Coping with Seasonality in a Quarterly CGE Model: COVID-19 and U.S. Agriculture

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January 25, 2021

Abstract

Most dynamic CGE models work with periods of one year. This limits their applicability for analyzing the effects of shocks that operate over a short period or with different intensities through a year. It is relatively easy to convert an annual CGE model to shorter periodicity, for example a quarter, if we ignore seasonal differences in the pattern of economic activity. But this is not acceptable for agriculture. This paper introduces seasonal factors to the agricultural specification in a detailed quarterly CGE model of the U.S. The model is then applied to analyze the effects of the COVID pandemic on U.S. farm industries. Taking account of the general features of the pandemic such as the reduction in household spending, we find that these effects are mild relative to the effects on most other industries. However, agriculture is subject to potential supply-chain disruptions. We apply our quarterly model to analyze two such possibilities: loss of labour at harvest time in Fruit & nut farms; and temporary closure of meat-processing plants. We find that these disruptions are unlikely to cause noticeable reductions in the supply of food products to U.S. households.

Key words: Quarterly CGE modelling; seasonal factors in agriculture; COVID pandemic; supply-chain disruption; U.S. agriculture.

JEL codes: C68; Q11; I19

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1. Introduction

The length of a period in most dynamic computable general equilibrium models (CGE) is one year. It is relatively easy to convert an annual CGE model to a shorter periodicity if we are prepared to assume that activities in each period are the same. However for agriculture there is a strong seasonal element in the pattern of activities. In this paper, we show how within-year differences in agricultural activities can be accommodated in a quarterly CGE model without requiring changes in the mathematical structure of the model from period to period.

We develop our method in the context of CGE simulations of the effects of COVID-19 on U.S. agriculture. We start by presenting projections of the effects of COVID on outputs and incomes in ten farm industries over the two years from March 2020. These projections take account of COVID-related changes in demand for agricultural products, including the effects of reductions in consumer spending and diversion of consumer spending between products caused by shutdowns of industries such as restaurants. After this we consider two specific COVID-related potential supply-chain problems for agriculture:

- labor shortages affecting the ability of fruit and nut farmers to harvest their crops; and
- closure of meat-processing plants.

Real-life examples of these and other supply-chain problems in agriculture (such as mismatch between demand and supply of vegetables) are the subject of numerous descriptive reports

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published in the first half of 2020.[1] Analysing such problems in a CGE model requires explicit recognition of the patterns of agricultural activities within a year.

The paper is organized as follows. Section 2 contains background material on our CGE model, USAGE, and its conversion from annual to quarterly periodicity. Then we outline our method for introducing seasonal factors in the quarterly model to facilitate analysis of agricultural supply-chain problems. Section 3 sets out our projections for the effects of COVID-19 on U.S. farm industries taking account of general features of the pandemic. Section 4 analyses the effects of the two potential special problems for agriculture listed above. The results are described in non-technical and we hope intuitive terms. Technical material on how we handle the seasonality factors are set out in Appendix 1. Section 5 contains concluding remarks.

2. USAGE and USAGE-Q

USAGE (U.S. Applied General Equilibrium) is a detailed computable general equilibrium model of the U.S. economy. It has been continuously developed at the Centre of Policy Studies (CoPS) over the last 18 years. The model has been applied 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. Topics addressed include: import restraints, free trade agreements, baseline forecasting & validation, oil prices, greenhouse policies, illegal immigration, the Obama stimulus package, the national export initiative, biofuel policy, environmental regulation, terrorist events and counterterrorism policies, US jobs supported by trade with Canada, North American integration, Buy American policies, airport infrastructure (NextGen), rail infrastructure, road infrastructure, driverless trucks, the H1N1 epidemic, and COVID-19. For an overview of USAGE and its applications see Dixon *et al.* (2013).

The industry/commodity classifications in USAGE are based largely on the BEA Benchmark input-output tables (see https://www.bea.gov/industry/input-output-accounts-data). These tables identify about 400 industries. While the model is sometimes applied at the 400 level, it is usually convenient to compute with less industries. In the applications in this paper we used a version with 115 industries and 118 commodities. We retained the full available disaggregation for agriculture (10 industries/commodities) and for food processing (28 industries/commodities).

