Who will pay for improved health standards in U.S. meat-processing plants?
Simulation results from the USAGE model

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Summary

The Cybersecurity and Infrastructure Security Agency (CISA) is sponsoring a project on the economic effects in the United States of COVID-19. The project is being conducted by the Centre of Policy Studies through the Center for Accelerating Operational Efficiency (CAOE). It aims to quantify COVID-19 effects on the U.S. macro economy, industries and regions. The original aim of the project was extended to include a special study of COVID-19 effects on the U.S. agricultural sector. The agricultural extension is being conducted in cooperation with the Center for Cross Border Threat Screening and Supply Chain Defense. This report is part of the work on the agricultural extension.

(1) The motivation for the paper is the possibility that changes in work practices introduced in U.S. meat-processing plants to reduce the spread of Covid become permanent.

(2) We use USAGE-Food to simulate the effects on the U.S. economy of 10 per cent permanent increases in labor and capital requirements per unit of output in meat processing. The 10 per cent is illustrative. The approximate effects of different percentages can be deduced by scaling.

(3) USAGE-Food is a CGE model with a detailed treatment of agriculture and food processing. With regard to meat, the model identifies 3 farm industries, Cattle ranching, Other animals (mainly pigs) and Poultry & eggs, and three associated processing industries, Beef processing, Other animal processing and Poultry processing.

(4) We show how extra processing costs are allocated between farmers and consumers of meat products.

(5) In our modeling, farmer-family labor and land are treated as approximately fixed factors. Other factors in the meat supply chain are mobile. On this basis, we expected increased meat-processing costs to be borne mainly by meat-producing farmers.

(6) Contrary to this, the USAGE-Food simulations show that extra processing costs are paid mainly by meat consumers, not famers.

(7) Farmers avoid over 80 per cent of extra processing costs because they have the opportunity to operate in markets in which U.S. processing costs are irrelevant. These markets include direct exports of farm products, replacement of imported farm products and direct sales of farm products (e.g. eggs) to households.

(8) We use a demand and supply diagram to explain the importance of direct sales of farm products in determining the allocation of processing costs, even when these sales are a small proportion of the total sales of farm products.

(9) Although over 80 per cent of extra processing costs are borne by meat consumers, they still impact significantly on farm incomes. Our simulations of the effects of 10 per cent increases in labor and capital requirements in processing show reductions in farm incomes of between 1 and 2.5 per cent.

(10) The effects on the macro economy of even quite large increases in processing costs are minor. We find that a 10% increase in primary-factor requirements in all U.S. meat-processing industries reduces GDP in the long run by about 0.03%.

1. Introduction

Meat-processing plants have are particularly dangerous workplaces for the spread of the Covid virus.[1] This has led to changes in the way these plants are organized, including the requirement for greater distances between workers, improved hygiene measures and the installation of separation barriers. These changes increase costs per unit of meat processed.

In this paper we use the USAGE model to examine the effects on the U.S. economy of increased costs in meat processing. USAGE is a detailed computable general equilibrium (CGE) model.[2] We refer to the version applied here as USAGE-Food.[3] This version distinguishes 392 industries. These include Beef processing, Other Animal processing (mainly pigs) and Poultry processing, together with related farm industries, Cattle ranching, Other animal farms and Poultry& egg farms.

There is no clear information on the extent to which Covid-related changes have increased the costs of meat processing, or on the permanency of these changes. In the scenarios we examine, the health-related improvements, and therefore cost increases are maintained post-Covid. We assume that the improved practices add 10 per cent to the primary factor requirements (capital and labor) per unit of output in each of the three meat processing industries. Our results are close to linear with respect to this 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 for effects after 5 years. Literally, we model the cost increases in meat processing as occurring in 2015 and we look at how these cost increases affect the economy of 2020. Almost all our results are percentage deviations. 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 what 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 labor 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 (levels that would apply without the assumed cost increases).

Models such as USAGE-Food contain many thousands of equations. These equations describe optimizing behavior 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 data, see Dixon *et al.* (2017). It is not practical to set out the model

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[1] See, for example, Weiner-Bronner (2020), Waltenburg *et al.* (2020) and Sents (2020),

[2] USAGE (U.S. Applied General Equilibrium) has been continuously developed at the Centre of Policy Studies (CoPS) over the last 15 years. The model has been applied on a wide variety of topics by and on behalf of: the U.S. International Trade Commission; the U.S. Treasury; the Mitre Corporation; the Cato Institute; the Canadian Government; and the U.S. Departments of Homeland Security, Commerce, Agriculture, Transportation and Energy. For an overview of USAGE and its applications see Dixon *et al.* (2013).

