Partial Factor Productivity within the Australian Vegetable Industry

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Introduction

Productivity is vitally important to the long term growth and sustainability of any industry. It refers to a farms ability to increase the yield of produce (output) while maintaining the same level of expenses (input). By this definition, productivity can be viewed as an increase in a farm's production efficiency in terms of its ability to utilise resources into producing a valued good.

Productivity is important to growers because it defines how efficient their businesses are at utilising resources. High productivity means that their business is making the most out of the resources available and costs are being kept to a minimum. Low productivity demonstrates that resources are not being used efficiently and that costs may be a lot higher than what they should otherwise be. In this sense, productivity can have a large effect on a grower's yearly profit margins.

This study is particularly timely in today's economic climate. Data provided by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) in their report titled "Australian Vegetable Growing Farm Survey" suggests that total cash costs including seed, fertiliser and labour costs have increased by over 127 per cent since 2005-06. Over the same period, revenue generated from vegetable produce has also risen by 97 per cent. As growth in cash costs exceeds the growth in revenue it is clear that farms are spending larger proportions of money on input costs than what they are getting back in returns. This issue highlights the importance of understanding the industry's productivity in terms of the returns earned from each dollar spent on production resources.

Productivity studies are not uncommon to other agricultural industries in Australia. ABARES produces productivity reports on several different agricultural industries including wheat, cattle and dairy. These studies tend to involve a basic calculation of productivity of the various inputs and output produced from these industries. These studies are quite thorough in their results and accompanying analysis, however the simplicity of the estimation process can lend itself to inaccurate or misleading results.

This study fills a research gap by being the first of its kind to present productivity estimates for the vegetable industry. Thus bringing the industries key economic indicators to the same standard as those already made available by ABARES. Furthermore, this study seeks to improve upon other studies by estimating productivity using a statistically unique and technical approach that produces both theoretical and empirical conclusions for studies of this type.

This discussion paper has three primary objectives. Firstly, it seeks to discuss and explain key economic concepts relating to productivity. By explaining these concepts, it is the hope of the author that readers will be able to think more in economic terms and be able to conduct a deeper analysis when faced with business decisions. Secondly, this study seeks to fill a research gap by conducting a statistical study that estimates the "marginal productivity" of various inputs from eight separate vegetable industries. These estimates are important because they allow growers to compare their industries productivity estimates against other industries to determine if there are productivity gains to be made. And thirdly, this study hopes to further ignite discussion and future research projects into the productivity of the vegetable industry in order to promote it as a key agenda for long-term industry growth.

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Methodology

There are two measures of productivity that are used frequently by economists. Total Factor Productivity (TFP) refers to an increases in output upon change in the level of *all* inputs whereas Partial Factor Productivity (PFP) refers to an increase in output pertaining to an increase in only a single specific input factor. The most well-known PFP measure is yield per hectare which measures the amount of output per unit of land (input) used within the production process.

One of the methods used to measure PFP is by estimating the “marginal productivity” of that input. The marginal productivity refers how much additional output (i.e. tonnes of produce) is produced by increasing an input (e.g. land) by one additional unit. Marginal productivities are important because they essentially determine the value of the next unit of an input. The amount of additional produce generated from each input naturally plays a crucial role in the decision making process of whether to employ more labour or purchase additional capital goods.

For example, when you are deciding whether to employ another staff member at your farm how do go about this task? A logical approach would be to approximate their worth to your business and determine if that worth is greater than the cost (wages) of employing them. One way of estimating an employee’s worth is by determining their impact on your production process or output capabilities i.e. the employee’s marginal productivity. The higher the potential employee’s marginal productivity, the more value that candidate would add to your business and the greater the chances of that potential employee earning a position.

What happens when you face a decision of whether to hire additional labour or purchase additional machinery (i.e. to purchase one input over another?). The first step is to estimate the marginal productivity of both of these inputs separately. Say for example you estimate that an employee’s marginal product is 800kg per week and that the marginal product of additional machinery is 500kg per week. Does this mean that you should employee the additional labour over the machinery? Another element that needs to be factored into this analysis is each inputs price. If the machinery costs $200 per week and the employee costs $600 per week then clearly you would prefer to purchase the machinery, as the additional output per dollar spent (500/200= 2.5kg per dollar spent) is higher than the additional output per dollar of labour (800/600=1.33kg per dollar spent).

Economic efficiency is all about the decision making process that was just described. A business or industry is economically efficient if it is able to correctly evaluate and make decisions that benefit it in the greatest possible way such as in the previous example. However, economic efficiency requires accurate estimates of both the marginal productivity and the associated costs of each of the inputs in order for the decision maker to make correct choices. One of the key challenges for economists is to be able to help explain the various methods used in decision evaluation including marginal productivity analysis so that we can help growers to enhance their economic efficiency.