A USAGE simulation normally consists of two runs: a baseline run and a perturbation run. In most cases, the baseline run is intended to show how the economy would develop in the absence of the event (in this case the COVID-19 pandemic) under consideration. The perturbation run introduces shocks representing the event. These are applied to the model and results are generated as deviations from the baseline.

In almost all applications, USAGE has been formulated as an annual model, that is, the flow variables such as GDP are flows over a year, and the stock variables such as capital or debt are values at the start and end of a year. However, a year is too long for understanding the likely economic effects of a shock that operates over a short period or operates with different intensities through a year. This is the case with epidemics and economic responses to

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[1] See for example, Bedord (2020), Chicago Sun Times editorial board (2020), Costa & Martin (2020), Jankowicz (2020), Sents (2020), and Walljasper (2020).

epidemics. Consequently in our USAGE-based study of the economic implications of H1N1 (Dixon *et al.* 2010), we developed a technique for converting an annual model (USAGE) into a quarterly model (USAGE-Q). In broad terms, the conversion technique consists of:

- reinterpreting annual data on flow variables as annual rates of flow in a quarter;
- reinterpreting values of start- and end-of-period stock variables (e.g. capital and debt) as values at the start and end of a quarter, rather than a year; and
- dividing dynamic adjustment parameters and variables by 4. Three examples. First, the rate of depreciation used in connecting the quantity of capital at the start of a period to the quantity at the end of the period in quarterly model is ¼-times the rate used in an annual model. Second, the rate of interest used in connecting the value of debt at the start of a period to the value at the end of the period in a quarterly model is ¼-times the rate used in an annual model. Third, the value of the parameter controlling the response of wage rates to changes in employment in a quarterly model is ¼-times the value used in an annual model.

An annual model converted to quarterly in this way is an adequate vehicle for simulating the effects of a disease that intensively reduces workforce participation in a particular quarter but not in the rest of the year, or triggers a government stimulus package that lasts for a few months but not a whole year. However, for studying some agricultural problems, we need an extra ingredient in the quarterly model, seasons.

In agriculture there are different activities at different times of the year. Saleable output of some farm industries occurs in a single quarter, while work towards this saleable output occurs at variable rates throughout the entire year. The economic effects of disruption of farm activities can depend on when the disruption occurs. For example, a disruption which stops the harvesting of the saleable product may be considerably more devastating to a farm industry than a disruption occurring at another time of year. Lost output at harvest time may embody considerable inputs from earlier in the production cycle.

By using phantom subsidies and artificial changes in technologies and artificial sales from inventories, we are able to introduce seasonality ideas in USAGE-Q without changing the structure of the model. This avoids the introduction of new equations and the revision of existing equations. However, the main advantage in maintaining the original structure of the model is for result interpretation. From economic theory and other USAGE projects, we know how subsidies, technologies and inventory sales affect endogenous variables such as employment and output by industry, wage rates, and trade. Consequently, by representing farm seasonality factors through subsidies, technologies and inventory sales we are immediately in a position to check and interpret simulation results.

The way in which we use these variables in simulating disruptions to farm output varies from product to product, depending on the seasonal pattern of the production process and the extent of embedded inputs. In general, we use technology-deterioration variables to introduce loss of embedded inputs when sales of the finished farm product are not realized because of unanticipated closure of processing plants or shortage of labor at harvest time. We use phantom subsidies and taxes to reconcile zero-pure-profit assumptions (standard in CGE modeling) with product prices that do not reflect input costs. We use artificial inventory flows into future quarters the price effects of shortages of finished products caused by processing or harvest problems. The examples in Section 4 and Appendix 1 will help to clarify our method.

3. Projected effects of COVID on U.S. farm industries

In June 2020 we applied USAGE-Q to make projections of the effects of COVID-19 on the U.S. economy. For year 1 (March 1, 2020 to Feb 28, 2021), we projected reductions in GDP, employment and private consumption of about 10 per cent. At the industry level, we found that output reductions averaging over 25 per cent through year 1 were likely for travel-related industries, education, and hotels & restaurants. Relative to most other industries, we found that agriculture would be only mildly impacted. Nevertheless, for year 1 we projected negative effects on output and real farm income (returns to land, capital and farm-family-supplied labour deflated by the CPI) in all 10 farm industries included in USAGE-Q, see Table 1 and Chart 1.

