dairy production in New Zealand. Other pastoral agriculture also benefits, with impacts on sheep production larger than those on beef production. The horticulture subsector shows significant benefits for some crops (e.g., potatoes, floriculture), while other crops are barely affected. The value of arable crop impacts is relatively small, a function of the size of the subsector. Impacts are relatively small for forestry and nil for seafood, due to lack of commercialized innovations in this last subsector.

Overall, these results point to uneven contributions of these biotechnologies across the primary sector. Some biotechnologies are so integrated in some subsectors as to be no longer remarkable. However, since they are so integrated, their impacts are significant. Other biotechnologies do not seem to produce large commercial returns, especially MAS. Furthermore, some parts of the primary sector have been barely touched by these biotechnologies.

Conclusion

The research reported in this article assessed the economic impact of the current commercial use of four biotechnologies in the primary sector. By choosing four specific biotechnologies and assessing only commercialized innovations, this research makes three contributions to previous studies. The first contribution is to estimate actual realized benefits, rather than potential future benefits. Secondly, the focus on commercially released technologies avoided potential issues regarding public perceptions and foreign market access that has dominated much policy debate in New Zealand. Thirdly, and most importantly, the study was able to disaggregate its results by subsector and biotechnology. The total annual direct net benefit of these biotechnologies to New Zealand primary sector producers was estimated at NZ$266 million. The sectors with the largest impacts are dairy, sheep, and horticulture. The biotechnology with the largest impact is clonal propagation/cellular manipulation, while marker-assisted selection had the least impact.

A report by the New Zealand Treasury (Black, Guy, & McLellan, 2003) notes that the primary sector was a standout performer in New Zealand's productivity growth, particularly between 1993 and 2002 when the annual productivity growth of the primary sector (2.45%) was nearly twice as high as the national average (1.32%). It is therefore sensible to ask what role biotechnology has played in this impressive performance by the sector. Based on estimated value of production and estimated gross margins, it was possible to address this question for the dairy, beef and veal, and sheep subsectors (Kaye-Blake et al., 2005). The value of dairy output at the farm gate in the 2003/04 season, for example, was estimated to be around NZ $5.3 billion (based on Ministry of Agriculture and Forestry [MAF], 2004), with a gross margin of NZ $0.79 per revenue dollar. This suggests an annual value of total gross margin in dairy equal to NZ $4.2 billion. In Table 1, the contribution made by the four biotechnologies to dairy gross margins is NZ $98.6 million; that is, about 2.4%. Similar calculations for beef and veal, and for sheep, suggest contributions of about 1.9% and 3.9%, respectively. These calculations suggest that biotechnology adoption has played a positive, but not a dominant, role in New Zealand's primary sector growth.

This analysis, however, does not address the non-marketed impacts of biotechnology. The interviews and the wider international literature both suggest that biotechnology could provide numerous non-marketed benefits, especially by reducing the negative environmental impacts of primary sector activities. Currently, both the extent and value of such positive externalities have not been measured, but they may be an important contribution to the country's overall social, economic, environmental, and cultural well-being.

References

Abeledo, L.G., Calderini, D.F., & Slafer, G.A. (2002). Physiological changes associated with genetic improvement of grain yield in barley. In G.A. Slafer, J.L. Molina-Cano, R. Savin, J.L. Araus, & I. Romagosa (Eds.), *Barley science - Recent advances from molecular biology to agronomy of yield and quality* (pp. 361-385). Binghamton, NY: Food Products Press.

Auld, B.A. (1998). On the social value of biological control of weeds. *International Journal of Social Economics*, *25*(6/7/8), 1199.

Bajaj, Y.P.S. (1990). Biotechnology in wheat breeding. In Y.P.S. Bajaj (Ed.), *Biotechnology in agriculture and forestry 13* (pp. 3-23). Berlin: Springer-Verlag.

Barney, J.B. (1986). Strategic factor markets: Expectations, luck, and business strategy. *Management Science*, *32*(10), 1231-1241.

Benbrook, C. (1999). *Evidence of the magnitude and consequences of the Roundup-Ready soybean yield drag from university-based varietal trials in 1998 (no. 1)*. Sandpoint, Idaho: Benbrook Consulting Services.

Benbrook, C. (2001). Do GM crops mean less pesticide use? *Pesticide Outlook*, *12*(5), 204-207.