This discussion paper seeks to achieve this goal by providing an industry wide analysis of partial factor productivity (marginal productivity). It does this by using high level statistical regression methods to estimate an economic model of the industry. The next section of this paper will describe some of the results of this economic model in terms of the marginal productivity estimates and its implications for the industry.

Results

The economic model developed in *appendix B* is estimated using a statistical technique called Ordinary Least Squares (OLS) for each of the eight Australian vegetable industries. Based on the estimation results there are five key findings that have been discovered in the process of undertaking this discussion paper. These results are summarised as follows:

1. **The marginal productivities of labour and plant and equipment have a nonlinear, quadratic relationship with output.** This means that the product produced from the addition of another unit of labour or plant and equipment is not constant. For example, an additional staff member will not always increase production by a constant 10 tonnes. In other words there is a maximum point after which additional labour has a detrimental effect on output.

2. **Labour appears to have a negative effect on production**. The results of this study have found that labour has, initially, a negative effect on production. However, this negative effect becomes positive after a particular level has been achieved. Several reasons have been given to explain this effect including a theoretical explanation (*Appendix D*) and the requirement for capital stock in order for labour to increase productivity.

3. **Plant and Equipment has an instantaneous, positive effect on production**. The results indicate that investment into plant and equipment appears to have a direct, positive impact on production (until a maximum point) implying that within certain bounds, the more investment that is made into plant and equipment the greater the output produced.

4. **Farm Specialisation has a strong effect on the marginal productivity of labour.** This result indicates that those farms that produce only one crop tend to benefit from enhanced labour productivity. This is likely to be due to the fact that labour is able to focus on one particular task as opposed to having to learn multiple, varying tasks on those farms that produce more than one crop.

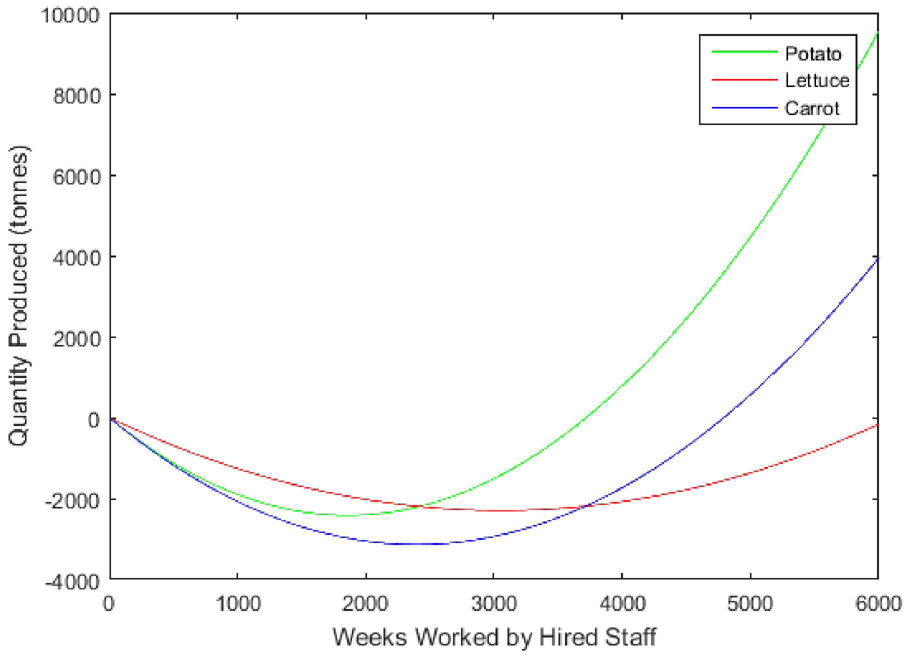
5. **The top 25 per cent of farms have higher marginal productivities because they have more money, on average, invested into capital goods such as plant and equipment**. A key determinant of productivity includes the amount of investment made into capital goods such as plant and equipment.

The remainder of this section will discuss the specifics of the above listed industry results based on partial factor productivity. Due to the scale of the results discovered, the partial factor productivity has been narrowed down to a discussion on the marginal productivity of labour and Plant and Equipment. The purpose of this discussion is to present the results of the industry estimates for each input, as well as to describe some of the reasons why we may be seeing the results listed above.

Partial Factor Productivity – Labour

Figure 1 presents a graphical representation of the estimated marginal productivity of Labour for the potato, carrot and lettuce industries. An interesting feature of these productivity estimates is that there is a non-linear (ie. quadratic) relationship between the number of weeks worked by hired staff and the quantity produced.

