The impacts of research in an era of more stringent performance evaluation

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Invited paper presented at the New Zealand Agricultural and Resource Economics Society (NZARES) Conference, October 19-20, 2017, Rotorua, New Zealand.

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Summary

In response to an increasing requirement for Crown Research Institutes to demonstrate impact to their stakeholders, a new approach to the economic evaluation of the impacts of research undertaken by The New Zealand Institute for Plant & Food Research Limited (PFR) on the economic performance of five stakeholder sectors has been developed. A combination of quantitative data analysis and qualitative workshops was employed to estimate changes in the economic performance of each sector between 2000 and 2015, and allocate these among five key drivers of change. The drivers were 'Industry Initiatives'; 'the Market', 'Government', 'PFR Research', and a 'Wildcard' to account for significant changes driven by other events.

Keywords

Research evaluation; CRIs.

Introduction

The New Zealand National Statement of Science Investment has launched an era of more stringent performance evaluation across New Zealand's Science and Innovation System, and Crown Research Institutes are increasingly required to demonstrate the impact of their research to Government funding organisations. The New Zealand Institute for Plant & Food Research Limited (PFR) sought to establish a benchmark level for the value of its impact for a new key performance indicator in its Statement of Corporate Intent.

This paper presents the results of the most recent work in a programme of research monitoring and evaluation commissioned by PFR over many years to assess the impacts of its research on target industries, and to determine how those impacts occur and how they might be improved. Previously this work has involved a number of case studies of particular projects/programmes. However, some Government ministries have now signalled concern that the case-study approach may be seen as "cherry-picking" the good stories, with the result that benefit: cost ratios and rates of return are extraordinarily high, and that the full costs of delivering research are not accurately reflected. Consequently, the original objective of this study was to design and test a methodology to estimate the economic contribution of PFR to the primary sector as a whole. However, it was recognised that this task was too large to be completed within the required timeframe, and the scope of the study was reduced to focus on five of the largest industries with which PFR engages to deliver impact for New Zealand. These include the apple, avocado, kiwifruit, seafood and wine industries.

Analysis of economic impacts of agricultural research

Internationally the economic impact of agricultural research has been studied for decades. A seminal study examined hybrid corn in the United States (Griliches, 1957), and since that time such evaluations have been conducted in many countries, including New Zealand. Work by Julian Alston and co-workers (for example: Alston, et al., 2000; Alston, et al., 2009; Alston, 2010;) has included project-specific analysis, macro analysis, and meta-analysis. Alston's (2010) overall conclusion is that agricultural research has generated considerable benefits, at least an order of magnitude greater than costs (Alston, 2010, p. 16), and that this holds even where benefits are heavily discounted to counteract any upward bias that may have resulted from data issues or inappropriate choices of analytical approach.

In New Zealand, Hall & Scobie (2006) noted that "the literature is not replete with estimates of the impact of R&D investment". Their evaluation of the role of research and development in productivity growth in New Zealand agriculture from 1927 to 2001 built on earlier work on productivity growth, including Johnson (2000), Johnson et al. (2005) and Scobie & Eveleens (1987). Hall & Scobie (2006) used macroeconomic modelling techniques to estimate the contribution of both New Zealand agricultural research and foreign knowledge to productivity growth in the sector. They concluded that domestic research and development played a significant role in productivity development, but that in a small open economy the knowledge flow from overseas was also an important contributor.

Two main approaches to assessing economic impacts have been used in the past. The first of these is the "top-down", or macro-economic approach used by Hall & Scobie (2006). This approach is appropriate when examining the impacts of agricultural research at the national or state level, but not where it is necessary to examine the contribution of a particular organisation to specific sectors, because official statistics are not sufficiently disaggregated to identify impacts at these levels.

The second approach is the "bottom-up" project-focused or case-study approach. This method has been used in a series of case studies conducted for PFR (including Greer, 2013; 2014, 2015, 2016), Greer & Kaye-Blake, 2008; Kaye-Blake & Ferguson, 2007), and there are many examples of such studies in the Australian literature.

While these case-studies have given PFR and researchers a good understanding of how PFR works with different industries and the types of impacts that scientific research is likely to have, case studies have two limitations that affect their use in demonstrating the overall contribution of a CRI.

Firstly, case-studies may be subject to 'sselection bias'. The results from case-studies can be, and often are, dismissed as 'cherry-picking' – selecting the highest-impact projects and ignoring the others. Cherry-picking may lead to a false picture of the research programme as a whole, because the sample selected is biased. Larger, more visible, or more successful programmes tend to be selected since, from an organisation's perspective, it is more important to understand the performance of large programmes than small programmes.

