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A pig in a poke?

Accounting for uncertainty about elasticity values in an EDM of the Australian pig industry

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Abstract

Recently Griffith *et al.* (2010) updated an existing equilibrium displacement model (EDM) of the Australian pig industry which was then used by Slattery *et al.* (2010) to estimate the potential industry impacts from an increase in demand for low cholesterol pork (see Bellhouse *et al*. 2010). In that model the specified market parameters were chosen on the basis of economic theory, previous studies and some assumptions made by the authors. While it was concluded those values adequately represented the price responsiveness of market participants within the industry, uncertainty still exists about their true values. This may have implications for the results generated from the model. In this paper stochastic sensitivity analysis is undertaken to account for that uncertainty. Overall, the EDM results are found to be relatively robust. However, the methodology used allows for the calculation of probabilities to determine the chances of a result contrary to that obtained using the original point estimates. These calculations suggest the rankings of alternative industry investments may change for particular combinations of parameter values, away from the rankings implied by the point estimates, and that an investment shown to have a positive return of $0.67 million using the point investments may in fact vary from a loss of $0.1 million to a gain of $1.14 million with 95 per cent probability under the stochastic sensitivity analysis.

Introduction

The literal meaning of the centuries old phrase *pig in a poke* refers to the inadvertent purchase of an inferior quality pig (or even a cat or dog in place of a pig) because of neglect by the buyer to inspect the actual contents of the poke (bag). Today the expression takes on a broader meaning, for example, accepting something without knowledge of its correct value or accepting an opinion or belief without completely understanding it.

Recently Griffith *et al.* (2010) highlighted some of the issues involved in updating an existing economic model using, as an example, an equilibrium displacement model (EDM) of the Australian pig industry (Mounter *et al.* 2004, 2005a, 2005b). The revised model was subsequently used by Slattery *et al.*

(2010) to estimate the potential aggregate-industry impacts from an increase in demand for low cholesterol pork (see Bellhouse *et al*. 2010).

The EDM framework requires the specification of elasticity values that sufficiently reflect the nature of the demand, supply, input substitution and production transformation relationships under consideration. The market parameters in the existing EDM of the Australian pig industry were chosen on the basis of economic theory, previous studies and some assumptions made by the authors.[1] Griffith *et al.* (2010) concluded that those values still provide an adequate representation of the price responsiveness of market participants within the current Australian pig industry structure. However, uncertainty about the true values of the market parameters still exists and herein is our *pig in a poke*. Up to this point we have accepted the assumed elasticity values without knowledge of their true values. But what if those values are incorrect?

The robustness of estimated welfare benefits, given the uncertainty surrounding true market-parameter values, has been one of the main areas of concern in the EDM literature.[2] Changes in magnitude of one or more parameter values have been shown to have consequences for the distribution of total welfare changes among various economic agents (Alston and Scobie 1983, Mullen, Alston and Wohlgenant 1989, Holloway 1989). This type of uncertainty can readily be accounted for using sensitivity analysis. It has always been the intention to undertake such an exercise with respect to the Australian pig industry EDM and, with the update and application to the original model, now seems an appropriate time to do so.

Discrete sensitivity analysis, changing one or more parameter values at a time, can be used to examine the sensitivity of the results to changes in individual parameters. However, this approach becomes impractical when there is uncertainty surrounding numerous parameter values. Even if it was possible to empirically estimate all the conceivable combinations of alternative parameter values, little inference can be made about which values represent the true parameter values. A more rigorous approach based on stochastic sensitivity analysis, as proposed in Zhao *et al.* (2000), is used in this paper.