Figure 1 – Marginal Productivity of Labour



Due to the quadratic nature of the relationship shown in figure 1, the marginal productivity of labour is initially *negative* for potato, lettuce and carrot but after a "minimum point" is reached, the marginal productivity becomes positive and it can be seen that labour begins to have a positive effect on production.

For example, the minimum point for the potato industry occurs when the number weeks worked by hired staff exceeds 1860 weeks. This evidence suggests that those potato farms that hire more than 1860 weeks of hired staff are much more likely to be able to get more produce out of those additional staff (i.e. have a positive marginal productivity) than those farms that hire less than 1860 weeks' worth of labour within the potato industry.

Another interesting characteristic from figure 1 is the point at which labour appears to have a *positive* effect on production, (i.e. the average amount of labour required to create positive returns on production). Within the potato industry, it can be seen that this point is reached when the number of work hours is 3719 weeks. These results suggest that those potato farms that employee more than 3719 weeks' worth of labour start to see larger, more positive effects of each member of the labour force onto production.

Table 1 below presents the "minimum point", "positive production point" and the estimated measurement of the product of labour for growers performing bottom 25 per cent, middle 50 per cent and top 25 per cent in each industry incorporated into this study where it is both applicable and statistically significant:

Table 1 – Marginal Productivity Statistics by Industry

Industry	Minimum Point	Positive Production Point	Bottom 25 per cent	Middle 50 per cent	Top 25 per cent
Potato	1859.58	3719.17	-2.67	-211.43	-2122.8
Pumpkin	0.00	0.00	0.00	0.83	175.38
Lettuce	3055.05	6110.08	-1.55	-123.52	-1462.18
Carrot	2396.64	4793.30	-2.70	-214.25	-2372.5
Greenpea	1451.27	2902.54	-1.71	-134.35	-1172.54

The results in table 1 are interesting in that, with the exception of pumpkin, all of the positive production points exceed over 2900 weeks of labour. For example, within the potato industry you need an average of 3719 weeks of labour before any positive production returns are realised.

This observation is further realised when looking at the Bottom, Middle and Top percentages of labour. As you can see, the labour usage in the top 25 per cent of farms have a larger negative impact on production than the middle and the bottom categories. Similarly, the middle 50 percent appears to have a larger negative effect, on average, than the bottom 25 per cent of farms. In short, the results indicate that the more labour that is employed within farms, the larger the negative impact that the labour has on production outcomes.

It is a strange result for this dataset to show negative returns from labour within all industries. Appendix C provides a theoretical explanation of why these results have occurred. However, another explanation of these results may be due to the fact that labour requires equipment in order to be productive. Employees by themselves may have coordination issues or struggle to be productive without the required capital equipment (i.e. machinery) to help them produce a given crop. Although these results are curious, they can still be used to describe labour productivity within a given industry. Highlighting, with particular importance the nonlinear, quadratic relationship that exists between labour and production.

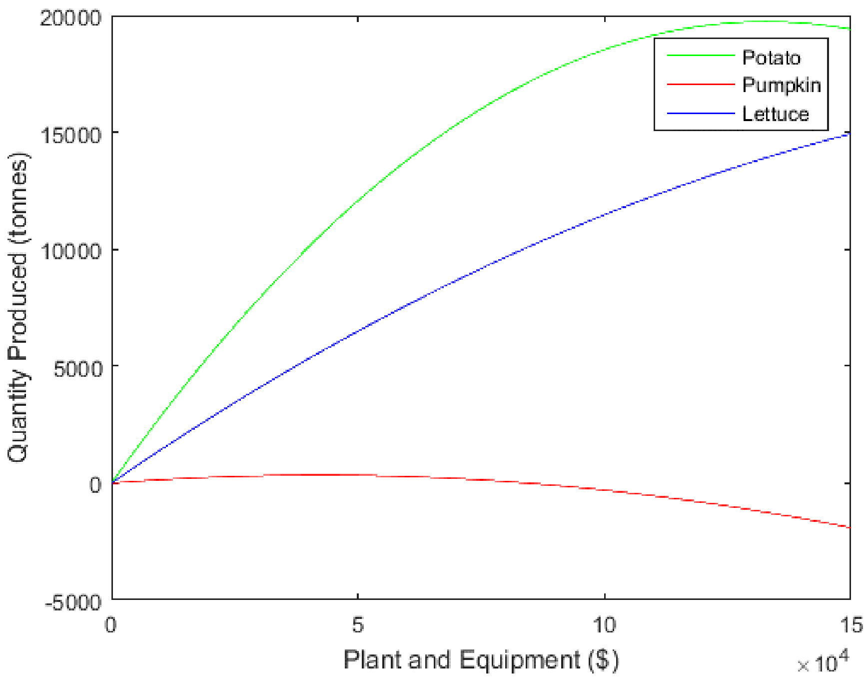
Partial Factor Productivity – Plant and Equipment

Similar to the previous section, figure 2 below plots the estimated relationship between the amount of plant and equipment purchased and the quantity of output produced within the potato, carrot and lettuce industries.