Secondly, case-studies by their nature focus in considerable detail on the specific programme being evaluated. The depth of research and understanding required to develop a single case-study makes the approach unwieldy to apply across a whole organisation. In addition there are also considerable attribution problems in separating cause and effect, in particular spill-ins and spill-overs, in bottom-up analysis, or in attempting to sum values from case studies.

A promising approach has been suggested by work on recently established datasets to develop detailed productivity estimates for specific industries. Statistical work focusing on firm-level data has produced disaggregated productivity measures (Fabling, et al., 2014; Fabling & Maré, 2015). For example, Apatov, et al. (2015) provided estimates of productivity in the sheep sector based on data from 31,920 agricultural firms. However, Statistics New Zealand has expressed several concerns with the use of microdata for this purpose, including the short period for which data are available and the inability to distinguish trend from noise (John Upfold, Project Manager, Statistics New Zealand, pers. comm.), and declined to make data available for this purpose.

The French National Institute for Agricultural Research (*L'Institut national de la recherche agronomique* - INRA) has developed a recent innovation in analysis of the impacts of research. Like PFR, INRA sought to understand the mechanisms by which its research produces impacts, be accountable for funding, and communicate with stakeholders about the research and its impacts (Colinet, et al., 2014). INRA has encountered the same research evaluation difficulties as others (Colinet, et al., 2014). There are difficulties in conducting systemic analysis of impacts; the systems to do such work are lacking, and the academic literature has not settled on a definitive method of evaluation. Most importantly there is a divide between the theoretical literature and the evaluation methods actually used in practice. Consequently, INRA researchers developed a new method for evaluating research programmes, known as ASIRPA (Analysis of the Impacts of Public Agricultural Research) (Colinet, et al., 2014; Joly, et al., 2015).

This methodology was based on a case-study approach, but involved analysis of a large number of research projects/programmes (33) that had been conducted in the reasonably recent past (15 years), specifically selected to reflect the diversity of impacts that INRA research had on its stakeholders. The research method demonstrated both an understanding of the wide literature on the impacts of research, particularly the emerging practice of impact pathway analysis, and a pragmatic approach to generating information that provides insights into how and from which investments INRA generates impact for stakeholders.

It was not possible to conduct large numbers of case-studies of the research undertaken for each key stakeholder sector within the constraints of the resources available for the PFR impact evaluation. However, several key features of the ASIRPA approach were considered to be of value in attempting to estimate PFR’s impact.

They included the use of experts to provide information and judgement, rather than relying solely on statistical data. The first step in evaluating each programme was the development of a chronology of key changes or events that resulted in improvements in the economic performance of the industry over the period from 2000 to 2015, including the research and its impacts. Researchers and experts then developed quantitative measures of the relative importance of the changes/events driving industry during that timeframe using a 5-point scale. They recognised that subjective judgement was involved applying these, but noted the importance of developing simple, widely applicable, comparable metrics.

Method

A novel method to estimate the economic impacts of primary sector research was developed that used both quantitative and qualitative approaches to estimate the impacts of research on five primary industries that are key areas of research focus for PFR. The industries were the apple, avocado, kiwifruit, seafood, and wine industries. The method included three steps: estimating the economic performance of the industries from 2000 to 2015; undertaking workshops at which key changes/events that led to changes in industry performance were identified along with the relative importance of the drivers of those changes; and allocating the total change in GDP contribution by each industry amongst the drivers of change.

Estimating the Economic Performance of the Industries

The measure of economic performance selected for the analysis was the industry contribution to New Zealand's Gross Domestic Product (GDP). The annual value of exports from each sector for each year from 2000 to 2015 was used as a proxy for the total gross output of the sector because reliable data on the value of domestic sales were not available for several of the industries analysed, and exports generate a very high proportion of revenue for these industries.

Separation of the returns to the primary and post-harvest sectors was necessary because of differences between them in the levels of value-added and intermediate inputs employed and, therefore, in their contributions to GDP. Data on the total value of exports from each sector were available from the official export statistics (Statistics New Zealand, 2015a). A range of data, including MPI farm monitoring data (MPI, various years), statistics published by industry organisations (NZ Wine 2015; New Zealand Avocado,2015) and land use statistics reported in the Agricultural Production Census (Statistics New Zealand, 2015b), was used to estimate the proportion of total export values from the land-based industries attributable to the production and processing sectors. Lack of data made this exercise impossible for the seafood sector.

