The Australian Journal of
Agricultural and
Resource Economics

Australian Journal of Agricultural and Resource Economics, 66, pp. 400–423

Who will pay for workplace reforms in U.S. meat-processing plants? Simulation results from the USAGE model*

Peter B. Dixon and Maureen T. Rimmer†

It is possible that COVID will trigger permanent changes in work practices that increase costs in U.S. meat-processing plants. These changes will be beneficial for the safety and economic welfare of meat-processing workers. However, they will have economic costs. In assessing reform options, policymakers seek guidance from analyses based on models embracing micro detail and an economy-wide perspective. In this paper, we use USAGE-Food, a highly disaggregated computable general equilibrium (CGE) model of the United States, to work out how additional processing costs would be distributed between consumers of meat products and farmers. We also calculate industry and macroeconomic effects. Despite modelling farmers as owning fixed factors, principally their own labour, we find that the farmer share in extra processing costs is likely to be quite moderate. Throughout the paper, we support simulation results with back-of-the-envelope calculations, diagrams and sensitivity analyses. These devices identify the mechanisms in the model and key data points that are responsible for the main results. In this way, we avoid the black-box criticism that is sometimes levelled at CGE modelling.

Key words: back-of-the-envelope explanations, computable general equilibrium simulations, diagrammatic analysis, split of meat-processing costs between farmers and consumers, workplace reform in U.S. meat processing.

JEL classifications: D58, Q12, Q13, Q17, Q18

1. Introduction

Meat-processing plants have proved to be dangerous workplaces for the spread of the COVID virus in the United States. This has highlighted broader problems in the U.S. meat-processing industry and has led to a wide-ranging discussion of the need for workplace reforms; see, for example, Kelemen (2021), Lakhani, (2020), Schlosser (2020), Taylor et al. (2020) and Yearby (2021). Recommended reforms are both COVID-related and more general. COVID-related measures include barring attendance of sick workers, greater distances between workers on production lines and installation of separation barriers. More general measures include increases in minimum pay, provision

*In preparing the paper, we benefitted from helpful comments by Greg Pompelli, Glynn Tonsor, David Anderson and Katelyn McCullock.

†Peter B. Dixon (email: peter.dixon@vu.edu.au) and Maureen T. Rimmer are Professors at Centre of Policy Studies, Victoria University, 300 Flinders Street, Melbourne 8001, Victoria, Australia.

doi: 10.1111/1467-8489.12470

of health insurance and protection of the right to organise labour unions. All these potential reforms will increase costs per unit of meat processed.

The aim of this paper is to contribute to the discussion by estimating the effects on the U.S. economy of increased processing costs. A particular focus is the effects on farmer incomes and consumer prices.

In making our estimates, we use the USAGE model. USAGE is a detailed computable general equilibrium (CGE) model of the U.S. economy.[1] The version applied here is USAGE-Food, described in Dixon et al. (2020). This version distinguishes 392 industries. These include 13 agricultural industries and 24 industries producing manufactured food products. Among these industries are three meat-animal producers [Cattle ranching, Other-animal farms and Poultry & egg farms] and three meat-processing industries [Beef processing, Other-animal processing (mainly pigs) and Poultry processing].

There is no clear information on the extent to which recommended reforms would increase the costs of meat processing. We use the model to explore hypothetical possibilities. This is an important role of models in the preliminary stages of policy formulation: policymakers look for guidance on economy-wide effects of proposed policies and answers to the question of who will pay. In the scenarios we examine, cost increases are introduced through the production functions of the processing industries as 10 per cent capital- and labour-using technical changes. Our results are close to linear with respect to the 10 per cent assumption. Readers can deduce the effects of a 5 per cent increase in primary-factor requirements simply by halving the results presented here for a 10 per cent increase.

USAGE-Food is set up with a database for 2015 and produces results in a single-period computation for effects after 5 years. Literally, we model the cost increases in meat processing as occurring in 2015 and look at how these cost increases affect the economy of 2020. Almost all our results are percentage deviations from a baseline with no meat-processing reforms. For example, we will find that the assumed cost increases in the three meat-processing industries in 2015 would reduce GDP in 2020 by 0.031 per cent below where it would have been without the cost increases. To a close approximation, this can be thought of as the percentage effect on GDP in 2025 of cost increases occurring in 2020.

Why 5 years? This simplifies the analysis by allowing us to adopt long-run assumptions at the macro level for labour and capital. A period such as 5 years means that we abstract from short-run adjustment effects. We assume that 5 years is sufficient for wage rates throughout the economy to adjust to bring aggregate employment back to its baseline level. For capital, we assume that 5 years is sufficient for capital stocks to adjust to bring expected rates of return approximately back to baseline levels. By showing 5-year effects, our

[1] USAGE (U.S. Applied General Equilibrium) has been continuously developed at the Centre of Policy Studies (CoPS) over the last 15 years. For an overview of USAGE and its applications, see Dixon et al. (2013).

results complement those of Lusk et al. (2021) who focus on short-run COVID-specific effects.

Models such as USAGE-Food contain millions of equations. These equations describe optimising behaviour by U.S. households, investors, exporters and importers, and equilibration between demands and supplies and between prices and costs. The central database for setting the coefficients in the equations is an updated version of the BEA's Benchmark input–output tables (see Dixon et al. (2017)). It is not practical to set out the model in a journal paper, and even if it were possible to provide full technical detail, it is not clear that this would help readers with limited time budgets to assess the results. So how do we meet the 'black-box' criticism?

Our method is to provide back-of-the-envelope (BOTE) explanations. This method not only explains the results but also tells readers about the model. It allows readers to make an informed assessment about what is being taken into account in deriving the results and what has been left out. The BOTE approach has been prominent in Australian CGE modelling since the 1970s; see, for example, Dixon et al. (1982), Adams (2005) and Dixon and Rimmer (2013). While in theory each result from a CGE model depends on thousands of parameters, data points and every detail of the equation system, in practice any particular set of CGE results depends on a small subset of these items. For each application, the challenge for CGE modellers is to identify the relevant items and to use them in a convincing BOTE explanation of the principal results.

In this paper, we provide BOTE explanations of the CGE results for the effects of increased meat-processing costs on:

- *farm-gate and supermarket prices of meat products*. In explaining these prices, we draw on the data in the model for the share of processing costs in prices to consumers, and we highlight the mechanisms in the model through which cost increases in the supply chain to consumers are passed back as reductions in farm income.
- *outputs and employment in U.S. industries*. We explain that output falls in the processing industry that experiences the cost increase but employment rises. Both output and employment fall in the corresponding farm industry, but these falls are muted by trade effects. Consumers substitute away from the cost-affected meat product, generating positive output and employment results for other meat products and food products more generally.
- *macro variables*. The effects on macro variables are small and are explained via a stylised production function incorporating data on the share of processing costs in GDP.
- *the division between farmers and consumers in bearing cost increases from the processing industry*. We start by showing that these cost increases are financed by reductions in farm incomes and extra payments by consumers. This reflects our modelling assumption that factors of production in meat processing are mobile within our 5-year period. Then, using 4-quadrant

diagrams supported by a stylised algebraic presentation of relevant parts of the model, we explain why our simulation results indicate that the share of processing costs borne by farmers is low. This is despite the presence of fixed factors in the farm sector. The diagrams and sensitivity analysis identify how this result depends on a variety of substitution elasticities in production and consumption.