The farm industry with the most pronounced reduction in output in year 1 is Green nurseries. The product of this industry is sold predominantly to households and has a high expenditure elasticity of demand. Consequently, demand for the Green nurseries product is severely impacted by the COVID-related overall reduction in real private consumption. By contrast, the expenditure elasticity of demand for Poultry and eggs is low. This explains its relatively small output reduction in year 1.

The main factor determining the movement in real farm income relative to output in each farm industry is what happens to the real product price (the farm-gate price of the industry's output relative to a general price deflator such as the CPI). For eight of the farm industries (the exceptions are Grain farm and Veg melon), relatively low supply elasticity means that the COVID-related reduction in demand reduces the real price of their products. This reduces real farm income relative to output.[2] For seven of these eight industries (the exception being Green nurseries), this price effect turns out to be sufficiently negative to give an overall net negative movement in real farm income relative to output.

Another factor affecting the movement in real farm income relative to output is the ratio of the imputed value of farm-family labor to total farm income. In farm industries with a high proportion of family-supplied labour in their total labour input, the effect of demand-related reductions in output on farm income is cushioned by shedding hired labour. In this way, the ratio of farm income to output can even increase with a reduction in output, despite the price effect. This is the case for Green nurseries in which the year-1 percentage reduction in output (7.64 per cent) exceeds the year-1 percentage reduction in real farm income (7.57 per cent).

Because we projected that the U.S. economy would be adversely affected by COVID-19 relative to most other economies, we projected real devaluation for the U.S. Grain farm and Veg melon are trade exposed and thus in our simulations they benefit from real devaluation, with their product price increasing relative to the CPI. This is the reason that the year-1 results in Table 1 and Chart 1 show COVID-induced increases in real farm income relative to output for these two industries.

In year 2 (March 1, 2021 to Feb 28, 2022), we projected a strong macroeconomic recovery for the U.S. However, consumer demand remains below where it would have been in the absence of COVID. With macroeconomic recovery, the COVID-induced deviation in output

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[2] Assume that the ratio of sales to farm income in farm industry j is 2. Assume that the price of product j decreases by 10 per cent relative to the CPI with no change in the output of j. This generates a 10 per cent decrease in the value of farm output relative to the CPI, all of which is lost by the farmer. With farm income being half the value of output, real farm income decreases by 20 per cent.

Table 1. COVID-19 effects on output and real income of farm industries
% deviations from no-COVID baseline

	Farm industries	Output		Real farm income	
		Year 1*	Year 2*	Year 1	Year 2
1	OilSeedFarm	-2.50	-1.64	-3.25	1.81
2	GrainFarm	-2.71	-1.74	-1.41	6.65
3	VegMelonFarm	-1.97	-1.16	-0.92	0.99
4	FruitNutFarm	-1.88	-0.45	-3.36	0.65
5	GreenNursPrd	-7.64	-2.61	-7.57	-2.56
6	OthCropFarm	-4.35	-2.46	-5.75	-1.68
7	CattRancFarm	-4.27	-1.67	-10.25	-4.49
8	DairCattProd	-5.08	-1.90	-8.02	-3.90
9	OtherAnimal	-3.31	-0.41	-5.43	-0.25
10	PoultryEgg	-1.16	-2.04	-6.03	-3.92
	Total farm sector	-3.25	-1.64	-5.22	-0.76

* Years 1 and 2 are the years starting March 1, 2020 and March 1, 2021.

in nine out of ten farm industries is less negative than in year 1, see Table 1 and compare Charts 1 and 2.

Stronger consumption in year 2 noticeably stimulates demand for high-expenditure elasticity products such as Green nurseries. Whereas Green nurseries showed an output deviation of -7.64 per cent in year 1, the deviation in year 2 is -2.61 per cent.