Export values attributed to grower and post-harvest activities were multiplied by their respective value-added ratios from the National Accounts input-output tables to estimate GDP contribution by activity. The sum of these values is the estimated GDP contribution from the sector as a whole. In the seafood sector, the value-add ratios for the two activities were averaged, and the result applied to the total export value. The calculation can be written as:

$$GDP = X_G \times VA_G + X_P \times VA_P$$

Where:

GDP is sector GDP contribution

X_G is sector export attributed to growers

VA_G is the value-add ratio for growers

X_P is exports attributed to post-harvest activities

VA_P is the value-add ratio for post-harvest activities.

The annual contributions were converted to real 2015 dollars using the consumers' price index (CPI) (Statistics New Zealand, 2015c).

In order to estimate the changes in GDP over time it is necessary to compare the annual GDP estimates with a baseline or counterfactual. GDP is affected by the level of inputs and by productivity changes in the sector, but it was not possible to estimate the changes in inputs or productivity levels of individual sectors. Several analytical approaches to estimating the change in GDP contribution were considered, including a microeconomic firm-level approach, and an industry-level approach based on estimates of employment, capital investment, and land values. However, it was determined that the most appropriate approach given the data limitations was to estimate a baseline value-added per hectare for each year from 2000 to 2015 that incorporated changes in the number of hectares used for production and changes in proportion of commodity exported. The baseline was an estimate of sector value-added each year, under the assumption of constant productivity per hectare and in the absence of changes driven by markets, research, technology, or industry initiatives.

The changes in the contribution to GDP that can be attributed to changes in productivity in each of the five industries analysed were calculated by subtracting the baseline values from the estimated annual GDP contribution. Generally, the counterfactual scenario includes all influences on productivity except the impacts of the innovation under evaluation. However, using this approach the total change in productivity is attributed to key drivers of change, during the next stages of the analysis.

The counterfactual for the seafood industry, which is not primarily land-based, could not be estimated using the approach described above because of the lack of data available on the industry. The baseline contribution to GDP was assumed to be the 2000 level of GDP contribution in constant (real) dollars. The New Zealand quota system limits the amount of fish caught each year, effectively limiting the wild-catch industry. With this cap in place, it is difficult for the industry to grow by increasing the quantity of fish caught. Instead, increases in GDP could only arise as a result of increased productivity in processing the harvest, selling the current catch into higher-value markets, or increasing the value of the raw product. which can be considered to be productivity improvements.

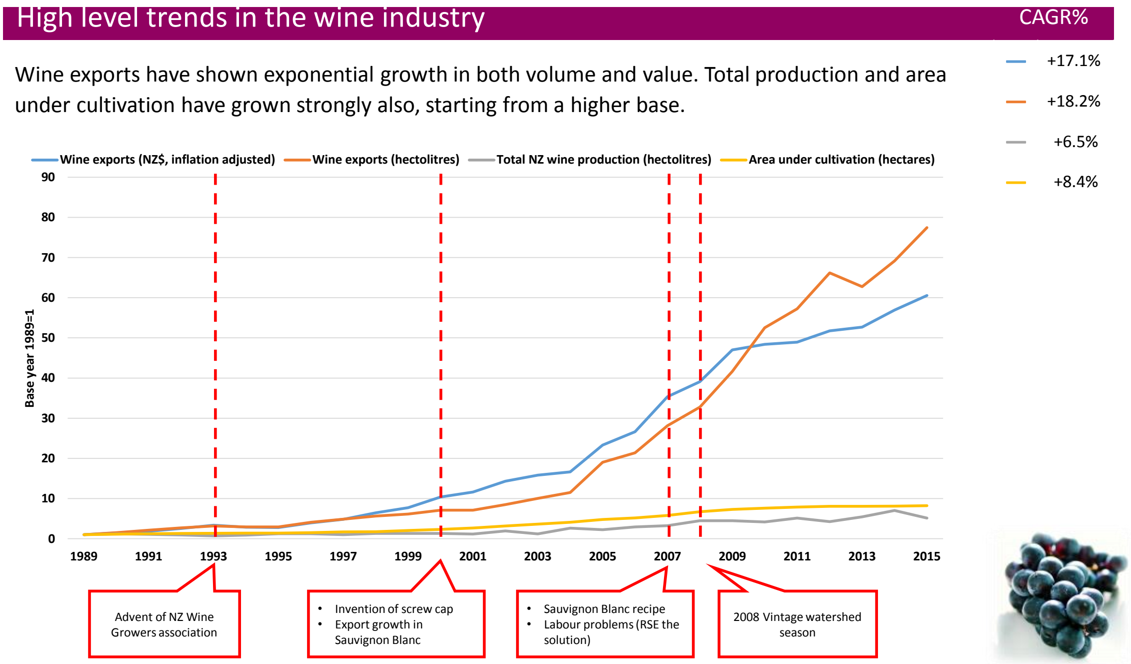
Industry Workshops to Identify Key Drivers of Change

Since the data required to evaluate the contribution of PFR research to the increase in productivity in key export sectors since 2000 were not available from secondary sources, a novel approach to obtaining ‘expert opinion’ on the key influences on productivity growth was developed. This approach involved using expert workshops to derive an understanding of the milestones underpinning industry development in each of the five industries and the drivers behind those milestones. A second round of evaluation, conducted by means of an email survey, allowed participants to refine their estimates in the light of the group “average” responses.