Once again, the relationship between Plant and equipment and the quantity produced appears to take a nonlinear (quadratic) relationship. All three industries in figure 2 show positive marginal productivities (positive returns) from the use of additional plant and equipment throughout all industries. However, these productivities vary significantly between industries.

The potato industry has by far the highest marginal productivity from plant and equipment of all the industries. This suggests that plant and equipment is extremely valuable to the potato industry in terms of both production and productivity. In contrast, the pumpkin industry shows a positive marginal productivity up to a "maximum point" of $42,253 that has been spent on plant and equipment. After this point, the data suggests that the quantity produced begins to fall, due to the marginal productivity of capital becoming negative.

Figure 2 – Marginal Productivity of Plant and Equipment



Another important characteristic from Figure 2 is that plant and equipment instantaneously produces additional output. This differs from the marginal productivity of labour which requires a large amount of labour before positive returns are realised.

Table 2 below presents the "maximum" or "minimum" turning points for the marginal productivity of plant and equipment estimates for each of the industries represented in the dataset. The table again provides productivity estimates for the farms that are part of the bottom 25 per cent, middle 50 per cent and top 25 per cent of the dataset.

Table 2 – Marginal Productivity Statistics for Plant and Equipment by Industry

Industry	Maximum Point	Positive Production Point	Bottom 25 per cent	Middle 50 per cent	Top 25 per cent
Potato	132729.91	0	326.36	1057.38	8557.56
Pumpkin	42252.58	0	33.941	56.58	329.18
Lettuce	239325.08	0	306.64	518.96	4436.95
Cabbage	148320.0	0	140.73	237.71	1949.59
Greenbean	-31780.40	0	-90.90	-157.27	-1962.06

The first observation from the results in table 2 is that, with the exception of the green bean industry, investment in plant and equipment appears to have an instantaneous, positive effect on the amount of product harvested. In other words, the marginal productivity of plant and equipment is always positive. These result indicates that the more money spent on plant and equipment, the larger the results in terms of production quantities.

It is important to note that that these positive returns from plant and equipment have limitations. The maximum point shows the estimated point where the returns from plant and equipment tend to become negative, on average. For example, within the potato industry, there are positive returns from spending on plant and equipment up until $132,729.91. After this point is reached, the data indicates that any additional spending beyond this limit may begin to have a negative impact on production.

In the case of the potato industry, the largest observation within the dataset spent $150,102.2 on plant and equipment. This observation is not very far outside the present day maximum point for the industry ($132,729.91) and so it can be concluded that most farms within the data are operating efficiently with regards to maximising their returns from plant and equipment.

The results from this analysis of the marginal productivity of plant and equipment is emphasised by looking at the average results from the bottom 25 per cent, middle 50 per cent and top 25 per cent. With the exception of the Green bean industry, it can be seen that the top 25 per cent of farms have much larger returns from plant and equipment than both the middle 50 per cent and the bottom 25 per cent. An explanation for this result is that the top 25 per cent of farms are likely to use more plant and equipment than the other two categories. Both the marginal productivity of plant and equipment is generally always positive, therefore, those farms that use more plant and equipment should logically produce larger quantities of product.

The Role of Specialisation in Productivity

As the data used in this study was taken from a series of surveys conducted by ABARES (*See Appendix A*) an additional variable named "Intensity" was included which represents the proportion of the total land which was used in the production of the given crop in question. The variable "Intensity" can be viewed as a representation of the degree of specialisation a farm has in the production of its vegetable crop. For example, a potato farm with an intensity value of 75 per cent means that three quarters of its available land is used in the growing of potatoes. A farm with an intensity value of 75 per cent is therefore obviously much more specialised in production than another farm that only has an intensity value of 5 per cent.

Through the inclusion of the intensity variable within the economic modelling, it was possible to be able to study the effects of farm specialisation on the marginal productivity of labour. Figure 3 presents the results of this analysis.