[3] USAGE-Food is described in Dixon and Rimmer (2019).

in a short paper. However, we hope that our description of results is sufficient for readers to be able to identify and assess relevant assumptions and data items.

The results are presented in four sections, covering consumer prices, real farm incomes, industry outputs and employment, and the macro economy. Concluding remarks are in section 6.

2. Effects on prices to households

In our simulations we assume that cost increases in meat processing have no effect on aggregate consumer prices (cpi). 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 cents. 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 their real incomes.

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 given by $1.596 = 0.498*1.529+0.171*1.465+0.331*1.764$, and the percentage movement in the price of Food is given by $0.356 = 0.233*1.596+(1-0.233)*(-0.020)$.

The results in the last 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.

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

Table 2 shows percentage effects of increased processing costs on real farm incomes, defined as returns to farm land, farm capital and farmer-supplied labor. We treat farmer labor as a fixed factor, and we allow only limited possibilities for moving farm land 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 each

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)

	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

of our three simulations, increased costs in a meat-processing industry are passed back as income losses to the corresponding farm industry. A 10 per cent increase in primary-factor requirements per unit of output in Beef processing reduces the income of Cattle ranchers by 2.405 per cent. In the same way, 10 per cent increases in primary-factor requirements in Other animal processing and Poultry processing reduce incomes of Other animal farmers and Poultry farmers by 1.036 per cent and 1.517 per cent. But also consistent with economic theory, cost increases in meat processing, as we saw in Table 1, are partially passed forward to households through supermarket prices. They are also passed forward to households indirectly through their purchase of meals from restaurants and other food-serving industries.

How are cost increases in meat processing distributed between farmers and consumers? To answer this question we need to examine additional results and data items.

The additional results that we need are the diagonal entries at the bottom of Table 2, reproduced in Tables 3, rows 4i - iii. These give percentage effects on the basic prices of processed meat products. Basic prices are factory-door prices. They differ from consumer prices, such as the supermarket prices shown in Table 1, for two reasons. First, consumer prices include imported as well as domestic products. Second, consumer prices include taxes and margin costs (transport, retail and wholesale) that are incurred in transferring meat products from processors to households. Because unit margin costs are largely independent of processing costs, the percentage changes in consumer prices are a damped version of those in basic prices. For example, in the Beef-processing simulation, the basic price of Beef processing increases by 2.341 per cent whereas the supermarket price increases by only 1.488 per cent.

The additional data that we need are available from the USAGE-Food baseline database. As set out in Table3, 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.

Now we can answer the question for Beef processing about the distribution of cost increases in meat processing between farmers and consumers. A 10 per cent increase in primary-factor requirements in Beef processing imposes an impact cost on the industry of $3.500b (=10% of $34.998b, row9 Table 3). The industry passes $2.823b to its customers in the form of higher

Table 2. Percentage effects on real farm incomes 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	Other animal processing	Poultry processing	Total meat processing
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				
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

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 closely match the increased cost in Beef processing (3.500 ≈ 2.823+0.621).

For Other animal processing, the USAGE-Food baseline database shows: value added of $12.098b; basic value of sales of $47.268b; and income in Other animal farming of $22.783b. A 10 per cent increase in primary-factor requirements in Other animal processing imposes an impact cost $1.210b (=10% of $12.098b). As shown in Table 3, this is split between farmers and consumers: a loss to 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 closely match the increased cost in Other animal processing (1.210 ≈ 0.236 + 1.060).

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 imposes an impact cost $2.194b (=10% of $21.942b). This is split between farmers and consumers: a loss to farmers of $0.293b (= 1.517% of $19.316b) and an extra expense to consumers of $1.937b (= 2.362% of $81.986), see Table 3. Together, the loss to farmers and the increased cost to consumers closely match the increased cost in Poultry processing (2.194 ≈ 0. 293 + 1.937).