The only farm industry with a larger negative output deviation in year 2 than in year 1 is Poultry and egg (-2.04 per cent compared with -1.16 per cent). The product of this industry has a low expenditure elasticity and thus the industry gains little from the recovery of aggregate private consumption in year 2. But this doesn’t explain why the output deviation for Poultry and egg is more negative in year 2 than in year 1.

The explanation is found in our modelling of shutdowns in the first two quarters of year 1. The shutdown of entertainment, hotels, restaurants and tourism, diverts household expenditure onto products that do not face shutdown restrictions. This includes supermarket products such as food. Relaxation of the restrictions removes this diverting effect. For Poultry and egg, removing the diverting effect has a sufficiently negative impact to outweigh the positive but weak (low expenditure elasticity) effect from the stimulus to aggregate consumption.

Recovery of the U.S. and world economies in year 2 increases the prices of agricultural commodities. For 9 out of the 10 farm industries this is sufficient to generate a higher farm-income-to-output ratio in year 2 than in year 1. The exception is Green nurseries. For this industry, the farm-income-to-output ratio is slightly lower in year 2 than in year 1. The strong increase in Green nurseries output as we go from year 1 to year 2, and the consequent negative farm-family-labour effect, slightly outweighs the positive price effect.

In our year-2 projections, the U.S. real exchange rate remains low. With recovery of world trade and consequent increases in the prices of traded agricultural products, there are positive deviations in real farm incomes in year 2 for trade-exposed industries, not just in the ratio of farm income to farm output. These industries include not only Grain farm and Veg melon, but also Oilseed farm and Fruit nut farm.

4. Potential special problems for agriculture: two case studies

Although the expected negative effects of COVID-19 on U.S. agriculture are relatively mild, the sector faces some special risks, mainly concerned with supply-chain disruptions. In this section we provide USAGE-Q simulations illustrating the effects of two such possibilities.

Chart 1. Effects of COVID-19 on output and real farm income in year 1 (% deviations from no-COVID baseline)