Figure 3 – Productivity Returns from Specialisation

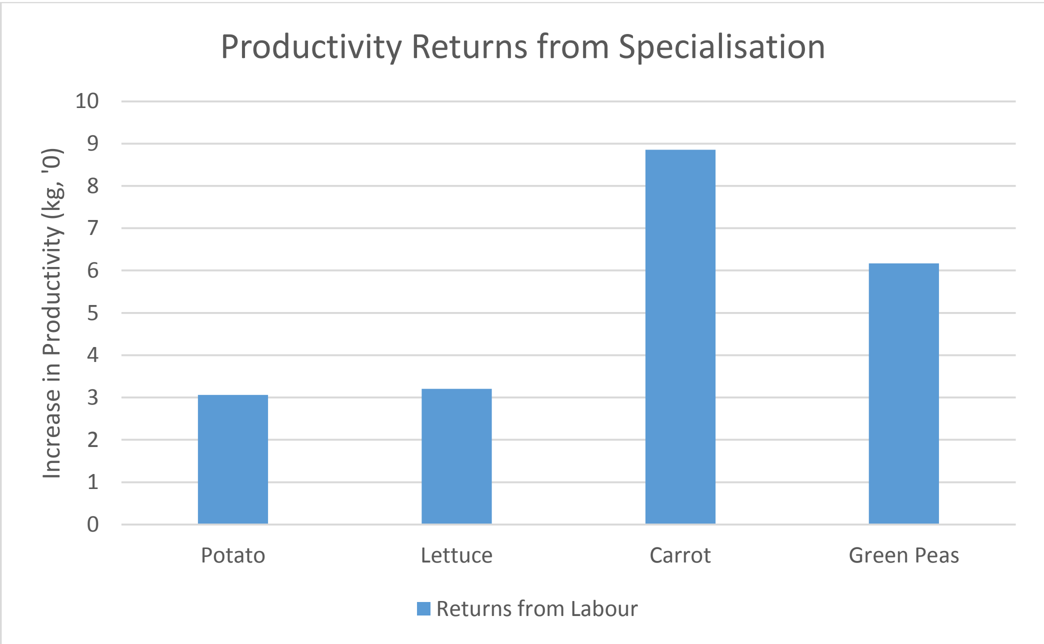


Figure 3 shows that there are significant labour productivity returns from specialisation within the Potato, Lettuce, Carrot and Green pea industry. Within the carrot industry, each additional percentage increase in intensity leads to an average 88.5 kilo increase in the productivity of labour. Similarly, for each additional percentage increase in intensity leads to a 61.7 kilo increase in the productivity of labour within the Green Pea industry.

This result is particularly significant in helping to understand one of the drivers of productivity growth within the vegetable industry. Figure 3 shows that there are clear labour productivity gains from enhanced farm specialisation. On the one hand, growers may produce different crops in order to diversify production and have less exposure to risky events such as price or weather fluctuations. On the other hand, these results show that a significant cost associated to crop diversification is the labour productivity losses that can occur. This result can encourage growers to ensure that they account for these significant productivity losses within their decision making process when considering crop diversification.

Average Farm Results

To highlight the importance of marginal productivities and to highlight their differences between industries, I have defined a typical farm for the bottom 25 per cent, middle 50 per cent and top 25 per cent in terms of the amount of inputs used (on average, across all industries) in their respective production processes. These averages are reported in table 3 below.

Table 3 – Average Farm Results by Percentile

Input	Bottom 25 per cent	Middle 50 per cent	Top 25 per cent
Buildings (QKBB)	247.41	865.05	8583.88
Plant and Equipment (QKPL)	2123.72	3605.40	32847.21
Land (QKL)	37.13	116.85	2051.82
Labour (QLH)	1.03	83.31	1213.99
Intensity	0.04	0.10	0.69

For example, the average number of weeks worked by labour in the bottom 25 per cent of farms within the dataset was 247 weeks. Similarly, the average number of weeks worked by labour within the top 25 per cent of farms was 1,214 weeks.

The figures from table 3 were then input into the models presented and an amount of produce grown was then forecasted by the model for each industry. By studying the variance of the output between industries, the importance of each industries marginal productivity becomes more apparent due to the same mix of inputs being used in each industry model.