The rest of the paper is organised as follows. Sections 2 to 5 present results covering consumer prices, real farm incomes, industry outputs and employment, and the macroeconomy. Section 6 contains sensitivity analysis identifying important determinants of the split of extra processing costs between farmers and consumers. Concluding remarks are in Section 7.

2. Effects on prices to households

Table 1 shows percentage effects on consumer prices (prices paid at the supermarket) of 10 per cent increases in primary-factor requirements per unit of output in each of the meat-processing industries. In our simulations, we assume that cost increases in meat processing have no effect on aggregate consumer prices. Thus, the results in Table 1 indicate relative price movements. For example, a 10 per cent increase in primary-factor requirements per unit of output in Beef processing raises the price of beef products in supermarkets by 1.488 per cent relative to the general consumer price level. Similarly, 10 per cent increases in primary factor requirements per unit of output in Other-animal processing and Poultry processing raise the prices of these products sold to households by 1.444 per cent and 1.673 per cent relative to consumer prices in general.

The first step in understanding these results is to look at meat-processing primary-factor costs incurred in delivering meat products to households. In the USAGE-Food database, these costs per dollar of household spending on Beef, Other-animal products and Poultry are 19.6 cents, 17.8 cents and 19.1

Table 1 Percentage effects on prices to households of increased costs in meat processing (effects after 5 years of 10% increases in primary-factor input per unit output in meat processing industries) [Colour table can be viewed at wileyonlinelibrary.com]

	Beef processing	Other-animal processing	Poultry processing	Total meat processing
Food	0.172	0.059	0.123	0.356
Meat-processing products	0.760	0.255	0.573	1.596
Beef	1.488	0.004	0.037	1.529
Other animals (mainly pork)	0.003	1.444	0.017	1.465
Poultry	0.066	0.024	1.673	1.764
Other food products	−0.006	−0.001	−0.013	−0.020
Non-food products	−0.011	−0.004	−0.008	−0.023
All products (cpi)	0.000	0.000	0.000	0.000

cents, respectively. On this basis, we calculate the impact effects on supermarket prices of 10 per cent increases in primary-factor requirements in meat processing as 1.96 per cent, 1.78 per cent and 1.91 per cent. The simulated effects are noticeably lower than these impact effects. As we will see in Table 2, part of the cost increases in processing are passed back to farmers as reductions in farm prices and in farm incomes.

The results in the fourth column of Table 1 for the effects of a 10 per cent increase in primary-factor requirements per unit of output in *all* three meat-processing industries are approximately sums of the results in the other three columns. For shocks of this magnitude, the percentage responses of endogenous variables in USAGE-Food are well approximated by linear functions of percentage changes in exogenous variables.

The shares of Beef, Other animals and Poultry in household expenditure on meat-processing products are 0.498, 0.171 and 0.331, and the share of meat products in household expenditure on food is 0.233. These shares in combination with the price results for the three meat products explain the price results in Table 1 for meat-processing products and food. For example, in the fourth simulation, the percentage movement in the price of meat-processing products is 1.596, given by 0.498*1.529 + 0.171*1.465 + 0.331*1.764, and the percentage movement in the price of food is 0.356, given by 0.233*1.596 + (1-0.233)*(−0.020).

Table 2 Percentage effects on real farm incomes and basic prices of increased costs in meat processing (effects after 5 years of 10% increases in primary-factor input per unit output in meat processing industries) [Colour table can be viewed at wileyonlinelibrary.com]

	Beef processing	Other-animal processing	Poultry processing	Total meat processing
Real farm incomes				
Oil seeds	0.000	0.005	−0.040	−0.036
Grains	−0.138	0.004	−0.133	−0.268
Vegetables & melons	−0.026	−0.005	−0.023	−0.055
Fruit & nut farms	−0.011	−0.001	−0.014	−0.026
Green nurseries	−0.021	−0.006	−0.013	−0.040
Other crops	−0.098	−0.001	−0.010	−0.110
Cattle ranching	−2.405	0.083	0.132	−2.191
Dairy cattle	0.001	0.001	−0.011	−0.008
Other animals (mainly pigs)	0.094	−1.036	0.050	−0.893
Poultry & eggs	0.246	0.088	−1.517	−1.183
All farms	−0.326	−0.108	−0.156	−0.591
Basic prices, farm products				
Cattle ranching	−0.894	0.024	0.038	−0.832
Other-animal farm	0.032	−0.518	0.019	−0.467
Poultry & eggs	0.069	0.029	−0.408	−0.311
Basic prices, processed prods				
Beef processing	2.341	0.010	0.065	2.417
Other-animal processing	0.015	2.242	0.035	2.292
Poultry processing	0.101	0.037	2.362	2.502

3. Effects on real farm incomes and the allocation of extra processing costs between farmers and consumers of meat products

The top panel of Table 2 shows percentage effects of increased processing costs on real farm incomes, defined as returns to farmland, farm capital and farmer-supplied labour. We treat farmer labour as a fixed factor, and we allow only limited possibilities for moving farmland between agricultural industries. Consistent with economic theory, USAGE-Food indicates that increases in processing costs are partially passed back to the owners of fixed factors. In the first three simulations, increased costs in a meat-processing industry are passed back as reductions in the basic (farm-gate) price of the corresponding farm product (middle panel, Table 2) with consequent income losses for the corresponding farm industry (top panel). Also consistent with economic theory, cost increases in meat processing are partially passed forward through higher basic (factory-door) prices for processed-meat products (bottom panel, Table 2). These increases in the basic prices of processed products are passed on in damped form to supermarket prices (Table 1) and prices for meals from restaurants and other food-serving industries. For example, in the Beef-processing simulation, the basic price of Beef processing increases by 2.341 per cent (Table 2), whereas the supermarket price increases by only 1.488 per cent (Table 1). Consumer prices include the prices of imported processed-meat products (as well as domestic processed-meat products) and the costs of margins incurred in transferring meat products from processors to households. The prices of imports and the costs of margins are largely independent of U.S. processing costs.

How are cost increases in meat processing distributed between farmers and consumers? Items from the USAGE-Food 2020 baseline database and calculations necessary to answer this question are presented in Table 3.

As set out in the table, value added in Beef processing is \$34.998 billion, the basic (factory door) value of beef-processing sales is \$120.597b, and farm income in Cattle ranching is \$25.816b. With a 10 per cent increase in primary factor requirements, the Beef-processing industry passes \$2.823b to its customers in the form of higher prices (= 2.341% of \$120.597b, row 7, Table 3). At the same time, Cattle-ranch farmers suffer a reduction in their incomes of \$0.621b (= 2.405% of \$25.816b, row 6, Table 3). Together, the loss to farmers and the increased cost to consumers total \$3.444b (=0.621 + 2.823). This closely matches the impact cost of the increase in primary factor requirements in Beef processing, \$3.5b (= 10% of 34.998, row 1). Because we assume that labour and capital in meat-processing industries are mobile, these factors do not bear any of the long-run increase in processing costs.