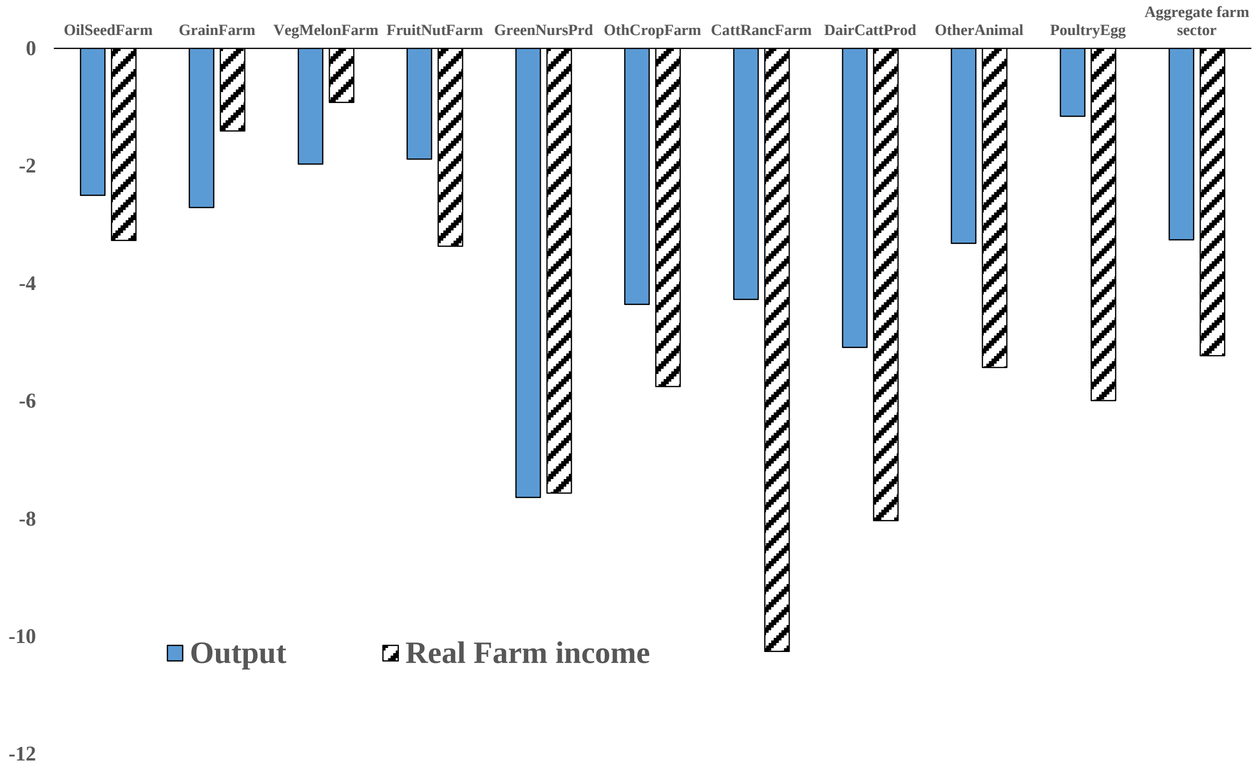
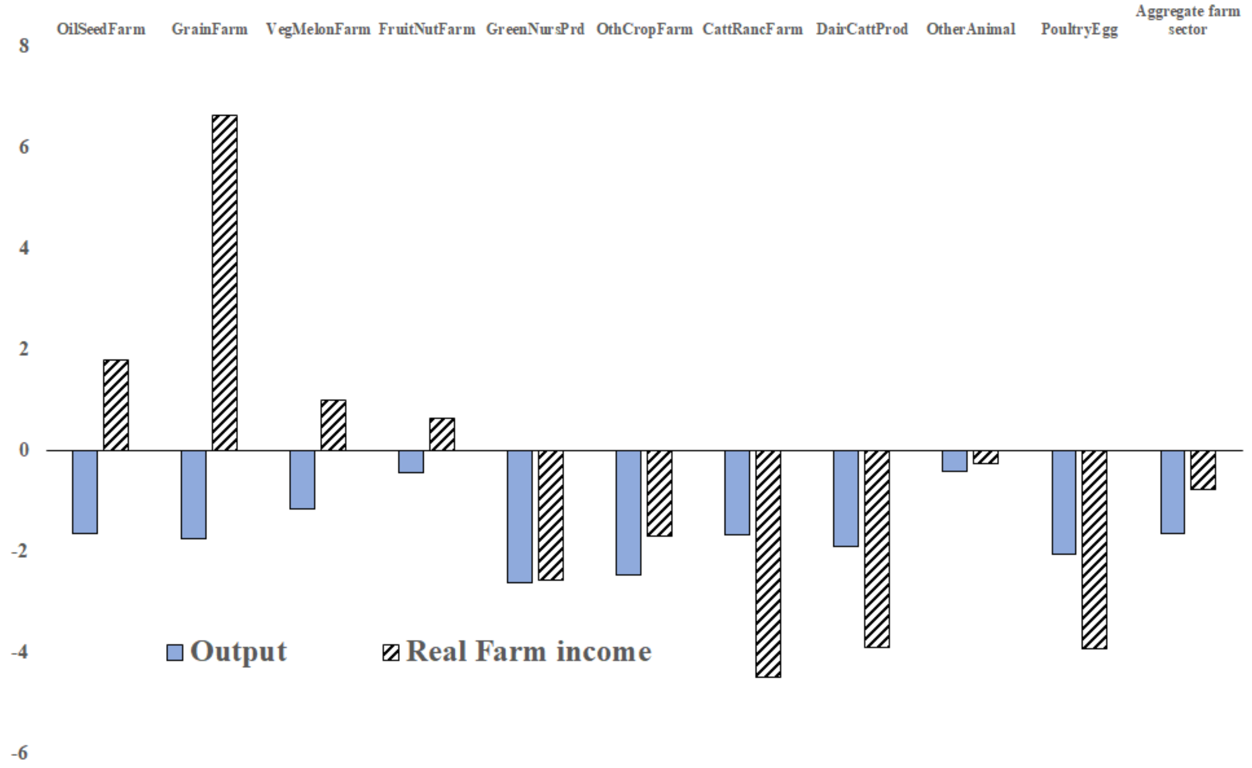