Stochastic Sensitivity Analysis

Stochastic sensitivity analysis involves specifying subjective probability distributions for the model's parameters. This procedure enables the derivation of probability distributions for the estimated economic surplus changes. The probability distributions specified for the parameters in the EDM are either truncated normal distributions or mixed truncated normal and exponential distributions. Economic theory prescribes that parameters are restricted by sign. It is expected that own-price elasticities of demand and product transformation elasticities have negative signs. Similarly, own-price elasticities of supply, input substitution elasticities and cross-price domestic demand elasticities are expected to take positive values.[3] Parameters are restricted to negative or positive values by truncating the distributions from above or below at zero, respectively. In some instances asymmetric distributions may result because of the restrictions, which have understandable implications for the probabilities for particular ranges of values. However, the truncations specified in this analysis are greater than three standard deviations from the mode and have little effect on the distributions.

With a normal distribution there is equal probability that values will fall either side of the subjectively specified mode (most likely value), with approximately 68 per cent of the data within one standard deviation and 95 per cent within two standard deviations of the mode. For example, the specified value for the retail elasticity of demand for pork in the EDM is -1.2 (Mounter *et al*. 2005a). A truncated normal distribution around this specified value $N(-1.2, 0.25^2|<0)$ restricts the parameter to negative values with a standard deviation of 0.25. Therefore, approximately 95 per cent of values should fall between -0.7 and -1.7.

Where truncated normal distributions may not best represent the probabilities that the parameter values may assume, mixed truncated normal and exponential distributions were specified. For example, input substitution elasticities between farm and processing inputs are typically assumed to take a small value of 0.1 but have been empirically estimated as high as 0.72 (Wohlgenant 1989). In this case a mixed truncated normal and exponential distribution would provide the necessary skewed shape to allow a long tail to the right. In addition, some parameter probability distributions are conditional on other subjectively specified parameter distributions. Where two different parameters are assumed to take the same mode, a mixed distribution may be chosen for the first parameter with the second parameter normally distributed around the first distribution. For example, assumed values of 0.1 are given to all input substitution elasticities between the pork meat input and pork processing inputs and between the bacon meat input and bacon processing inputs at various stages of the supply chain in the EDM. A mixed distribution with 0.7 probability of being truncated normal N(0.065, 0.1^2|>0), to yield positive values, and 0.3 probability of a rightward exponential shift 0.08+Exp(4.1) (see Zhao 1999) was specified for the input substitution elasticity between pork and pork processing inputs. This allows 0.74 probability for values between zero and 0.2, 0.24 probability for values between 0.2 and 0.7 and 0.02 probability of values greater than 0.7. The other input substitution elasticities are assumed to be normally distributed around this distribution with a standard deviation of 0.05.

The subjectively specified probability distributions for the parameters in the model are listed in Table 1.

Table 1. Subjective probability distributions for market parameters

Market Parameter (Elasticity)	Probability Distribution
Supply of pigs	~ N(1.5, 0.25^2|>0)
Factor supply: [a]	
Pork processing inputs	~ N(5.0, 1.70^2|>0) with 0.5 probability
	~ 4.5 + Exp(0.2) with 0.5 probability
Bacon processing inputs	~ N(pork processing inputs, 0.50^2|>0)
Pork primary processing inputs	~ N(pork processing inputs, 0.50^2|>0)
Bacon/ham secondary processing inputs	~ N(pork processing inputs, 0.50^2|>0)
Domestic retail demand:	
Pork	~ N(-1.2, 0.25^2|<0)
Bacon/ham	~ N(-0.9, 0.15^2|<0)
Cross-price pork elasticity wrt bacon ham price	~ N(0.6, 0.10^2|>0)
Cross-price bacon/ham elasticity wrt pork price	~ N(0.2, 0.05^2|>0)
Export pork demand	~ N(-5.0, 1.0^2|<0)
Input substitution elasticity between: [a]	
Pork & pork processing inputs	~ N(0.065, 0.10^2|>0) with 0.7 probability
	~ 0.08 + Exp(4.1) with 0.3 probability
Pork & pork primary processing inputs	~ N(Pork & pork processing inputs, 0.05^2|>0)
Bacon & bacon processing inputs	~ N(Pork & pork processing inputs, 0.05^2|>0)
Bacon & bacon secondary processing inputs	~ N(Pork & pork processing inputs, 0.05^2|>0)
Imported pig meat & bacon secondary processing inputs	~ N(Pork & pork processing inputs, 0.05^2|>0)
Bacon & imported pig meat	~ N(0.5, 0.10^2|>0)
Product transformation elasticity between:	
Domestic and export pork	~ N(-0.5, 0.1^2|<0)

[a] Mixed normal and exponential truncated distributions are based on specifications by Zhao (1999).