The series of two-hour workshops, each involving stakeholders from a single industry, was held between April and June 2016, at locations central to each of the industries. The participants invited to each of the workshops were selected after consultation with industry representatives and key researchers working with those industries, and included both industry stakeholders and researchers. The numbers of participants, excluding the presenters, ranged from 10 to 15. While the groups comprised stakeholders representing different parts of the industries, it cannot be assumed that the views expressed by small groups such these are truly representative of industry as a whole. However, the inclusion of experts with a wide range of roles in the industries and their research communities provided an opportunity for participants to consider industry development in a broader context than their own area of expertise alone.

Before the workshops were held, a desktop exercise was conducted to identify the pathways of industry development during the last 20 years and key events that appeared to have influenced development. From this, a diagrammatic chronology of industry development for each industry was prepared using key parameters (such as total exports, production volumes or areas planted) in which changes have been observed over the period were charted, and times of very significant change identified. Figure 1 shows the chronology presented to the wine industry workshop.

Figure 1: Chronology Presented at the Wine Industry Workshop



The chronologies were described in a presentation at the beginning of each workshop before group participants were asked to identify any important changes/events that had not been identified by the researchers. This process involved considerable debate during each of the workshops and the participants as events that had not been included in the original lists were added. The most important events influencing recent industry development (between five and nine events) were then selected. The nature of the changes/events selected was diverse, and they included (but were not limited to) changes in industry structure and cohesion; changes in market demand; regulatory change; significant developments as a result of research into new cultivars; production systems; postharvest technologies; and the impacts of programmes established to improve product quality and market acceptability.

For each change/event participants were asked to assess whether the key drivers were ‘Market’, ‘Industry’, ‘Research’, ‘Government’, and/or a ‘Wild-card’ driver particular to that industry. The drivers were explored in terms of the nature of their impacts and their relative importance to the achievement of change. Drivers included factors that initiated an industry response/change and those behind the response itself. For example, Psa-V (a bacterial disease that decimated the gold kiwi fruit industry) caused a significant change in the kiwifruit industry (a wildcard driver specific to that industry), but the response driven by industry, research, and government resulted in a solution that not only overcame that problem but also resulted in acceleration of growth in industry productivity.

The workshop format facilitated interaction amongst the participants that enabled them to refine and evaluate their own views in the light of the opinions of others, but no attempt was made to reach a group consensus during the workshops. Instead, after the group discussion of the drivers, participants were asked to consider each of the most important events and, using a form provided, rate the drivers they considered to have had any impact on the outcome. A five-point scale on which 1 = Minor importance to 5 = Vital importance, was used to rate all drivers that had contributed to the outcome (Colinet, et al., 2014). Drivers not considered relevant to each milestone were assigned a value of zero. The drivers were assessed according to their contribution to the outcome, rather than directly against each other, so assigning the same rating to more than one driver was acceptable.

A simple version of the Delphi technique, which has been widely used as a method of achieving convergence of expert opinion on topics for which hard data are not readily available since the 1950s, was used to refine the estimates of the contribution of each driver to industry developments. After each workshop the average, maximum and minimum ratings given to each milestone were calculated, and these data were sent back to participants by email. They were asked to re-rate the drivers behind each of the key milestones in the light of the summarised data. Most respondents participated in the second-round ranking exercises.

Estimation of the PFR contribution to industry performance

For each of the events or changes identified, the relative importance of the drivers of that change was estimated to be the second round rating assigned to the driver divided by the total of average second round ratings assigned to the change or event. For example, the drivers of the changes associated with the arrival of Psa-V and the kiwifruit industry response to this were assigned ratings that totalled 17.7 on average, while the average rating assigned to PFR research was 4.6. The contribution of PFR research to those changes was estimated to be 26 per cent.

The impacts of each of the changes that resulted in increases in GDP were treated cumulatively, and the impacts of each change were assumed to continue from the date of the change to the end of the analysis period. Consequently, the difference in GDP contribution in any year was assumed to be the result of all the key events or changes that had occurred until that time. This approach was intended to capture the lags that occur between milestone events and their long term impacts on the economic performance of the industry.