Figure 4 – Estimated Production Based on Fixed Farm Inputs

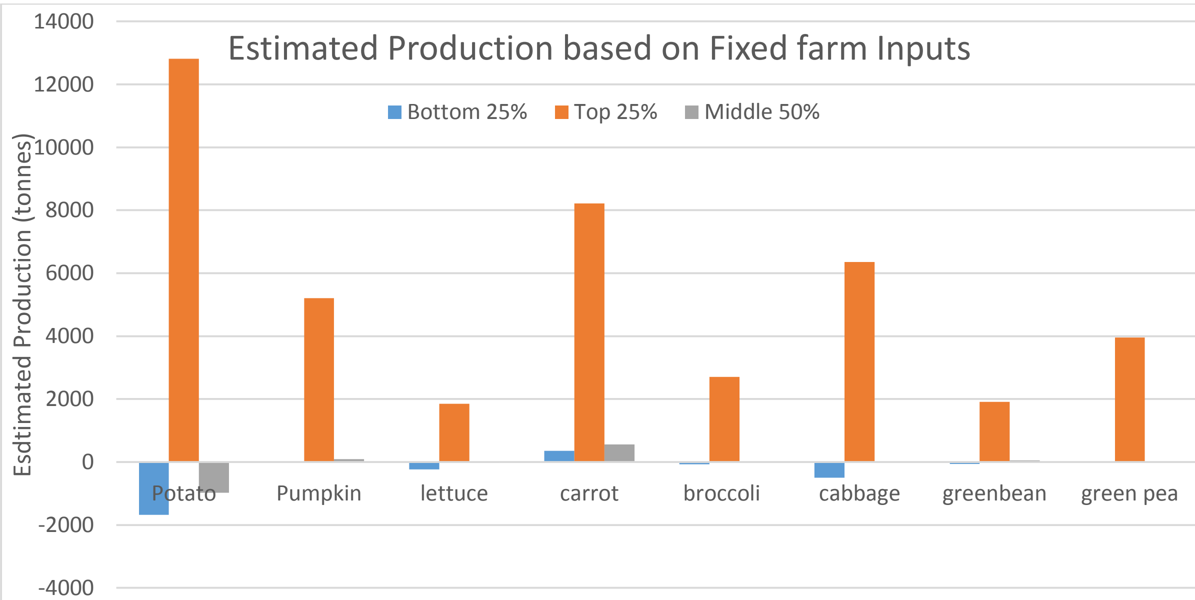


Figure 4 shows that, when the same amount of inputs are used within different industries the models estimated production varies dramatically. This variation is apparent for all three categories of farms however it appears to be the largest for the top 75 per cent of farms. For example, when the average inputs of the top 25 per cent of farms are used within the potato industry, that mix of inputs produces an estimated 12,816 tonnes of potatoes. However, when that same input mix is used within the lettuce industry, the model predicts a production of only 1,846 tonnes.

One obvious explanation for the large variance presented in figure 4 is that the nature of the different crops produced require differing levels of inputs. For example, perhaps the carrot industry is more labour intensive and less plant and equipment intensive than the other industries.

Another explanation for the variance in production between industries seen in figure 4 is the differing marginal productivities. For example, we have already discussed the marginal productivity of labour and plant and equipment in previous sections of this discussion paper and shown how it differs (significantly) between vegetable industries. From these results, it was shown how the potato and pumpkin industry has a significantly larger marginal productivity of plant and equipment in comparison to the other industries.

Similarly, one of the drivers for the carrot industry would be the high level of specialisation seen in the industry. As has already been mentioned, specialisation plays a significant role in increasing the marginal productivity of labour. Those increases are particularly large within the carrot industry (an average of 8.85 tonnes per percent increase in intensity) and are likely to be the key reason as to why the carrot industry is the second highest industry illustrated in figure 4.

A final observation made from figure 4 is the large variance in the production estimates between the top 25 per cent and the middle 50 per cent and bottom 25 per cent. Those farms that are within the top 25 per cent produce significantly larger production than the other two groups. This characteristic occurs throughout all the industries shown in figure 4.

The question needs to be asked, why does the top 25 per cent of farms produce much more than the two other categories? The short answer to this question is because the top 25 per cent of farms have a higher specialisation (intensity) and higher marginal productivity than the two other groups. Table 4 below presents the average amount of labour and plant and equipment spent in these three groups:

Table 4 – Average Farm Results by Percentile

Variable	Bottom 25 per cent	Middle 50 per cent	Top 25 per cent
Plant and Equipment (QKPL)	2123.72	3605.40	32847.21
Labour (QLH)	1.03	83.31	1213.99

The average amount of money spent on plant and equipment in the top 25 per cent of farms is $32,847.21 this is in comparison to the middle 50 per cent of farms that average only $3,605.40. Table 4 shows that there is a lot more money (811 per cent more), on average, being spent on plant and equipment within the top 25 per cent of farms than the middle 50 per cent. This is perhaps one explanation for the increased marginal productivity in this category. More money is spent on plant and equipment which can have a flow on effect in terms of increasing the marginal productivity of labour. These results provide evidence to show that increased investment in plant and equipment has extremely positive results for on farm productivity levels.

Conclusion

This discussion paper set out three objectives that it needed to achieve. These objectives were to define and explain economic concepts surrounding productivity, to be the first publication of productivity results for the vegetable industry and to ignite further discussion as well as research and development into the productivity of the vegetable industry so that it can become part of a key agenda in a plan for long-term economic growth within the industry.