For Other-animal processing, the USAGE-Food baseline database shows the following: value added of \$12.098b; basic value of sales of \$47.268b; and income in Other-animal farming of \$22.783b. As shown in Table 3, a 10 per cent increase in primary factor requirements in Other-animal processing

Table 3 Back-of-the-envelope calculation of allocation of extra processing costs between farmers and consumers of meat products

		Beef processing	Oth animal processing	Poultry processing
	Items from 2020 baseline data			
1	Value added in processing industry, $b	34.998	12.098	21.942
2	Basic value of sales from processing ind., $b	120.597	47.268	81.986
3	Income in farm industry, $b	25.816	22.783	19.316
	Simulation results (percentage changes)			
	Basic prices of meat processing			
4i	Beef processing in 1st simulation, %	2.341		
4ii	Other-animal processing in 2nd simulation, %		2.242	
4iii	Poultry processing in 3rd simulation, %			2.362
	Real farm income			
5i	Cattle ranching in 1st simulation, %	−2.405		
5ii	Other animals in 2nd simulation, %		−1.036	
5iii	Poultry in 3rd simulation, %			−1.517
	***Back-of-the-envelope* (BOTE) calculations**			
6	Loss of farm income, $b (= row3*row5/100)	0.621	0.236	0.293
7	Cost to customers, $b (= row2*row4/100)	2.823	1.060	1.937
8	Total cost to households & farmers $b, (= row 6 + row 7)	3.444	1.296	2.230
9	Farmer % of total costs (=100*row 6/row 8)	18.03	18.21	13.14

imposes a loss on farmers of $0.236b (= 1.036% of $22.783b) and an extra expense to consumers of $1.060b (= 2.242% of $47.268). Together, the loss to farmers and the increased cost to consumers total $1.296b (=0.236 + 1.060), closely matching the impact cost in the processing industry of $1.210b (= 10% of 12.098b).

For Poultry processing, the relevant database items are value added and basic value of sales in the processing industry of $21.942b and $81.986b, and income in Poultry farming of $19.316b. A 10 per cent increase in primary factor requirements in Poultry processing reduces the income of farmers by $0.293b (= 1.517% of $19.316b) and increases costs to consumers by $1.937b (= 2.362% of $81.986b). Together, the loss to farmers and the increased cost to consumers total $2.230b, closely matching the impact cost in the processing industry (10% of 21.942b).

To us, a surprising aspect of Table 3 is the smallness of the farmer shares in extra processing costs. In the Beef-processing simulation, Cattle ranchers pick up only 18.03 per cent of the explained extra cost of processing, row 9. In the Other-animal-processing simulation, farmers pick up 18.21 per cent of the explained extra costs, and in the Poultry-processing simulation, farmers pick up 13.14 per cent.

A priori, our simple picture was of farmers with inelastic supply curves selling their product to processing industries with a fixed ratio of farm product to processed product. This picture is a reference case sometimes used in discussions of the long-run effects on returns to farmers of changes in farm-to-retail price spreads; see, for example, Hahn (2004, page 8). It suggests that farmers would pick up very high shares of extra processing costs. What does the model know that is missing from this simple picture? This question is answered in Section 6 where we conduct sensitivity analysis to identify the key parameters that explain the split of extra processing costs between farmers and households.

4. Effects on outputs and employment by industries

Tables 4 and 5 show results for output and employment by industry. We present the results in full detail for agricultural and food-related industries. To keep the tables manageable, results for other industries are presented in aggregated form.

4.1 Beef processing

As shown in Table 1, a 10 per cent increase in primary-factor requirements per unit of output in Beef processing increases the consumer price of the processed product. This leads to a reduction in demand and a consequent reduction in output (−1.933 per cent, row 32, col 1, Table 4). Households substitute towards other meat products. This explains the positive results in Table 4 for Other-animal processing, Poultry processing and Seafood in rows 33, 34 and 35 of column 1, and corresponding positive results in column 1 for the primary industries Other animals, Poultry & eggs and Fishing & hunting (rows 10, 11 and 13). The output of Cattle ranching declines, but by a smaller percentage than the output of Beef processing (−1.175 per cent, row 8 compared with −1.933 per cent). Cattle ranchers mitigate the effects of reduced processing output by partly replacing imports. In our database, these imports are about 3.3 per cent of total sales of the Cattle-ranch product in the United States.

With the exception of the Beef-processing industry, the employment results in column 1 of Table 5 follow the same general pattern as the corresponding output results in Table 4. For Beef processing, employment increases by 6.219 per cent (row 32, Table 5), whereas output falls by 1.933 per cent. This sharp increase in the labour/output ratio for Beef processing reflects the assumed 10 per cent increase in the industry's primary-factor inputs per unit of output. For all other industries, the change in the labour/output ratio is small. For most farm industries, there is a small amount of substitution of land, released from Cattle ranching, for other primary factors leading to a reduction in the labour/output ratio. For most non-farming industries, the labour/output ratio increases reflecting a reduction in the real wage rate to be discussed in Section 5.

Table 4 Percentage effects on industry outputs of increased costs in meat processing (effects after 5 years of 10% increases in primary-factor input per unit output in meat processing industries)

		Beef processing (1)	Other-animal proc (2)	Poultry processing (3)	Total meat processing (4)
1	Agriculture	−0.159	−0.029	−0.093	−0.282
2	Oil seeds	0.038	0.005	0.009	0.052
3	Grains	−0.060	0.005	−0.063	−0.118
4	Vegetables & melons	0.004	−0.001	0.002	0.005
5	Fruit & nuts	0.035	0.002	0.027	0.065
6	Green nurseries	−0.005	−0.001	−0.003	−0.009
7	Other crops	−0.038	0.002	0.008	−0.028
8	Cattle ranching	−1.175	0.044	0.075	−1.057
9	Dairy cattle	0.016	0.003	0.000	0.020
10	Other animals (mainly pigs)	0.065	−0.595	0.035	−0.496
11	Poultry & eggs	0.142	0.046	−0.780	−0.592
12	Forestry & logging	0.004	0.003	−0.002	0.004
13	Fishing & hunting	0.087	0.031	0.061	0.179
14	Agriculture support	−0.092	−0.003	−0.030	−0.125
15	Mining	0.000	0.001	−0.002	−0.001
16	Utilities	−0.009	−0.003	−0.006	−0.018
17	Construction	−0.005	−0.002	−0.004	−0.011
18	Manufacturing, excl. food	−0.003	0.000	−0.006	−0.009
19	Food manufacturing	−0.299	−0.101	−0.168	−0.541
20	FlourMaltMill	0.004	0.002	−0.029	−0.023
21	WetCornMill	0.022	0.009	−0.006	0.024
22	SoyOilProc	0.022	0.006	−0.057	−0.028
23	FatsOils	−0.015	−0.005	−0.022	−0.042
24	BreakCereal	−0.019	−0.006	−0.014	−0.039
25	SugarConfect	−0.011	−0.004	−0.010	−0.025
26	FrozFood	−0.073	−0.028	−0.081	−0.181
27	FrtVegCanning	−0.061	−0.022	−0.012	−0.095
28	MilkButter	0.005	0.001	−0.008	−0.003
29	Cheese	0.023	0.007	0.012	0.042
30	DryCondEvapDairy	0.010	0.001	−0.005	0.006
31	IceCream	0.042	0.017	0.026	0.085
32	BeefProc	−1.933	0.058	0.065	−1.810
33	OthAnimProc	0.169	−1.958	0.082	−1.711
34	PoultryProc	0.104	0.034	−1.840	−1.702
35	Seafood	0.140	0.072	0.096	0.308
36	BreadBakery	−0.013	−0.003	−0.007	−0.023
37	CookiePasta	−0.020	−0.006	−0.006	−0.033
38	SnackFood	−0.021	−0.008	−0.010	−0.038
39	CoffTea	0.012	0.006	0.001	0.018
40	FlavorSyrup	0.013	0.007	0.011	0.031
41	SeasoningDressing	−0.055	−0.018	−0.006	−0.079
42	OthrFoodManu	−0.026	−0.004	−0.010	−0.040
43	SoftDrinks	−0.007	−0.002	−0.004	−0.013
44	OtherServices	−0.012	−0.004	−0.008	−0.023
45	Health	−0.011	−0.004	−0.006	−0.022
46	FoodServingSpecialists	−0.022	−0.008	−0.018	−0.048
47	Accom. & hotels	−0.012	−0.004	−0.010	−0.026
48	Full serv restaurants	−0.025	−0.009	−0.019	−0.054
49	Lim. serv restaurants	−0.022	−0.008	−0.020	−0.051