Black, M., Guy, M., & McLellan, N. (2003). *Productivity in New Zealand, 1988 to 2002* (Working Paper No. 03/06). Wellington: New Zealand Treasury.

Burtt, E.S. (Ed.). (2004). *Financial budget manual 2004*. Canterbury, New Zealand: Lincoln University.

Caswell, M.F., Fuglie, K.O., & Klotz, C.A. (1998). *Agricultural biotechnology: An economic perspective* (Report 687). Washington, DC: Economic Research Service, United States Department of Agriculture.

Commission of the European Communities (CEC). (2000). *Economic impacts of genetically modified crops on the agri-food sector*. Brussels, Belgium: Author.

Duffy, M. (2001, December). *Who benefits from biotechnology?* Paper presented to the American Seed Trade Association meeting, Chicago, IL.

Duvick, D.N., Cooper, J.S.C., & Smith, M. (2004). Changes in performance, parentage, and genetic diversity of successful corn hybrids, 1930-2000. In C.W. Smith, J. Betran, & E.C.A. Runge (Eds.), *Corn: Origin, history, technology, and production* (pp. 65-97). Hoboken, NJ: John Wiley.

Evenson, R.E. (2003). Production impacts of crop genetic improvement. In R.E. Evenson and D. Gollin (Eds.), *Crop variety improvement and its effect on productivity* (pp. 447-471). Wallingford, UK: CABI Publishing.

Evenson, R.E., & Gollin, D. (Eds.). (2003). *Crop variety improvement and its effect on productivity*. Wallingford, UK: CABI Publishing.

Fernandez-Cornejo, J., & McBride, W. (2000). *Genetically engineered crops for pest management in U.S. agriculture: Farm-level effects* (Report 786). Washington, DC: Economic Research Service, United States Department of Agriculture.

Fernandez-Cornejo, J., & McBride, W. (2002). *Adoption of bioengineered crops* (Report 810). Washington, DC: Economic Research Service, United States Department of Agriculture.

Gianessi, L.P., Silvers, C.S., Sankula, S., & Carpenter, J.E. (2002). *Plant biotechnology: Current and potential impact for improving pest management in U.S. agriculture*. Washington, DC: National Center for Food and Agricultural Policy.

HortResearch. (2003). New Zealand horticulture facts and figures. Palmerston North, New Zealand: Author.

Kaye-Blake, W., & Saunders, C. (2006, July 23-26). *Estimated contribution of four biotechnologies to New Zealand agriculture*. Paper presented at the American Agricultural Economics Association Conference, Long Beach, CA.

Kaye-Blake, W., Saunders, C., Emanuelsson, M., Dalziel, P., & Wreford, A. (2005). *The economic contribution of four biotechnologies to New Zealand's primary sector* (AERU Research Report No. 270). Canterbury, New Zealand: Lincoln University.

Marra, M.C., Pardey, P.G., & Alston, J.M. (2002). *The payoffs to agricultural biotechnology: An assessment of the evidence* (Report 87). Washington, DC: Environment and Production Technology Division, International Food Policy Research Institute.

Ministry of Agriculture and Forestry (MAF). (2004). Situation and outlook for New Zealand agriculture and forestry. Wellington, New Zealand: Author.

New Zealand Government (2003). *New Zealand biotechnology strategy*. Wellington, New Zealand: Ministry of Research, Science and Technology. Available on the World Wide Web: http://www.morst.govt.nz/Documents/work/biotech/NZ-Biotech-Strategy.pdf.

Organisation for Economic Cooperation and Development (OECD). (2000). *Modern biotechnology and agricultural markets: A discussion of selected issues*. Paris, France: Directorate for Food, Agriculture and Fisheries, Committee for Agriculture.

Porter, M.E. (1991). Towards a dynamic theory of strategy. *Strategic Management Journal*, *12*, 95-117.

Shoemaker, R., Harwood, J., Day-Rubenstein, K., Dunahay, T., Heisey, P., Hoffman, L., et al. (2001). *Economic issues in agricultural biotechnology* (Agriculture Information Bulletin No. 762). Washington, DC: Economic Research Service, United States Department of Agriculture. Available on the World Wide Web: http://www.ers.usda.gov/publications/aib762/aib762.pdf.

Traxler, G., Falck-Zepeda, J., Ortiz-Monasterio, J.I.R., & Sayre, K. (1995). Production risk and the evolution of varietal technology. *American Journal of Agricultural Economics*, *77*(1), 1-7.

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