Results

The updated EDM described in Griffith *et al*. (2010) but now including the subjective probability distributions for the market elasticities as reported in Table 1, was solved for two different sets of scenarios. In each case, parameter values were randomly and independently drawn from the specified probability distributions. In all, 2,000 values were obtained for each parameter. These 2,000 sets of parameter values were used to generate 2,000 sets of economic surplus changes for the two different sets of scenarios.

Hypothetical One Per Cent Shifts

Nine hypothetical scenarios as listed in Table 2 were taken from Mounter *et al*. (2005a,b). Summary statistics for the benefit changes to Australian pig meat producers for each of the hypothetical scenarios are presented in Table 3a and Table 3b.[4] The potential benefits in millions of dollars are listed on the left side of each column and their shares as a percentage of the total benefits on the right. The 'point estimates' are the simulation results from the Griffith *et al.* (2010) updated EDM. The 'mean', 'standard deviation' and '95% probability interval' refer to summary measures from the 2,000 draws from the probability distributions.

Table 2. Selected hypothetical scenarios from Mounter *et al*. (2005a,b)

Scenario 1: Domestic pork advertising

A one per cent upward shift in the domestic demand for pork.

Scenario 2: Domestic bacon/ham advertising

A one per cent upward shift in the domestic demand for bacon and ham.

Scenario 3: Export pork advertising

A one per cent upward shift in the export demand for Australian pork.

Scenario 4: Porker production R&D

A one per cent downward shift in the supply of porkers.

Scenario 5: Baconer production R&D

A one per cent downward shift in the supply of baconers.

Scenario 6: Initial pork processing R&D

A one per cent downward shift in the supply of initial processing inputs in the pork industry.

Scenario 7: Initial bacon/ham processing R&D

A one per cent downward shift in the supply of initial processing inputs in the bacon and ham industry.

Scenario 8: Secondary bacon/ham processing R&D

A one per cent downward shift in the supply of secondary processing inputs in the bacon and ham industry.

Scenario 9: Primary pork processing R&D

A one per cent downward shift in the supply of primary processing inputs in the pork industry.

The values in Table 3a and Table 3b provide a measure of the variability of the potential benefit changes from using a stochastic sensitivity analysis compared with an analysis based only on point estimates of market parameters. For example, the mean benefit to pig meat producers from a one per cent upward shift in the domestic demand for pork (Scenario 1) is $1.95 million with an average 14.4 per cent share of the total benefits. This compares to the point estimate of $1.93 million or 14.2 per cent of the total benefits. The probability interval implies we have 95 per cent confidence that pig meat producers receive between 10 per cent and 20 per cent of the total additional industry returns under the assumptions of Scenario 1.[5]

In the EDM, the mode (most likely value) was chosen for each parameter based on empirical estimates and, in some instances, judgments made by the authors. Hence, the means from the probability distributions are likely to differ from the subjectively specified modes. However, as Tables 3a and 3b reveal, in most cases, the differences between the point estimates and the means of the probability distributions of outcomes are small.