Table 5 Percentage effects on industry employment of increased costs in meat processing (effects after 5 years of 10% increases in primary-factor input per unit output in meat processing industries)

		Beef processing (1)	Other-animal proc (2)	Poultry processing (3)	Total meat processing (4)
1	Agriculture	−0.121	−0.071	−0.034	−0.226
2	Oil seeds	0.016	0.004	−0.006	0.014
3	Grains	−0.050	0.003	−0.050	−0.096
4	Vegetables & melons	−0.003	−0.001	−0.004	−0.008
5	Fruit & nuts	0.019	0.002	0.012	0.033
6	Green nurseries	−0.006	−0.001	−0.004	−0.011
7	Other crops	−0.038	0.001	0.002	−0.034
8	Cattle ranching	−0.941	0.035	0.057	−0.850
9	Dairy cattle	0.008	0.003	−0.001	0.011
10	Other animals (mainly pigs)	0.060	−0.574	0.033	−0.482
11	Poultry & eggs	0.099	0.034	−0.557	−0.424
12	Forestry & logging	0.003	0.003	−0.003	0.003
13	Fishing & hunting	0.099	0.036	0.069	0.203
14	Agriculture support	−0.109	−0.004	−0.035	−0.148
15	Mining	−0.001	0.001	−0.004	−0.003
16	Utilities	−0.012	−0.003	−0.008	−0.024
17	Construction	−0.005	−0.002	−0.004	−0.011
18	Manufacturing, excl. food	−0.001	0.000	−0.004	−0.005
19	Food manufacturing	0.913	0.313	0.584	1.778
20	FlourMaltMill	0.004	0.003	−0.036	−0.030
21	WetCornMill	0.021	0.009	−0.006	0.023
22	SoyOilProc	0.023	0.008	−0.059	−0.028
23	FatsOils	−0.013	−0.003	−0.027	−0.043
24	BreakCereal	−0.017	−0.005	−0.013	−0.035
25	SugarConfect	−0.011	−0.004	−0.011	−0.026
26	FrozFood	−0.060	−0.023	−0.070	−0.153
27	FrtVegCanning	−0.042	−0.015	−0.012	−0.068
28	MilkButter	0.005	0.001	−0.009	−0.003
29	Cheese	0.022	0.008	0.010	0.040
30	DryCondEvapDairy	0.009	0.002	−0.006	0.004
31	IceCream	0.044	0.019	0.026	0.088
32	BeefProc	6.291	0.061	0.090	6.453
33	OthAnimProc	0.174	6.290	0.090	6.571
34	PoultryProc	0.148	0.050	6.387	6.599
35	Seafood	0.147	0.070	0.099	0.317
36	BreadBakery	−0.013	−0.003	−0.007	−0.022
37	CookiePasta	−0.020	−0.006	−0.008	−0.033
38	SnackFood	−0.021	−0.007	−0.011	−0.038
39	CoffTea	0.012	0.006	0.001	0.018
40	FlavorSyrup	0.016	0.008	0.012	0.036
41	SeasoningDressing	−0.023	−0.007	−0.005	−0.035
42	OthrFoodManu	−0.023	−0.002	−0.008	−0.034
43	SoftDrinks	−0.006	−0.002	−0.004	−0.012
44	OtherServices	−0.012	−0.004	−0.008	−0.025
45	Health	−0.011	−0.004	−0.006	−0.020
46	FoodServingSpecialists	−0.019	−0.007	−0.016	−0.042
47	Accom. & hotels	−0.012	−0.004	−0.010	−0.026
48	Full serv restaurants	−0.021	−0.008	−0.016	−0.044
49	Lim. serv restaurants	−0.021	−0.008	−0.019	−0.047

4.2 Other-animal processing

Column 2 of Tables 4 and 5 give industry results for the effects of a 10 per cent increase in primary factor requirements per unit of output in Other-animal processing. These show a reduction in the output of Other-animal processing of 1.958 per cent (row 33, col 2, Table 4) and a smaller percentage reduction in the output of the corresponding farm industry, 0.595 per cent (row 10, col 2, Table 4). Other-animal farmers partly mitigate the effects of reduced demand from the processing industry by replacing imports and expanding exports. In our database, imports of Other-animal farm products are 11.7 per cent of total sales of these products in the United States and exports are 3.7 per cent of U.S. output. Other effects that can be seen in column 2 of Tables 4 and 5 include the following: substitution towards other meat products with positive output results for Beef processing, Poultry processing and Seafood (rows 32, 34 and 35); positive output results for Cattle ranching, Poultry & eggs and Fishing & hunting (rows 8, 11 and 13); a sharp increase in the labour/output ratio for Other-animal processing (compare row 33, col 2, Table 5 with the corresponding entry in Table 4); small negative movements in labour/output ratios for most farm industries; and small positive movements in labour/output ratios for most non-farm industries.

In the USAGE-Food database, value added in Other-animal processing is only about 1/3rd of that in Beef processing. Thus, the 10 per cent shock in the second simulation is on a smaller base than the 10 per cent shock in the first simulation. For this reason, the results in column 2 of Tables 4 and 5 for industries apart from those directly affected by the shock are generally smaller in magnitude than those in column 1.

4.3 Poultry processing

Value added in Poultry processing is about 2/3rds of that in Beef processing and about twice that in Other-animal processing. Consequently, the magnitude of results in column 3 of Tables 4 and 5 for industries not directly affected by the shock is generally between those in columns 1 and 2.

For Poultry processing, the percentage reduction in output in column 3 is quite similar to the percentage reductions in output of Beef processing in column 1 and Other-animal processing in column 2. For the farm industry Poultry & eggs, the output reduction in column 3 (−0.780 per cent, row 11, Table 4) is greater than that for Other animals in column 2 (−0.595 per cent) but less than that for Cattle ranching in column 1 (−1.175 per cent). Of the three meat-producing farm industries, Poultry & eggs has the least direct exposure to international trade, giving it the least opportunity to replace imports and expand exports. On this basis, we might expect Poultry & eggs to be poorly placed to mitigate the effects of reduced demand from the processing industry. However, Poultry & eggs has considerable direct sales to households (sales of eggs) that do not depend on demand from the processing industry.

5. Effects on macro variables

Macro results are given in Table 6. We focus on the results in column 4.

A good framework for looking at these results is the aggregate production function:

$$Y = A * F(K, L) \tag{1}$$

where Y is output or GDP; A is technology; K is aggregate capital; L is aggregate labour, and F is a constant-returns-to-scale production function. In percentage change form, (1) can be written as:

$$y = a + S_L * \ell + S_K * k \tag{2}$$

where
y, a, ℓ and k are percentage changes in Y, A, L and K, andS_L and S_K are the shares of labour and capital in GDP (0.62 and 0.38).