The estimated contribution of each driver to the total increase in GDP over the base level in any year was estimated to be the sum of its contribution to each of the events that had contributed to the increase. Consequently the contribution of PFR research, and other drivers, to the increases in GDP of an industry varies throughout the analysis period.

Results

The events identified and relative importance of key drivers differed widely amongst the industries included in the study. As an example, the results of the analysis of PFR's contribution to the apple industry are described below.

Workshop Results – Apple Industry

At the apple industry workshop participants identified a short list of the seven most important milestones. The milestones and the dates from which they influenced the industry's economic performance are shown in Table 1.

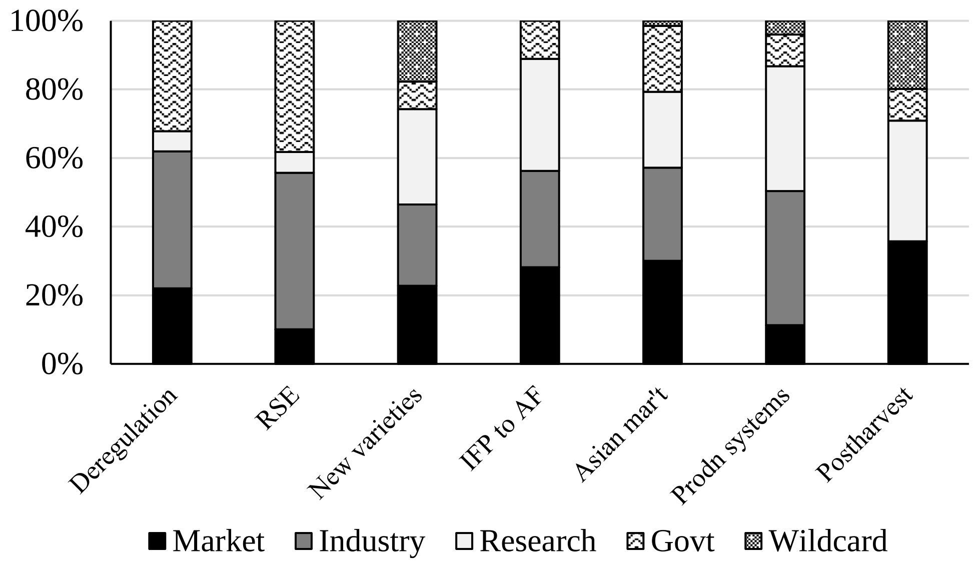
Table 1: Key milestones and dates for the apple industry

Year[a]	Milestone
1992	Production systems – M9 dwarf rootstock plantings, pruning and planting regimes
1996	Integrated fruit production (IFP)
2000	Post-harvest systems tailored to target markets
2000	New varieties introduced targeting specific markets, e.g. Jazz, Envy
2001	Deregulation of industry
2003	Asia as a new market for exports
2008	Recognised Seasonal Employer (RSE) legislation

[a] The dates listed were estimated by workshop participants to be the dates from which changes affected industry performance. It was difficult to assign exact dates to some events.

The average values (0 to 5) assigned by workshop participants to the five potential drivers of change (Market, Industry, PFR Research, Government, and a Wild card category to capture the impacts of other factors), associated with each of the key events are shown in Figure 2. These results were derived from the second-round ranking, but were very similar to those of the first round for most drivers, suggesting that participants were confident that the ratings assigned at the workshops fairly represented the views of the stakeholders involved.

Figure 2: Second Round Driver Ratings – Apple Industry



The average driver scores assigned at the workshop are presented in Table 2. Over all milestones, industry was the most important driver of change in the apple industry (average score 4.3), followed by research (3.1) and market (3.0).

Table 2: Average Score for Each Driver by Key Milestone for the Apple Industry

Milestone	Market	Industry	Research	Government	Wildcard
Deregulation	2.6	4.8	0.7	3.9	0.0
RSE	1.1	4.9	0.6	4.1	0.0
New Varieties	3.9	4.0	4.7	1.4	3.0
IFP	4.0	4.0	4.6	1.6	0.0
Asian Market	4.4	3.9	3.2	2.8	0.2
Production Systems	1.2	4.2	3.9	1.0	0.4
Post-Harvest	3.9	4.1	3.8	1.0	2.1
Average	3.0	4.3	3.1	2.3	0.8