Table 3a. Summary statistics: Benefit changes ($million) and benefit shares (%) to pig producers, scenarios 1-5

	Scenario 1 Domestic pork advertising		Scenario 2 Domestic bacon/ham advertising		Scenario 3 Export pork advertising		Scenario 4 Porker production R&D		Scenario 5 Baconer production R&D	
Pig Meat Producers	**$m**	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**
Point estimate	1.93	14.22	3.13	3.63	0.10	7.75	1.06	21.46	0.50	7.55
Mean	1.95	14.37	3.18	3.69	0.10	7.75	1.17	23.68	0.69	10.42
Standard deviation	0.33	2.43	0.51	0.59	0.03	2.33	0.31	6.27	0.40	6.04
95% prob. interval	1.42	10.46	2.37	2.75	0.06	4.65	0.68	13.76	0.24	3.63
	2.71	19.97	4.34	5.04	0.17	13.18	1.91	38.66	1.84	27.79

Table 3b. Summary statistics: Benefit changes ($million) and benefit shares (%) to pig producers, scenarios 6-9

	Scenario 6 Initial pork processing R&D		Scenario 7 Initial bacon/ham processing R&D		Scenario 8 Secondary bacon/ham processing R&D		Scenario 9 Primary pork processing R&D	
Pig Meat Producers	**$m**	**%**	**$m**	**%**	**$m**	**%**	**$m**	**%**
Point estimate	0.1	16.13	0.05	2.24	1.11	1.54	1.00	10.78
Mean	0.1	16.13	0.04	1.79	0.94	1.30	0.91	9.81
Standard deviation	0.03	4.84	0.05	2.24	0.59	0.82	0.42	4.52
95% prob. interval	0.04	6.50	-0.06	-2.69	-0.40	-0.55	0.05	0.54
	0.16	25.81	0.16	7.17	2.01	2.78	1.73	18.64

Taking the analysis a step further provides additional insights into the results. Table 4 lists the nine hypothetical modeling scenarios in terms of the percentage share of the total benefits received by pig meat producers, as ranked by the point estimates. Of the pork-specific simulations, Scenario 4 provides the greatest share of total benefits. However, the 95 per cent probability intervals suggest the rankings may alter for particular combinations of parameter values, contrary to the rankings implied by the point estimates. For example, the probability intervals for Scenario 1 and Scenario 4 overlap (Table 3a). The obvious concerns about the implications for the robustness of the results can be quantified by calculating probabilities from the simulation data to ascertain the likelihood that one scenario may deliver a larger or smaller share of the total benefits than another scenario. Table 5 displays the probabilities corresponding to returns to pig meat producers.[6]

Table 4. Scenario rankings in terms of % share of total benefits (%) to pig meat producers

Rank	Pork-Specific Scenarios	Rank	Bacon/ham-Specific Scenarios
1	S4 - Porker production R&D (21.4)	1	S5 - Baconer production R&D (7.6)
2	S6 - Initial pork processing R&D (16.1)	2	S2 - Domestic bacon/ham advertising (3.6)
3	S1 - Domestic pork advertising (14.2)	3	S7 - Initial bacon/ham processing R&D (2.2)
4	S9 - Primary pork processing R&D (10.8)	4	S8 - Secondary bacon/ham processing R&D (1.5)
5	S3 - Export pork advertising (7.8)		

Table 5. Probabilities of differences in pig meat producers' scenario rankings

Pork-Specific Scenarios

P (S4 - Porker production R&D) > (S6 - Initial pork processing R&D) = 100%

P (S4 - Porker production R&D) > (S1 - Domestic pork advertising) = 96.8%

P (S4 - Porker production R&D) > (S9 - Primary pork processing R&D) = 100%

P (S4 - Porker production R&D) > (S3 - Export pork advertising) = 100%

P (S6 - Initial pork processing R&D) > (S1 - Domestic pork advertising) = 66.5%

P (S6 - Initial pork processing R&D) > (S9 - Primary pork processing R&D) = 99.8%

P (S6 - Initial pork processing R&D) > (S3 - Export pork advertising) = 96.2%

P (S1 - Domestic pork advertising) > (S9 - Primary pork processing R&D) = 85.8%

P (S1 - Domestic pork advertising) > (S3 - Export pork advertising) = 98.7%

P (S9 - Primary pork processing R&D) > (S3 - Export pork advertising) = 68.4%

Bacon/ham-Specific Scenarios

P (S5 - Baconer production R&D) > (S2 - Domestic bacon/ham advertising) = 97.5%

P (S5 - Baconer production R&D) > (S7 - Initial bacon/ham processing R&D) = 100%

P (S5 - Baconer production R&D) > (S8 - Secondary bacon/ham processing R&D) = 100%