As mentioned in Section 1, we assume that our 5-year simulation period is sufficiently long for wage adjustment to eliminate effects on aggregate employment. Consequently, Table 6 shows zeros in row 7. With employment fixed, equation (2) can be reduced to.

$$y = a + 0.38 * k \tag{3}$$

In total, primary factors in Beef processing, Other-animal processing and Poultry processing account for 0.300 per cent of GDP (about \$69b out of \$23t). Thus, a 10 per cent increase in primary factor requirements per unit of output in meat processing is equivalent to a technological deterioration of 0.030 per cent. In terms of equation (3), $a = -0.030$. Our simulations imply that changes in meat-processing costs have only tiny effects on the economy's

Table 6 Percentage effects on macro variables of increased costs in meat processing (effects after 5 years of 10% increases in primary-factor input per unit output in meat processing industries)

		Beef processing (1)	Other-animal proc (2)	Poultry processing (3)	Total meat processing (4)
1	Real GDP (Y)	−0.016	−0.005	−0.010	−0.031
2	Real private consumption (C)	−0.016	−0.006	−0.011	−0.033
3	Real investment (I)	0.001	−0.003	−0.002	−0.004
4	Real public consumption (G)	−0.017	−0.006	−0.011	−0.033
5	Real exports (X)	−0.023	−0.006	−0.014	−0.042
6	Real imports (M)	−0.004	−0.004	−0.004	−0.012
7	Aggregate employment (L)	0.000	0.000	0.000	0.000
8	Aggregate capital (K)	−0.002	0.001	−0.002	−0.005
9	Real wage (W/P_c)	−0.015	−0.005	−0.009	−0.029
10	Exchange rate (+ = appreciation)	0.007	0.001	0.007	0.015
11	Price deflator for C (P_c)	0.000	0.000	0.000	0.000

aggregate K/L ratio. In column 4 of Table 6, the K/L ratio declines by 0.005 per cent (row 8 compared with row 7). Using equation (3), we now have a back-of-the-envelope (BOTE) approximation to the percentage movement in GDP:

$$y = -0.030 - 0.38*0.005 = -0.032 \quad (4)$$

This is close to the simulated effect on GDP of −0.031 (row 1, col 4, Table 6).

Broadly consistent with the reductions in GDP and capital, column 4 of Table 6 shows reductions in real private and public consumption of 0.033 per cent and real investment of 0.004 per cent. With the percentage reductions in real private and public consumption being about the same as that in GDP and the percentage reduction in investment being less than that in GDP, exports must decline relative to imports (rows 5 and 6). This is facilitated by real appreciation (row 10).

By reducing the marginal product of labour, a deterioration in technology causes a reduction in real wage rates (−0.029 per cent, row 9). This is another way of understanding how households would pay for extra costs in meat processing.

6. Understanding the split between farmers and consumers in paying for extra processing costs: sensitivity analysis

In this section, we return to the question raised at the end of Section 3: What are the major determinants in USAGE-Food of the split of extra processing costs between farmers and consumers? We start with a BOTE diagrammatic analysis. This points to the parameters that are likely to be important in determining the split. Guided by this information, we perform sensitivity simulations.

6.1 BOTE diagrammatic analysis

Figure 1 is a 4-quadrant diagram. The upward-sloping schedule A in the north-east quadrant represents the market-clearing price for a U.S. farm product at different levels of demand for the processed product. In stylised form, the demand and supply equations underlying the A schedule are as follows:

$$Q_F = a_{1d}*P_F^{-\eta} + a_{2d}*Q_P \qquad \textit{demand for farm product} \quad (5)$$

$$Q_F = a_s*P_F^{\epsilon} \qquad \textit{output of farm product} \quad (6)$$

where Q_F and P_F are the quantity and price of the farm product, Q_P is the output of the processed product, and a_{1d}, a_{2d}, a_s, η and ε are positive parameters. Equation (5) presents demand for the farm product in two parts.

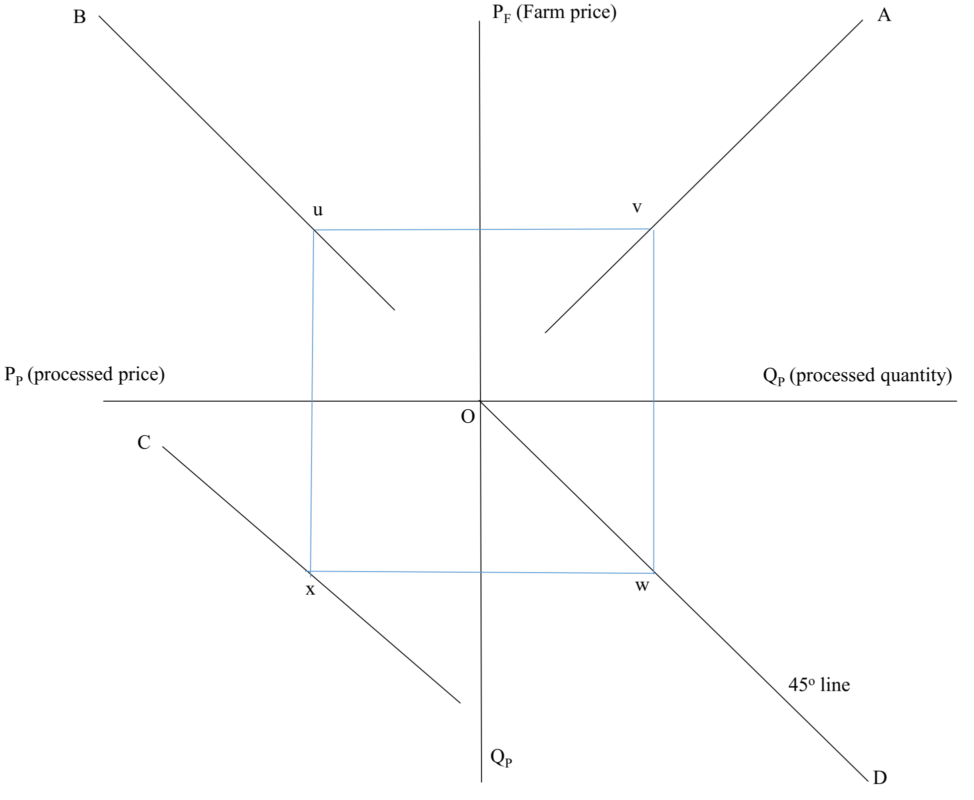

Figure 1 Determination of the prices and outputs of a farm product and the associated processed product. [Colour figure can be viewed at wileyonlinelibrary.com]

The first part is price-sensitive, with a demand elasticity of -η. It can be thought of as export demand or demand to replace imports. The second part is demand for the farm product to be used as an input to the processor. It is proportional to the output of the processor. Equation (6) is the farmer's supply function, with a supply elasticity of ε. Combining (5) and (6) and converting to percentage change form, we obtain:

$$p_F = \frac{SH}{[\epsilon + (1 - SH)*\eta]} *q_P \qquad \textit{market clearing} \qquad (7)$$

where p_F and q_P are percentage changes in P_F and Q_P, and $SH(= a_{2d}*Q_P/Q_F)$ is the share of the farm product that goes to the processor. Equation (7) confirms that schedule A is upward-sloping.

The upward-sloping B schedule in the north-west quadrant represents the relationship between the price of the processed product, P_P (horizontal axis), and the price of the farm product, P_F (vertical axis). B has a positive slope because increases in input costs to the processor lead to increases in the processor's output price.

The downward-sloping C schedule in the south-west quadrant is the demand curve for the processed product: increases in the price of the processed product reduce demand.

The 45 degree line, OD, in the south-east quadrant represents balance between demand for (vertical axis) and supply of (horizontal axis) the domestically produced processed product.