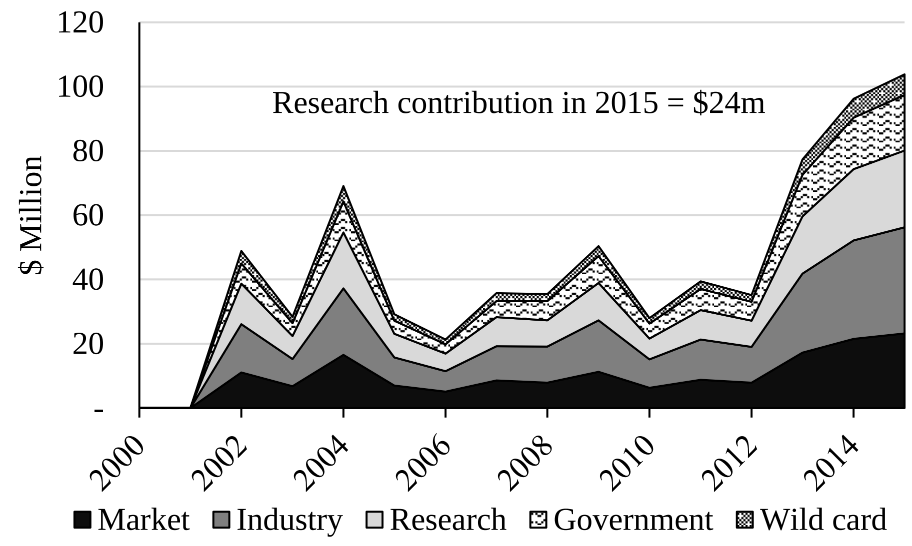
The average scores assigned to the drivers in the second round were used in the analysis to estimate the dollar contribution of each driver to the increase in the apple industry GDP relative to the counterfactual between 2000 and 2015.

Analytical results – apple industry

The economic performance of the apple industry has been variable. From the mid-2000s, export values declined below the value in 2000, but they have increased rapidly since 2012, and this trend is forecast to continue. Between 2012 and 2015 the area planted in apples increased by 11 per cent, and export production had increased by almost 16 per cent (Pipfruit New Zealand, 2015).

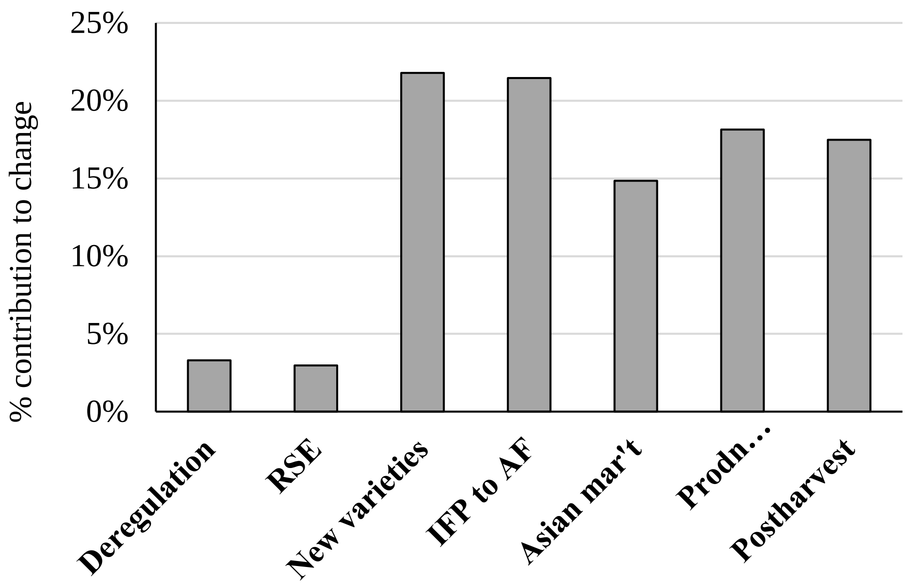
Many of the key milestones in the apple industry occurred in the early 2000s, but the impacts on export values took longer to be realised. This was particularly true of the new premium apple varieties, which take several years to reach full production. As Figure 3 shows most of the impact of change on GDP could be observed only after 2012. By 2015 the estimated growth in GDP was $103.8 million. The industry was considered by workshop participants to have been responsible for the largest share of the increase (32 per cent), while research contributed 23 per cent and market changes 22 per cent.

Figure 3: Contribution to Apple Sector GDP (base year = 2000)



In 2015, the estimated increase in apple industry GDP as a result of research was $23.9 million in total, but the contribution of research as a driver varied widely amongst the milestones that led to the economic growth of the industry. Research contributed most to the development of improved production systems (36 per cent), to the development of the pathway from Integrated Fruit Production to Apple Futures (33 per cent) and to the development of new varieties (28 per cent) (See Figure 4).