P (S2 - Domestic bacon/ham advertising) > (S7 - Initial bacon/ham processing R&D) = 75.8%

P (S2 - Domestic bacon/ham advertising) > (S8 - Secondary bacon/ham processing R&D) = 100%

P (S7 - Initial bacon/ham processing R&D) > (S8 - Secondary bacon/ham processing R&D) = 61.5%

These results agree with those from the point estimates (Mounter *et al*. 2005b) in that pig meat producers combined always receive a larger share of the total benefits from on-farm research than off-farm research (such as research in the processing sectors), or from an increase in export demand for Australian pork.[7] The results also indicate probabilities of approximately 97 per cent that pig meat producers receive a larger share of the total benefits from on-farm research than from increases in domestic demand for pork or ham/bacon.

Mounter *et al.* (2005a) demonstrate the differences in returns to pig producers from generic advertising of pork under non-trading and trading scenarios and assumptions of homogeneous and differentiated product from pork in other countries. The returns from generic advertising to the industry are less in a trading environment than in a non-trading environment. This is because, in addition to the domestic market, adjustments to a shift in domestic demand occur in export and import markets, so price rises are curtailed and producer surplus is lower. The returns are also less under the assumption of a differentiated rather than homogeneous product (less than perfectly elastic export demand curve). Exports are a relatively small part of the total industry and Australian pork is considered to be different from pork from other suppliers in export markets.

Somewhat less robust results were obtained for some of the other scenario comparisons. For example, there is a 33 per cent chance that an increase in domestic demand for pork (S1) will provide a larger benefit share to pig meat producers than (initial) pork processing research (S6). Likewise, there is a 38 per cent chance that secondary bacon/ham processing research (S8) will deliver a greater share of the returns to pig meat producers than initial bacon/ham processing research (S7). Hence certain combinations of parameter values can have distributional consequences for the surplus changes in these scenarios. Examples of this include differences in the magnitude of input substitution elasticities between primary commodity inputs (such as pork) and other processing inputs at different stages of the production chain and the relative magnitudes of retail demand elasticities and input substitution elasticities.[8] These results highlight the areas where more empirical research is required to better specify particular parameter values.

One additional comment is worth noting. Restrictions on the relative differences in elasticity values were not imposed on all parameters in generating the specified probability distributions. For example, the elasticity of supply of pigs is not constrained to be more elastic than the own-price domestic demand elasticities for pork or bacon/ham even though in the medium-term timeframe assumed here we would expect this to be the case. In approximately 20 per cent of the randomly generated sets of parameter values the own-price elasticity of demand for domestic pork is more elastic than the elasticity of supply of pigs. Less elastic supply suggests producers would receive a larger share of the total benefits. Determining the potential implications for the probabilities associated with the scenario rankings in Table 5 is a question for future empirical analysis.

An Increase in Demand for Low Cholesterol Pork

The stochastic sensitivity analysis outlined above also can be used to construct probability intervals for the Slattery *et al.* (2010) results in estimating the potential industry impacts from an increase in demand for low cholesterol pork. The summary statistics in Table 6 relate to the potential returns to pork producers from a 10 per cent increase in consumers' willingness to pay for low cholesterol pork, with and without an associated 10 per cent increase in the cost of production.

Under the assumption that production costs remain unchanged (Scenario 3), the returns to pork producers range between $7.3 million and $14.0 million with 95 per cent probability, with a mean of $10.2 million. This is similar to the point estimate, as is the share accruing to pig producers.