This paper began by defining productivity and explaining the importance of understanding the concept including its strong relationship with farm profitability. Economic productivity is all about ensuring that input resources (such as labour or plant and equipment) are utilised efficiently within a production process. If productivity within the industry is kept high, then growers are getting the most out of their input resources and costs can be kept to a minimum.

Continuing to explain core economic concepts, this discussion paper presented the ideas of total factor productivity and partial factor productivity. By understanding and being able to differentiate between these two concepts, the implications of the results of the quantitative analysis component of this paper would have been a lot clearer. The second half of the methodology section then provided several examples to help show the importance of an understanding of the economic concept of marginal productivity and how this indicator can effect business decision making.

The results section of this discussion paper presented industry estimates of the marginal productivity of both labour and plant and equipment. These estimates were discussed in detail and there were five key results that were concluded from this study. These results were:

1. The marginal productivities of labour and plant and equipment have a nonlinear, quadratic relationship with output.
2. Labour appears to have a negative effect on production.
3. Plant and Equipment has an instantaneous, positive effect on production.
4. Farm Specialisation has a strong effect on the marginal productivity of labour.
5. The top 25 per cent of farms have higher marginal productivities because they have more money, on average, invested into capital goods such as plant and equipment.

All of these results can have strong, practical implications for growers. Some of these results were unexpected while others were likely to help to provide supportive evidence for ideas that may have been already well known.

Productivity is vitally important to the long term growth and survival of every industry. In order to understand the drivers of productivity growth within the vegetable industry, a continuous focus needs to be placed on the measures we can employee to seek to enhance industry productivity. This discussion paper does not profess to know all of the answers surrounding productivity, however it seeks to get the ball rolling on a series of research focussed on the topic. The key to understanding any concept is to maintain a continuous flow of up-to-date information to the topic and it is my hope that this paper inspires motivation and continued commitment towards this goal.

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Appendix A: Data

Aggregate Data analysis

The data used in this paper is provided by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES). ABARES has a collection of survey data from its yearly Vegetable Farm Survey as well as data collected from several other agricultural surveys that it conducts. It was discovered that a lot of the farms surveyed in these other agricultural surveys also grew vegetables as a secondary occupation.

In order to increase the number of observations within the dataset for this study this discovery was exploited and data was obtained not only from the ABARES Vegetable Farm survey but also from the ABARES survey of irrigation farms in the Murray-Darling Basin, ABARES Australian Agricultural Grazing Industries Survey and the ABARES Australian Dairy Industry Survey. Table 5 presents the number of observations used for each of the eight vegetables within the model:

Table 5 – Sample Size Statistics

Sample size, 2010–11 to 2013–14	
Farm type	**Sample size (no.)**
Potato	561
Pumpkin	199
Lettuce	184
Carrot	168
Broccoli	164
Cabbage	163
Green Bean	133
Green Pea	117
Total	**1689**

These eight vegetable commodities represent over 35 per cent of the Australian vegetable industry. It is important to note that the sample size for potatoes is substantially larger that all the other vegetable commodities. There was no specific reason for this phenomenon however it is important to note that Potatoes represent over 17 per cent of the vegetable industry and so the additional observations used within the model for potatoes can thus be considered as justified. The data used in this analysis is sourced from most states in Australia and can be considered largely representative of the Australia Vegetable Industry.

Variable Description

Each of the models that are estimated within this study use a series of 10 variables. Each of these variables can roughly be categorised into one of four groups – land, labour, capital, production. Land, labour and production are self-explanatory in that they represent the quantity of land and labour used to produce a particular level of crop output (production). Variables grouped within the capital category represent resources or machinery that used with the farming process. Examples of capital include seed, fuel, machinery, electricity and chemicals. There is also a set of binary variables representing the time period for each observation (yr012-yr2014). The purpose of this group of variables is to be able to isolate the yearly changes in the estimation results. Table 6 presents a summary description of each of the 10 variables used within this study.

Table 6 – Variable Description

Variable Name	Description	Category	Variable Type
Quantity	The quantity of the vegetable produced in tonnes	Production	Dependent, Continuous
QKBB	Imputed quantity buildings and fixed improvements	Capital	Independent, Continuous
QKPL	Imputed quantity of plant and equipment	Capital	Independent, Continuous
QKL	average operated land area	Land	Independent, Continuous
QLH	weeks worked by hired staff	Labour	Independent, Continuous
YR2011	A binary variable equal to 1 if the year is 2011, 0 otherwise.	-	Independent, Dichotomous
YR2012	A binary variable equal to 1 if the year is 2012, 0 otherwise.	-	Independent, Dichotomous
YR2013	A binary variable equal to 1 if the year is 2013, 0 otherwise.	-	Independent, Dichotomous
YR2014	A binary variable equal to 1 if the year is 2014, 0 otherwise.	-	Independent, Dichotomous
Intensity	Area planted to the vegetable of interest as a proportion of the total area cropped	Land	Independent, Continuous