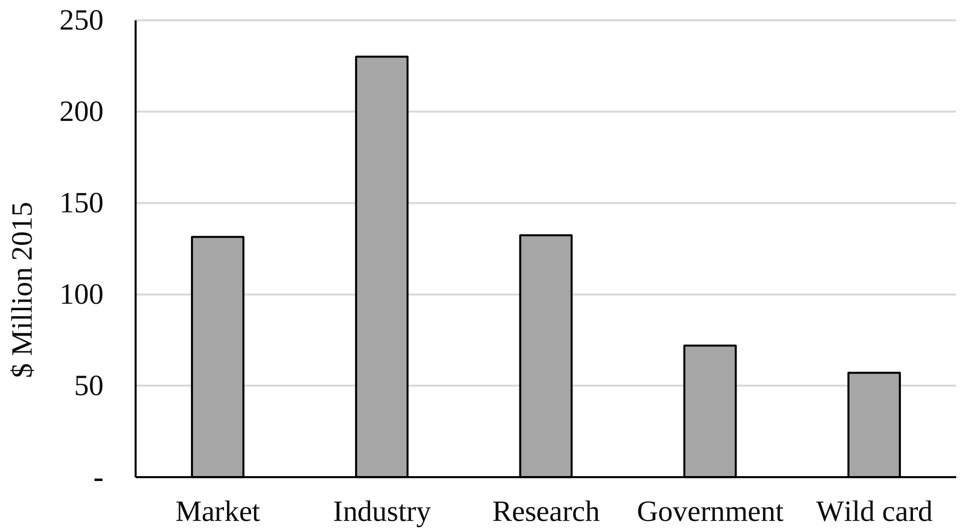
Figure 4: Average Rating of Research as a Driver of Industry Changes and its Contribution to Achievement of Change – Apple Industry



Analytical results across all industries

Although there was some variation amongst industries in the relative importance of the key drivers of change, industry initiatives were considered by participants at all workshops to have been the most important driver of the key changes that led to economic growth (30 to 46 per cent) (see Figure 5). The market and research made approximately similar contributions of between 20 and 25 per cent. PFR research is estimated to have accounted for 21 per cent of the total growth in GDP from exports between 2000 and 2015. In 2015 the value of exports in real terms was $623 million higher than in 2000, and the value of PFR's contribution was estimated to be $132 million.

Figure 5: Driver Contributions to Additional 2015 GDP From Exports, All Industries



Discussion

The approach developed for valuing the economic contribution of PFR research to primary sector industries differed from earlier economic evaluations of primary sector research in a number of key aspects. Firstly, it examines the contribution of PFR research and other drivers in the context of industry performance during the analysis period, rather than as the contribution of specific research outputs to solving industry problems. It recognises that research is only is one of several interacting drivers of economic performance, and estimates of the value of research were dependent not only on the actual improvements in economic performance, but also on the relative contributions of other drivers.

Secondly, in addition to using the most reliable quantitative data available, it relies heavily on the qualitative expert judgement of key industry stakeholders in relation to the relative importance of the research as a driver of change. Building on the approach used in the INRA research (Colinet, 2014), structured workshop exercises were conducted to elicit qualitative judgements about the relative impacts of the drivers of industry performance and express these as ratings. The ratings, in combination with the estimates of industry economic performance, were used to derive the contributions of the key drivers to GDP growth. This approach had a basis in prior work, but was more subjective than an econometric analysis of macroeconomic data series. Using expert opinion allowed us to incorporate elements of the case-study approach, while still focusing on the industry-level statistics.

Thirdly, it has established a standardised approach to collecting data, analysing economic performance, holding workshops, and calculating the impact of research across all the industries. Colinet, et al. (2014) reported that the advantages of a standardised approach were that it allows researchers to make comparisons across a number of different projects (where individual case studies were undertaken) and that it would allow the method to be replicated in later years to assess change over time. Although the industry-level approach precludes comparison of individual projects/programmes it does provide a framework for considering the role of research in facilitating different types of industry change.

The approach made it possible to provide quantitative estimates of the total value of PFR research to the primary sectors that benefit from the research. While there are limitations to the method, it is able to provide a sensible answer to a key question from stakeholders, including policy-makers.

It is important, however, to recognise some of the limitation of the approach used in the research. A number of assumptions and simplifications were required in order to derive estimates. A description of these assumptions may foster discussion about their impacts on the results.