To us, a surprising aspect of Table 3 is the smallness of the farmer shares in extra processing costs. In the first simulation, Cattle ranchers pick up only 18.0 per cent of the explained extra cost of processing (0.621 out of 3.444, rows 6 & 8). In the second simulation, Other animal farmers pick up 18.2 per cent of the explained extra costs (0.236 out of 1.296), and in the third simulation, Poultry farmers pick up 13.1 per cent (0.293 out of 2.230). Our *a priori* mental picture was Figure 1. In this figure, processing costs per unit of output are ad. The farmer receives the price P_f and consumers pay the price P_c. Total processing costs are the

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

		Sim 1: Beef processing	*Sim 2:* Oth animal processing	*Sim 3:* 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 BOTE loss $b, (= row 6 + row 7)	3.444	1.296	2.230
9	Impact cost in Processing, $b (=10% of row 1)	3.500	1.210	2.194

rectangle abcd. Relative to a situation in which there are no processing costs, the imposition of these costs reduces farmer income by the rectangle egcd (plus the triangle ghc which we ignore), and increases costs to consumers by the rectangle abge (plus the triangle bgh which again we ignore). As illustrated in the figure, with a relatively inelastic supply curve reflecting the existence of fixed factors, farmers bear the bulk of the processing costs. So why does USAGE-Food indicate the opposite?

In explaining what is going on in USAGE-Food, it is useful to think of each farm industry as producing commodities for two final customers. For customer 1, we introduce processing costs. Customer 2 buys the farm product unprocessed. We can imagine sales to customer 2 as direct sales to households or exports of raw farm products. We will argue later that sales replacing imports of raw farm products can also be thought of as customer-2 sales.

The two-customer situation we have in mind is illustrated in Figure 2. The straight line marked D_1 is the demand curve for the farm product delivered in processed form (customer-1 demands). The straight line marked D_2 is the customer-2 demand curve for the raw farm product. The supply curve is the upward-sloping straight line marked S. To aid comparison between the one-customer and two-customer models, we have drawn the D_1 line in Figure 2 in the same position and with the same slope as in Figure 1. We have drawn the S line in Figure 2 with the same slope as in Figure 1 but slightly to the right. Unlike Figure 1, Figure 2 recognizes that supply meets not only customer-1demands for processed products, but also a relatively small amount of demand from customer 2 for unprocessed product.

As in Figure 1, in Figure 2 we assume initially that processing costs are zero. The initial equilibrium supply is at point h. Customer 1 purchases the quantity represented by em and customer 2 purchases the quantity represented by ek (= mh). The initial price of the farm product for both customers is P_0.

Figure 1. Allocation of processing costs between farmers and consumers, simple model