Appendix B: Theoretical Framework – The Production Function Model

The development of a theoretical framework for an economic model involves a simplification of the real word so that mathematical methods can be applied to understand economic decision making. In the case of the estimation of the productivity of the vegetable industry, we will conceptualise a typical vegetable farm as an entity than takes in resources such as seed, fertilizer, labour or capital etc. (inputs) and combines those inputs to produce/grow a vegetable commodity (output). Figure 1 below illustrates this conceptualisation:

Figure 5 – Input/output Model

As figure 5 shows, a typical farm process takes in inputs and combines them, over time, to produce a given output e.g Crop. Mathematically, figure 5 can be re-written as follows:

$$O = f(I)$$

Where O represents output as a function, f of inputs, I. Inputs (I) can be further categorised in capital inputs (C), land (L), labour (K) such that the equation above then becomes:

$$O = f(C, L, K) \text{ – (Equation 2)}$$

Where output, O is given as a function of the combination of capital inputs, materials and labour. The key to this economic study is to try to understand the underlying function (process) that farms use to combine these three input categories to produce their given output. In order to do this, we will make some assumptions about this functional form of equation 2 and turn this function into a model that can be easily estimated using statistical techniques.

Estimating Partial Factor Productivity – The Econometric Model

Say, for example, we conceptualise a production function consisting of one output (carrots) and three inputs (capital, labour and productivity). A simplified version of this production function model (in mathematical terms) might look like the following:

$$\text{Carrots} = b0 + b1 * \text{Labour} + b2 * \text{Capital}$$

By using a statistical method called Ordinary Least Squares (OLS), values for b0, b1 and b2 can be determined as we can obtain statistical observations for both labour and capital. For example, purposes, if OLS determines that b0=3.5, b1=6.7 and b2=2.4 then our model would now become:

$$\text{Carrots} = 3.5 + 6.7 * \text{Labour} + 2.4 * \text{Capital}$$

Assuming that the coefficients (b1 and b2) of labour and capital are statistically significant these values represent marginal factor productivities. In the above example the coefficient of labour is 6.7, this means that for each additional unit of labour added the number of carrots produced increases, on average, by 6.7 tonnes. Similarly, the coefficient of capital is 2.4, this means that for each additional unit of capital added to the production process, the number of carrots produced increases by 2.4 tonnes, on average.

Parametric estimates of marginal factor productivity are admittedly complex to estimate; however, the results of the modelling procedure can be seen as much more accurate than their non-parametric counterparts. This is because the parametric estimates control for other inputs in the production process as well, whereas non-parametric methods do not.

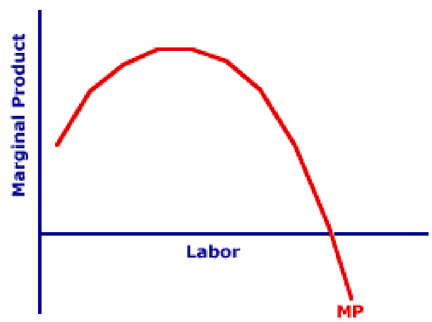
The error term, u in the above models contain values for the unexplained variation between output and the selected inputs in the production process. As previously mentioned, because productivity is unobservable we are unable to estimate its effects directly. However, the error term, u, will capture the effects of total factor productivity within the model (assuming that the model is well specified and represents a good fit of the data). In this sense, studies that are focused on estimating total factor productivity are therefore necessarily focussed on the values held within the error term of the model.

Appendix D: Theoretical Explanation for Negative Marginal Productivities

Another interesting observation that can be taken from the results is the estimation of negative marginal products on some of the input variables, differing by industry. For example, the coefficient of labour (QLHDM) for carrots is -0.8066. Interpreting this statistic means that for each additional week of labour reduces the amount of carrots produced, on average, by 806.6kg. The question arises, "Does it makes sense to have negative marginal productivities?" or "Why would additional labour actually reduce production levels?"

The simple answer is yes it does make sense to have negative marginal productivities. According to economic theory the marginal productivity of a given input typical takes an inverted "U" shape as demonstrated in figure 6. As shown in figure 6, when the amount of labour exceeds a certain threshold, the marginal product becomes negative.

Figure 6: Theoretical Marginal Productivity Curve



The reason for the inverted "U" shaped marginal productivity curve, and the decreasing and potentially negative marginal productivity results is due to what economists' call "The Law of Diminishing Returns". If you keep adding additional labour one unit at a time, but keep the amount of capital (equipment, seed etc.) fixed eventually, as you add more and more labourers they will not have any equipment to work with! As that additional labourer has less and.