Limitations of the workshop approach

The selection of the most important industry changes or events, and assignment of importance to the drivers of change reflected the opinion of workshop participants. It is possible that this resulted in selection bias, and that a different st5akeholder group may have reached different conclusions. In addition, workshop participants commented on the difficulty in assigning dates to some key milestones, while others clearly occurred at a specific time. Some changes were the result of a number of innovations, changes in production practices, industry organisation, etc. For example, in the apple industry, the introduction of new varieties has occurred over a long period of time from around 2000, but the RSE legislation was passed in 2008.

The importance of some key drivers has changed over time. For example, a wildcard driver, Psa-V, was the initial cause of very significant disruption in the kiwifruit industry, but the response by industry, Government and research allowed the industry to return to its pre-PSA growth trajectory. The wildcard driver was scored highly overall for the initial outbreak, but was unlikely to be a factor in subsequent years. Scoring each driver for each key change/event, in each year since it occurred would address this issue, but the complexity of this would be too great to be addressed in the workshop environment.

All key milestones are given an equal proportional rating. Some changes/events are likely to have more impact on economic performance of the industry than others. Obtaining rankings or weights for each change/event (for each year) would be burdensome on workshop respondents, and introduce additional subjectivity into the analysis.

Limitations on the analytical approach

Data limitations

The key analytical weakness revolved around estimating the growth in GDP. Unlike national level GDP, which is reported by Statistics New Zealand, the level or change in industry GDP can only be estimated from data on total industry revenues and input-output tables. A number of data limitations affected the estimation of changes in GDP contribution. These included the availability of export data only, which will have led to an underestimate of the total change in industry performance, and the use of "average" data from MPI farm monitoring models to estimate the national change in value-added, when the models apply only to particular regions or orchard sizes.

The choice of counterfactual

The choice of counterfactual was an important consideration for the analysis, and there was considerable discussion among the research team and at workshops about the use of alternative counterfactuals, especially for industries that had faced difficult market conditions. The counterfactual scenario for each of the land-based industries captured the change in area planted as a proxy for increasing inputs. As an area-based counterfactual was inappropriate for the seafood industry, for which land is not an important input, the counterfactual used was the baseline value for 2000. Ideally, a more complex counterfactual based on available quota could be developed for the industry.

An alternative to be considered in the future would be the development of detailed counterfactuals for each industry, based on expert understanding of production, market and other market trends. This would account for research and other contributions that assisted industries to mitigate the adverse impacts of the operating environment including market conditions, and the regulatory environment.

Calculation of the benefits of research using the approach described hinges on the ability of the primary sector to continue to grow and increase export revenues relative to the baseline. The analysis depends on the sector translating science and innovation into greater export revenues or greater GDP contributions. One of the industries analysed, the seafood industry, has not grown the value of its exports in recent years. The analytical method used allocates improvements in export performance among drivers, but specifically excludes the role of research in protecting and maintaining industries. As a result the estimated benefit of research in 2015 was zero, although workshop participants rated the contribution of research in several areas highly. In the wine and kiwifruit industries, which have shown strong export growth during the analysis period, the estimated impact of research, which is credited with contributing to that growth, has also increased significantly.

Other limitations

This study captures only the impacts of research that have occurred between 2000 and 2015, and does not include the ongoing impacts that will occur in the future. Prior research has suggested that the time lag between discovery and economic impact could be 15 years (Colinet, et al., 2014) or 24 years or more (Alston, 2010). While the study provides a reasonable estimate of the steady-state contribution of research, it is likely to be conservative.

The analysis did not include the impact of changes in foreign exchange rate, although it is acknowledged that future development of the approach should do so. Exchange rate fluctuations result in changes in the value of output that do not reflect changes in productivity and, consequently, to under or overstatement of the impacts of productivity change.

The time horizon selected; the exclusion of domestic market benefits; and the exclusion of a number of primary sectors for which PFR provides research services can be expected to have led to comparatively conservative estimates of the benefits of PFR research, while the impact of other assumptions is uncertain. The approach has been applied consistently across industries to the extent the data available have permitted and a repeatable analytical approach has been developed.

Finally, the method was reviewed by three (national and international) economists and who provided constructive feedback on the approach and agreed with the assessment that the value generated was an underestimation of the actual value. They commended the novelty of the approach and endorsed it as providing considerable insight into the field of RS&T evaluation and a useful, repeatable and transferable methodology. This exercise has enabled PFR to gain insights into the mechanisms by which impact is generated in partnership with its industry partners. It is a component of an ongoing programme of evaluation that is improving the evaluative capacity of PFR and extending its ability to estimate the potential value of investments, monitor and evaluation developments during research programmes and carry out more accurate post-research evaluations.

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