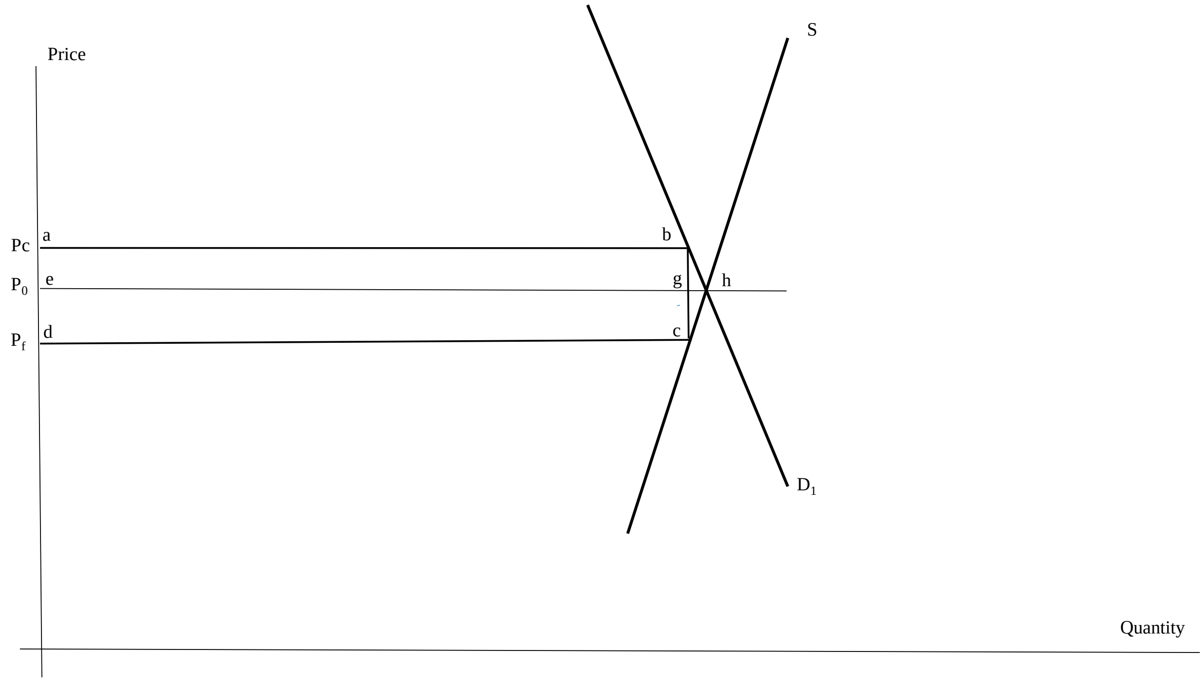
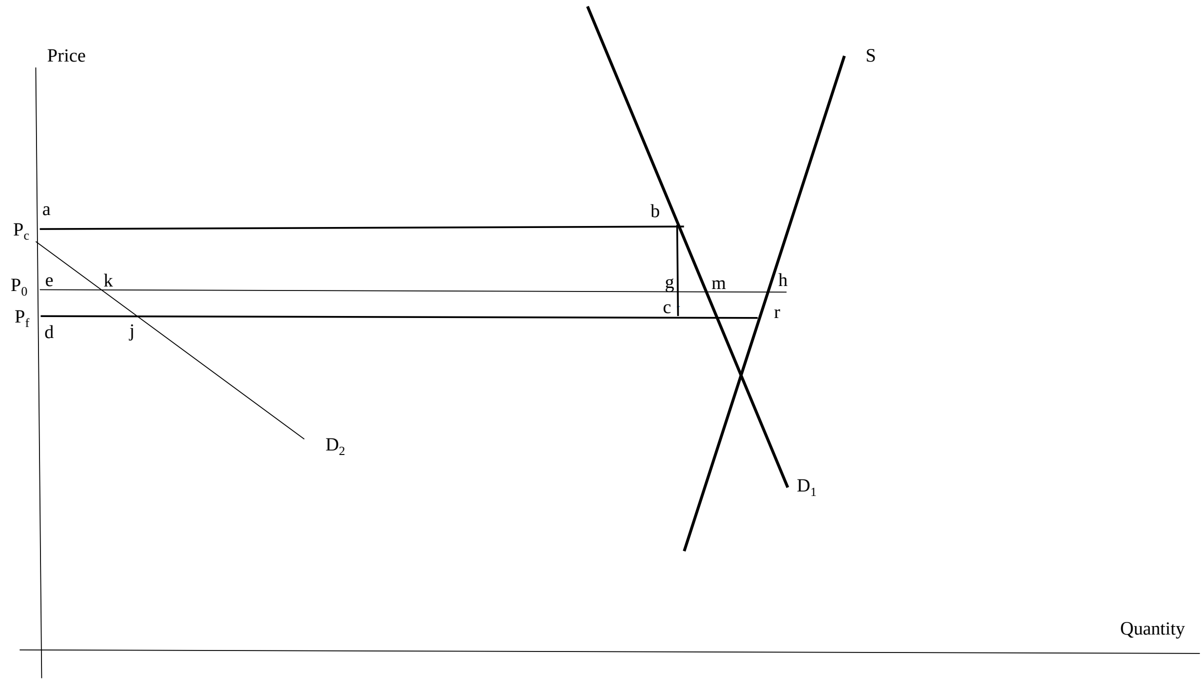


Figure 2. Allocation of processing costs in a two-customer model



Now we assume that customer 1 requires the raw product to be processed. The cost per unit of processing is bc, or equivalently, ad. Again, to aid comparison, ad in Figure 2 is the same length as ad in Figure 1.

With the introduction of processing costs, the new equilibrium supply in Figure 2 is at point r. Customer 2 now pays a lower price, P_f, and expands its demand to the quantity dj (= cr, up from ek). Customer 1 pays a higher price, P_c. This includes the cost of processing. Customer 1's demand contracts to the quantity ab (down from em). Total demand for the farm product contracts to dr, down from eh.