The solution of the model in Figure 1 occurs at the vertices of the rectangle uvwx.

Figure 2 introduces an increase in the cost of processing. This causes in the schedule in the north-west quadrant to shift to the left, from B to B': at any given value for P_F, there is an increase in P_P. The new solution is at points $u^1v^1w^1x^1$. The effects of the increase in processing costs can be seen by comparing this new solution with the original solution (uvwx). Consistent with the simulation results in Sections 2 to 4, Figure 2 and underlining equation (6) show that the outputs of both the farm and processed products fall, and the cost increase is shared between farmers and consumers. Farmers

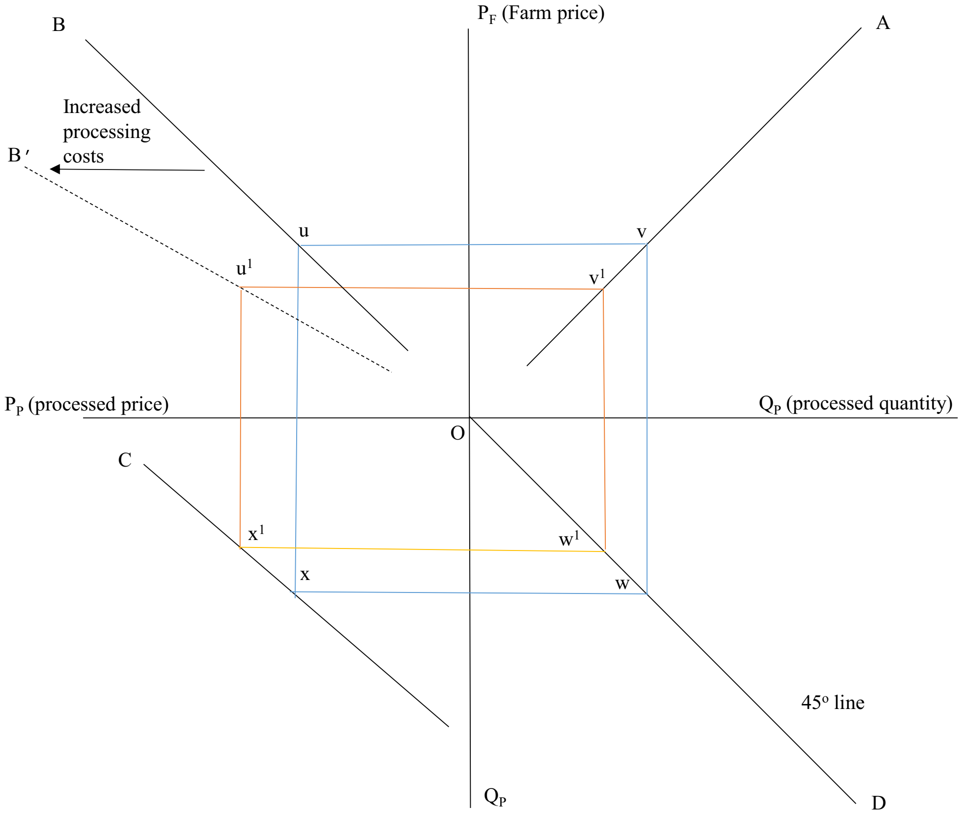

Figure 2 Prices and outputs of a farm product and the associated processed product: the effect of an increase in processing cost. [Colour figure can be viewed at wileyonlinelibrary.com]

get a lower price for their output (a reduction in P_F), and consumers pay a higher price for the processed product (an increase in P_P).

In Figures 3 and 4, we examine the sensitivity of these price and quantity effects to changes in the elasticities of the C schedule in the south-west quadrant and the A schedule in the north-east quadrant.

Figure 3 shows that a lower demand elasticity for the processed product (replacement of C with C') moves the solution from $u^1v^1w^1x^1$ to $u^2v^2w^2x^2$. This is good for farmers and bad for consumers. With less elastic demand for the processed product, the increase in processing costs causes a smaller reduction in the farm price and a larger increase in the price to consumers of the processed product.

Figure 4 shows the effects of adopting a larger elasticity (steeper slope) for the farm-product market-clearing schedule. In equation (7), this elasticity is $SH/[\epsilon + (1 - SH)*\eta]$. The replacement of A with A' could correspond to a lower supply (ε) or demand (η) elasticity for the farm product, or to a higher share for the price-insensitive sales of the farm product to the processor (SH). With a higher market-clearing elasticity, the solution moves from $u^1v^1w^1x^1$ to

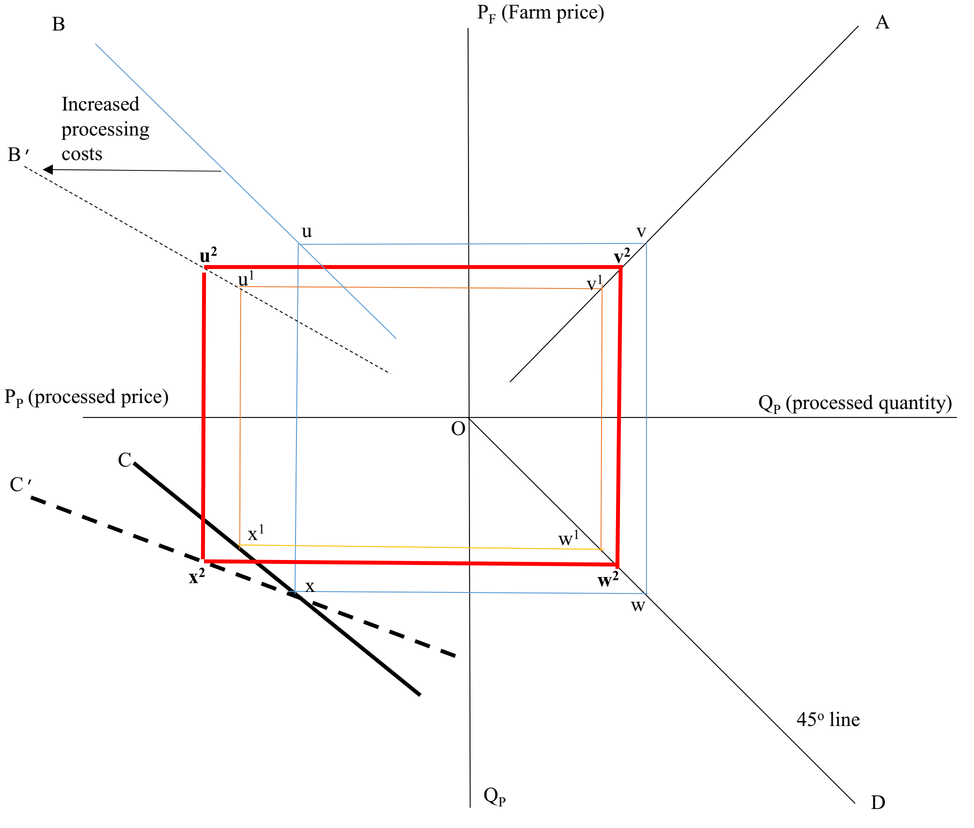

Figure 3 Effect of increased processing costs with lower elasticity of demand for the processed product. [Colour figure can be viewed at wileyonlinelibrary.com]