Taking a 10 per cent increase in the cost of production into consideration highlights the implications for the results when accounting for uncertain parameter values. The mean return to pork producers in this instance is just under $4.0 million, some 10 per cent less than the return calculated from the point estimates of the market parameters. The returns to pig producers could vary from an aggregate loss of $0.7 million to additional gains of $7.8 million, with 95 per cent probability. Within the 95 per cent probability interval there is 47 per cent probability of returns less than the mean ($3.96 million) and a 53 per cent probability of returns greater than the mean (up to the $7.76 million upper bound). The probability of negative returns to pork producers is 1.4 per cent.[9] Further disaggregation of the results reveals there is a 46 per cent chance of returns between $3 million and $5 million and a 77 per cent chance of returns between $2 million and $6 million. The probability of returns less than $2 million or greater than 6 million are 12 per cent and 11 per cent, respectively.

Table 6. Summary statistics: Benefit changes ($million) and benefit shares (%) to pig producers, scenarios 3 & 6 from Slattery *et al*. (2010)

	Scenario 3 10% increase in demand, no change in cost		Scenario 6 10% increase in demand, 10% increase in cost	
Pork Producers	**$m**	**%**	**$m**	**%**
Point estimate	10.00	7.1	4.39	5.0
Mean	10.16	7.2	3.96	4.5
Standard deviation	1.71	1.2	2.00	2.3
95% prob. interval	7.35	5.2	-0.66	-0.7
	14.05	10.0	7.76	8.8

A pig in a poke?

The main aims of the stochastic sensitivity analysis presented in this paper were to account for the uncertain value of the market parameters specified in the EDM and to be able to draw some conclusions about the results it generates. It was evident that in terms of percentage share of total returns to pig meat producers, particular combinations of parameter values provide conclusions contrary to the point estimates in the EDM. This was highlighted by constructing probability intervals around both the Griffith *et al*. (2010) and the Slattery *et al.* (2010) results and underlines the importance of having accurate estimates of market parameters. However, in the absence of these values, stochastic sensitivity analysis allows us to place a level of confidence around the estimates. So in *pig in a poke* parlance, we may not know the true quality traits of the pig but we can be confident it is not a dog or a cat, and probably not an inferior quality pig.

Overall, the sensitivity analysis has shown the EDM results to be relatively robust. The importance of this methodology is that probabilities can be attached to the chances of making a wrong decision (Griffiths and Zhao 2000). As it applies here it allows for the quantification of policy recommendations of relevance to the Australian pig industry.

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Footnotes

[1] See Mounter, S., Griffith, G. and Piggott, R. (2005a) for a description of the industry structure and specification of the EDM.

[2] Uncertainty can also come about in EDMs through the underlying price and quantity data used to fix the points of initial equilibrium. However, the focus of this paper is on market parameter uncertainty.

[3] As well, cross-price elasticities of demand for pork and bacon/ham are restricted to be less than the absolute values of the own-price elasticities of demand for pork and bacon/ham.

[4] Summary statistics for the other industry sectors are available from the authors on request.

[5] The 95 per cent probability intervals differ from those derived under conventional sampling procedures in that they are estimated from subjective prior distributions (Zhao 1999). The highest 2.5 per cent and the lowest 2.5 per cent of the 2,000 sets of economic welfare changes are omitted to obtain the interval estimate.

[6] Similar probabilities can be calculated for the other industry sectors.

[7] Based on equal percentage shifts in supply or demand as specified in Table 2 and not taking into consideration the costs involved in achieving these shifts (see Mounter et al. 2005b) .

[8] See Alston and Scobie (1983), Mullen *et al*. (1988), Holloway (1989), Freebairn (1992) and Zhao *et al.* (2000).

[9] The probability of negative returns corresponds to highly inelastic domestic demand values and highly elastic supply values. It is possible that combinations of parameter values drawn from the distributions allow for this to occur. The normal distributions specified for each of these parameters allow for approximately 95% of values to fall within two standard deviations of the mode. Therefore, for example, within that range values of -0.6 and 2.0 could be drawn for the own-price elasticities of demand for pork and pigment supply, respectively.