As in Figure 1, total processing costs in Figure 2 are the rectangle abcd. However, unlike Figure 1, in Figure 2 the customers for the processed product pay the bulk of this, the rectangle abge. The remainder, egcd, is paid by farmers. The farmers also lose an additional small amount of producer surplus represented by ghrc.

What is the key difference between Figures 1 and 2 that flips the allocation of processing costs from farmers to consumers? In Figure 2, the existence of customer 2 enables farmers to switch supplies to a customer who doesn't require processing costs. This means that customers who do require processing costs must, to a large extent, pay these costs. Otherwise, the farmer simply sells to the customers who don't require processing costs.

The Other animal and Poultry & egg farm industries have direct exports worth 3.9 and 1.6 per cent of their sales. These are raw products (sales to customer 2). Although these shares may seem small, they are significant because exports are a high-elasticity market. Notice in Figure 2 that a high elasticity (flat) demand curve for customer 2 accentuates the extent to which customer 1 picks up the processing costs. If customer 2's demand curve were completely flat, then customer 1 would pick up all of the processing costs, even if customer 2 accounts for a very small initial share of the sales of the farm product.

But what about Cattle ranching? Direct exports for Cattle ranching are less than 0.5 per cent of output. However, there are significant imports of the Cattle ranching product. These imports are about 5 per cent of total sales of Cattle ranching in the U.S. Domestic farmers compete with imported farm products on a pre-process basis. Increases in domestic processing costs don't affect this competition. In USAGE-Food, we assume that import supply elasticities are very high (infinite) and that substitution elasticities between the domestically produced and imported Cattle ranch products are also quite high (2.0). Consequently, even a small reduction in the domestic price (such as ed in Figure 2) allows considerable import replacement. How does this relate to Figure 2? When farmers replace imports, we can think of them as selling to an importing agent. The importing agent is a type-2 customer who is concerned only with the pre-processing price of the domestic product relative to that of the imported product.

4. Effects on outputs and employment by industries

Tables 4 and 5 show results for employment and output 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.

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

Beef processing

As we saw 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). As explained in section 3, Cattle ranchers mitigate the effects of reduced processing output by partly replacing imports of the Cattle ranch product.

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 (row 32, Table 4). This sharp increase in the labor/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 changes in the labor/output ratio are 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 labor/output ratio. For most non-farming industries, the labor/output ratio increases reflecting a reduction in the real wage rate to be discussed in section 5.

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 (-1.958 per cent, row 33, col 2, Table 4); a smaller percentage reduction in the output of the corresponding farm industry (-0.595 per cent, row 10, col 2, Table 4); 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 labor/output ratio for Other animal processing (compare row 33, col 2, Table 5 with the corresponding entry in Table 4); small negative movements in labor/output ratios for most farm industries; and small positive movements in labor/output ratios for most non-farm industries.

In the USAGE-Farm 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. This is the reason that 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.

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 general magnitude of results in column 3 of Tables 4 and 5 for industries apart from those directly affected by the shock is between that in columns 1 and 2.

For Poultry processing, the reduction in output in column 3 is quite similar to the 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 industries, Poultry & eggs has the least exposure to international trade in its raw products. On this basis we might expect Poultry & eggs to have the least opportunity to use direct sales (customer 2 in Figure 2) to mitigate the effects of demand reduction for the product of its processing industry. However, Poultry & eggs has considerable direct sales to households (sales of eggs).

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 labor, 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, and
S_L and S_K are the shares of labor 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 aggregate K/L ratio. In column 4, 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

$$y = -0.030 - 0.38 * 0.005 = -0.032 \tag{4}$$

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

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

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 consumptions 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 labor, a deterioration in technology causes a reduction in real wage rates (-0.029 per cent, row 9). This result complements our analysis based on Figure 2. It is another way of understanding how households would pay for extra costs in meat processing.

6. Concluding remarks

It is possible that Covid will produce permanent changes in work practices that increase costs in U.S. meat-processing plants. These changes may be beneficial for the safety of meat-processing workers and the health of the community more generally. 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 macro economic 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 the bulk of additional meat-processing costs. However, the CGE model produces a different picture. By taking account of different markets in which farmers can sell their products, the CGE model showed that between 82 and 87 per cent of additional meat-processing costs would be borne by customers for meat products. Nevertheless, processing costs still impact significantly on farm incomes. Our simulations of the effects of 10 per cent increases in labor 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 macro-economic implications of Covid-related increases in meat-processing costs are 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%.

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