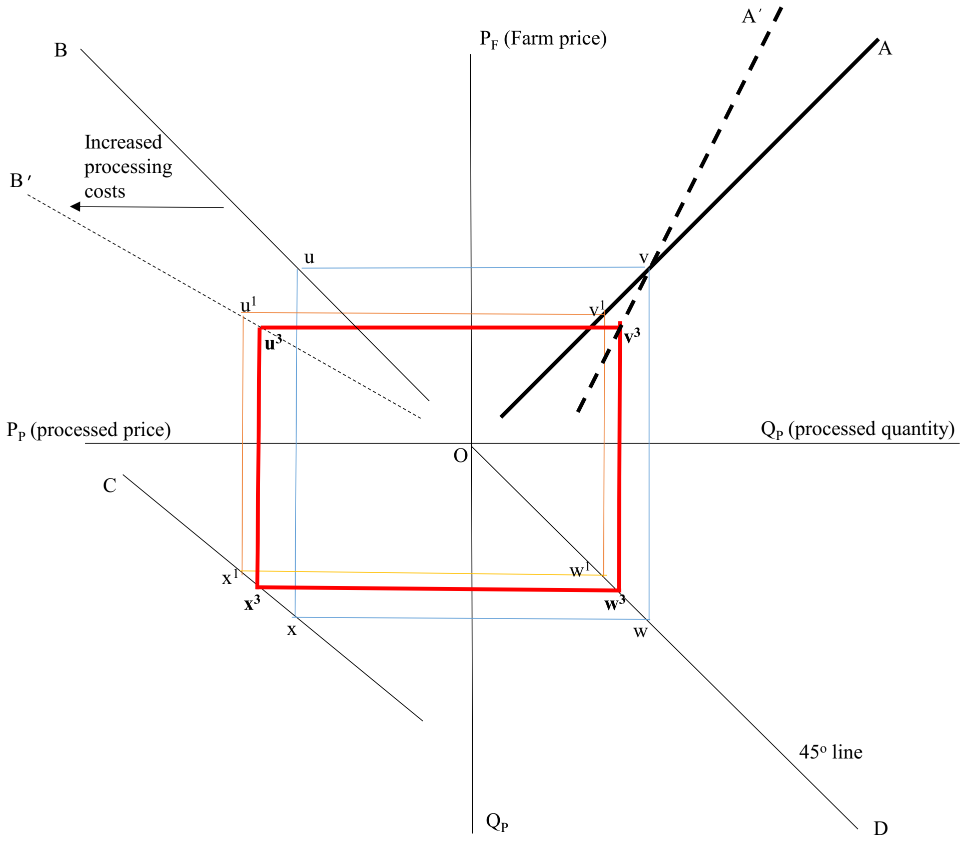

Figure 4 Effect of increased processing costs with lower demand and supply elasticities for the farm product. [Colour figure can be viewed at wileyonlinelibrary.com]

$u^3v^3w^3x^3$. This is bad for farmers and good for consumers. If farmers face a lower demand elasticity (lower η or higher SH) or have a lower supply elasticity (lower ε), then an increase in processing costs causes a greater reduction in the farm price. The lower farm price feeds through to a lower processed price, benefitting consumers.

6.2 Sensitivity simulations

The diagrams in Subsection 6.1 suggest there are three elasticities that play major roles in determining the split of processing costs between farmers and consumers:

1. The elasticity of demand for the processed product;
2. The elasticity of supply of the farm product; and
3. The elasticity of demand for the farm product.

In USAGE-Food, these elasticities are not parameters. There are many data items and parameters that contribute to their values. These are cost shares, sales shares and substitution parameters occurring in CES-nested production functions for meat-farm industries and associated processing industries, and in the utility functions for U.S. and foreign households. The share coefficients (such as SH) are derived from input–output data published by official statistical agencies, in this case, the Bureau of Economic Analysis. By contrast, the statistical basis for the substitution parameters is weak. In most CGE models, including USAGE-Food, the values adopted are based on judgement, informed over many years by what has produced credible results in a large number of applications. However, judgements can differ. Given this situation, we provide sensitivity analysis by varying the values adopted for the substitution parameters that are important in our current application.

Table 7 lists the relevant parameters classified by the critical elasticity to which they contribute. The table also shows values adopted in earlier sections for these parameters for Cattle ranching (a meat-farm industry) and Beef processing (the corresponding processing industry). These are denoted as standard values. We restrict the sensitivity analysis to the Beef-processing simulation. Similar sensitivity analyses could be conducted for the simulations concerned with cost increases in Other-animal processing and Poultry processing.

Table 7 Parameters in USAGE-Food that determine how extra processing costs are split between farmers and meat consumers

	Value
Category 1. Contributing parameters to the elasticity of demand for a processed meat product	
(i) Household elasticity of substitution between the processed product and all other meat products	1.0
(ii) Household elasticity of substitution between meat products and all other food products	0.5
(iii) Elasticity of substitution between the domestic processed product and the corresponding imported product	2.0
(iv) Absolute value of the elasticity of demand for U.S. exports of the processed meat product	3.0
Category 2. Contributing parameters to the elasticity of supply of a meat farm product	
(v) Elasticity of substitution between farm-family labour and hired labour in the farm industry	2.0
(vi) Elasticity of substitution in the farm industry between labour, capital and land	0.5
(vii) Elasticity of substitution in the farm industry between primary-factors and intermediate inputs	0.2
Category 3. Contributing parameters to the elasticity of demand for a meat farm product	
(viii) Elasticity of substitution between the domestic farm product and the corresponding imported product	2.0
(ix) Absolute value of the elasticity of demand for U.S. exports of the farm product	3.0
(x) Elasticity of substitution in the processed-meat industry between primary-factors and intermediate inputs	0.2

Higher values for items (i) to (iv) in Table 7 contribute to a higher overall demand elasticity for a processed product by generating for any given price increase larger shifts in household demand away from the product towards other meat products and non-meat products, and a larger shift towards imports and a larger reduction in exports.

Higher values for items (v) to (vii) contribute to a higher overall supply elasticity of the farm product by generating for any given price increase a larger uptake of hired labour to be combined with fixed farm-family labour, and larger increases in labour, capital and intermediate inputs to be combined with fixed land.

Higher values for items (viii) to (x) contribute to a higher overall demand elasticity for the farm product by generating for any given price increase a larger increase in imports, a larger reduction in exports and a larger reduction in the use of farm product per unit of output of processed product.

Column (0) in Table 8 contains results from the Beef-processing simulation with standard parameters setting. These results were analysed in previous sections. Columns (1) to (8) contain results from the Beef-processing simulation with different parameter settings for Cattle ranching and Beef processing.

In simulation (1), the category 1 parameters from Table 7, those contributing to the elasticity of demand for Beef processing, are doubled. All other parameter values are maintained at their standard values. In simulation (2), the category 1 parameters from Table 7 are halved.

In simulations (3) and (4), the category 2 parameters from Table 7, those contributing to the elasticity of supply for the Cattle-ranch product, are doubled and halved. All other parameter values, including the category 1 parameters, are maintained at their standard values.

In simulations (5) and (6), the category 3 parameters from Table 7, those contributing to the demand elasticity for the Cattle-ranch product, are doubled and halved. Again, all other parameter values are maintained at their standard values.

Simulations (7) and (8) are included in the table to show what has to be assumed about parameter values to support the view that farmers pick up the bulk of extra processing costs. We delay the description of these two simulations until after we have considered simulations (1) to (6).

Rows 1 to 3 of Table 8 contain data items for 2020 from the baseline. These differ slightly across the nine simulations. As explained in Section 1, USAGE-Food was set up with a database for 2015. The baseline data for 2020 are affected by parameter settings. In all simulations, the impact cost of a 10 per cent increase in primary factor requirements in processing is about \$3.5b, 10 per cent of the value-added numbers in row 1. As can be seen from row 9, in each simulation the costs allocated to farmers and consumers add closely to this total impact cost.

Table 8 The split between farmers and meat consumers of extra processing costs: how is this affected by changes in parameter values underlying demand & supply elasticities for Cattle-ranch and Beef-processing products? [Colour table can be viewed at wileyonlinelibrary.com]

	Simulation	(0)	(1) Demand elasticity	(2)	(3) Supply elasticity	(4)	(5) Demand elasticity	(6)	(7) D&S elasticities	(8)
			Processed beef		Ranch product		Ranch product		Ranch product	
	Parameters	Standard	High Cat1x2	Low Cat1x0.5	High Cat2x2	Low Cat2x0.5	High Cat3x2	Low Cat3x0.5	Low Sims (4) & (6). Also (1)	Very low Cats2&3 set at 0.01
Items from 2020 baseline data										
1	Value added in beef processing industry, $b	35.00	35.02	34.98	35.06	34.93	35.35	34.81	34.67	33.42
2	Basic value of sales from beef processing ind., $b	120.60	120.63	120.56	119.94	121.38	120.50	120.65	121.32	124.63
3	Farm income in cattle ranching, $b	25.82	25.84	25.80	24.71	27.01	25.63	25.92	27.17	32.88
Simulation results (percentage changes)										
4	Basic price of domestic processed beef product	2.34	2.00	2.56	2.51	2.13	2.52	2.24	1.57	0.14
5	Basic price of domestic cattle-ranch product	−0.90	−1.53	−0.48	−0.60	−1.27	−0.56	−1.09	−2.34	−4.76
6	Real farm income in cattle ranching	−2.41	−4.11	−1.29	−1.70	−3.19	−1.50	−2.92	−5.87	−9.66
***Back-of-the-envelope* (BOTE) calculations**										
7	Loss of farm income, $b (= -row3*row6/100)	0.62	1.06	0.33	0.42	0.86	0.38	0.76	1.59	3.18
8	Cost to consumers, $b (= row2*row4/100)	2.82	2.42	3.09	3.01	2.59	3.03	2.70	1.90	0.17
9	Total BOTE loss $b, (= row 7 + row8)	3.44	3.48	3.42	3.43	3.45	3.42	3.46	3.50	3.35
10	Farm income loss as per cent of simulated processing cost (=100*row 7/row 9)	18	31	10	12	25	11	22	46	95

Results from sensitivity simulations (1) to (6)

We start with simulation (2). Consistent with Figure 3, this simulation shows that halving the category 1 parameters (thereby reducing the implied demand elasticity for processed beef) favours farmers relative to consumers. There are a smaller reduction in the farm price (−0.48 per cent rather than −0.90 per cent) and a larger increase in the processed price (2.56 per cent rather than 2.34 per cent). The farmer share of extra processing costs falls to 10 per cent, down from 18 per cent under standard parameter settings (row 10). Doubling the category 1 parameters has opposite effects. In simulation (1), the farmers' share of extra processing costs moves to 31 per cent.

Consistent with Figure 4, simulation (4) shows that halving category 2 parameters (thereby reducing the implied supply elasticity for the ranch product) hurts farmers relative to consumers. There is a larger reduction in the farm price (−1.27 per cent rather than −0.90 per cent) and a smaller increase in the processed price (2.13 per cent rather than 2.34 per cent). The farmers' share of extra processing costs rises to 25 per cent (row 10). Doubling the category 2 parameters in simulation (3) reduces the farmers' share to 12 per cent.

Also consistent with Figure 4, simulation (6) shows that farmers are hurt relative to consumers by halving category 3 parameters (thereby reducing the implied demand elasticity for the ranch product). The farmer share of extra processing costs rises to 22 per cent (row 10). Doubling the category 3 parameters in simulation (5) reduces the farmers' share to 11 per cent.

Results from sensitivity simulations (7) and (8)

In sensitivity simulation (7), we move all the parameters against the farmers: category 1 parameters are set at twice their standard values [as in simulation (1)] and the category 2 and 3 parameters are set at half their standard values [as in simulations (4) and (6)]. This raises the farmers' share of additional processing costs to 46 per cent. However, it is unlikely that the standard parameter settings are systematically biased in favour of farmers. Consequently, we think that the farmers' share is likely to be well below 46 per cent.

Simulation 8 is set up with very low values (0.01) for all category 2 and 3 parameters. This is in accordance with the *a priori* picture described at the end of Section 3. In that picture, farmers with inelastic supply curves sell all their product to meat processors whose demand for the domestic farm product is also inelastic. With regard to our understanding of the model and as a check of its computational integrity, it is reassuring that the simulation shows farmers as bearing almost all of the costs of extra processing requirements. The simulation also helps us understand what is wrong with the *a priori* picture. What the model captures, but is missed by the simple picture, is that farmers *do* have considerable elasticity on both the supply and demand sides. Farmers can adjust supply by varying hired labour, capital and intermediate inputs. Taking trade opportunities into consideration, farmers are not faced with totally inelastic demands. Thus, in terms of our modelling, it is not plausible to set category 2 and 3 elasticities at close to zero as was required in simulation 8 to generate the *a priori* picture.

7. Concluding remarks

Triggered by COVID, there is an active discussion in the United States concerning work practices in meat-processing plants. The recommended changes would be beneficial for the safety and economic welfare of meat-processing workers. However, they will have economic costs. In this paper, we used a detailed CGE model to work out how those costs would be distributed between farmers and consumers of meat products. We also calculated the macroeconomic and industry effects.

A strength of CGE models is that they sometimes produce results that were unexpected *a priori* but seem reasonable *ex post*. This was the case here. Elementary theory suggests that farmers would bear most of additional meat-processing costs. However, the CGE model produces a different picture. By taking account of farm production flexibility and demand responses in the different markets in which farmers can sell their products, the CGE model showed that the bulk of additional meat-processing costs would be borne by customers for meat products, not the farmers. Nevertheless, processing costs still impact significantly on farm incomes. Our central simulations of the effects of 10 per cent increases in labour and capital requirements in processing show reductions in farm incomes of between 1 and 2.5 per cent.

By contrast, the macro results did not produce any surprises. In general, the macroeconomic implications of reform-related increases in meat-processing costs will be negative, but small. We find that a 10% increase in primary factor requirements in all meat-processing industries reduces GDP in the long run by about 0.03%. Among the industry results, perhaps the most interesting were those showing increases in employment in meat processing despite reductions in output.

Funding

This paper was prepared under Amendment 01 to Federal Award no. 17STQAC00001-03-00, Subaward no. ASUB00000508 issued by the U.S. Department of Homeland Security (DHS). The award is to support a project titled *Economic Modeling of the impacts of COVID-19* being undertaken by the Centre of Policy Studies at Victoria University in Melbourne through DHS's Center of Excellence for Accelerating Operational Efficiency (CAOE) at Arizona State University. Amendment 01 requires detailed modelling results to be produced for U.S. agriculture. This part of the project is being undertaken in cooperation with DHS's Center of Excellence for Cross Border Threat Screening and Supply Chain Defense at Texas A&M University.

Disclaimer

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Acknowledgements

Open access publishing facilitated by Victoria University, as part of the Wiley – Victoria University agreement via the Council of Australian University Librarians. Open access funding enabled by CAUL.

Conflict of interest

The authors have no conflict of interest to declare.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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[Correction added on 17 May 2022, after first online publication: CAUL funding statement has been added.]

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