Chart 2. Effects of COVID-19 on output and real farm income in year 2 (% deviations from no-COVID baseline)



In looking at this material, it will be useful for readers to keep in mind that we refer to two baselines. The first is the no-COVID baseline. The quantitative effects of COVID-19 on farm industries described in Section 3 are deviations from this no-COVID baseline. Here we also use a COVID baseline. Variables in the COVID baseline follow the USAGE-Q projections generated *with* COVID in place. When we are interested in the *extra* effects that could be generated by potential special agricultural problems beyond those in our standard COVID scenario, then we report the effects as deviations from the COVID baseline

Setting up the simulations described in this section presented some challenging technical problems. These were associated with introducing seasonal factors into a non-seasonal quarterly model and with handling shocks unanticipated by the economic agents leading to wastage of committed resources. Details of our solutions for these technical problems are in Appendix 1. In this section we specify the scenarios to be analyzed in a non-technical manner, set out the results and provide intuitive explanations.

4.1. A labor shortage for harvesting fruit & nuts

Fruit & nut is harvested once a year. Assume that COVID-19 leads to an unexpected 10 per cent labour shortage in the harvest quarter, which we will assume is Y1Q3 (September to November 2020). Assume that labour is the critical factor in harvesting and that a 10 per cent loss of labour leads to a 10 per cent loss of the *finished* product. In the USAGE-Q database, hired labour supplies 46.14 per cent of the labour input in the harvest quarter. The other 53.86 per cent is supplied by the farm family. We assume that farmer labour is fixed, unaffected by COVID-19. Thus, we are assuming that the unexpected labour shortage is a 21.67 per cent shortfall of planned input of hired labour in the harvest quarter (21.67 per cent of hired equals 10 per cent of total).

On the demand side, we assume that the loss of harvest causes a shortage of finished domestic Fruit & nut throughout the year: the harvest quarter and the next three quarters. We assume that this leads to price adjustments in each of these four quarters that cause sales[3] of domestically produced finished Fruit & nut to be 10 per cent below the COVID baseline (the level of sales with our COVID-19 scenario in place but without the harvest shortfall).

Column (1) in Table 2 shows macroeconomic effects of the Fruit & nut harvest shortfall. These are deviations from the COVID-baseline caused by the harvest shortfall. The shortfall has a direct negative effect on the income of farmers. It also raises the price of Fruit & nut. This reduces real incomes generally, with negative multiplier effects on consumer demand, employment and capital usage. Labour input and capital in use are reduced by 0.024 and 0.016 per cent.

In combination, the reductions in labour and capital input imply a 0.021 per cent reduction in primary-factor input (the per cent reductions in labour and capital added up with weights of 0.6 and 0.4). This is approximately a 0.021 per cent loss in real GDP. The 10 per cent loss in the Fruit & nut harvest is worth about $2.7 billion, which translates to a direct loss in real GDP of about 0.013 per cent. This leads to -0.034 per cent [= -0.021-0.013] as a back-of-the-envelope (BOTE) estimate of the GDP effect of the harvest shortfall. The simulated effect is in fact -0.034. In dollars, this is about $6.5 billion.

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[3] This is sales to intermediate users, exports and households. It excludes inventory accumulation.

Table 2. Macro effects of agricultural disruptions: harvest shortfall in Fruit & nut and loss of pig-processing capacity (% deviations from no-COVID baseline)

	(1)	(2)
	10% harvest shortfall in Fruit & nut in Y1Q3 **Average for the year Y1Q3-Y2Q2***	**10% loss of pig-processing capacity in Y1Q1** **Average for the year Y1Q1-Y1Q4***
Aggregate labor input	**-0.024**	**-0.0045**
Aggregate capital in use	**-0.016**	**-0.0028**
Primary factor input	**-0.021**	**-0.0038**
Direct loss,% of GDP	**-0.013**	**-0.0041**
Back-of-envelope GDP estimates	**-0.034**	**-0.0079**
GDP, simulation result	**-0.034**	**-0.0073**

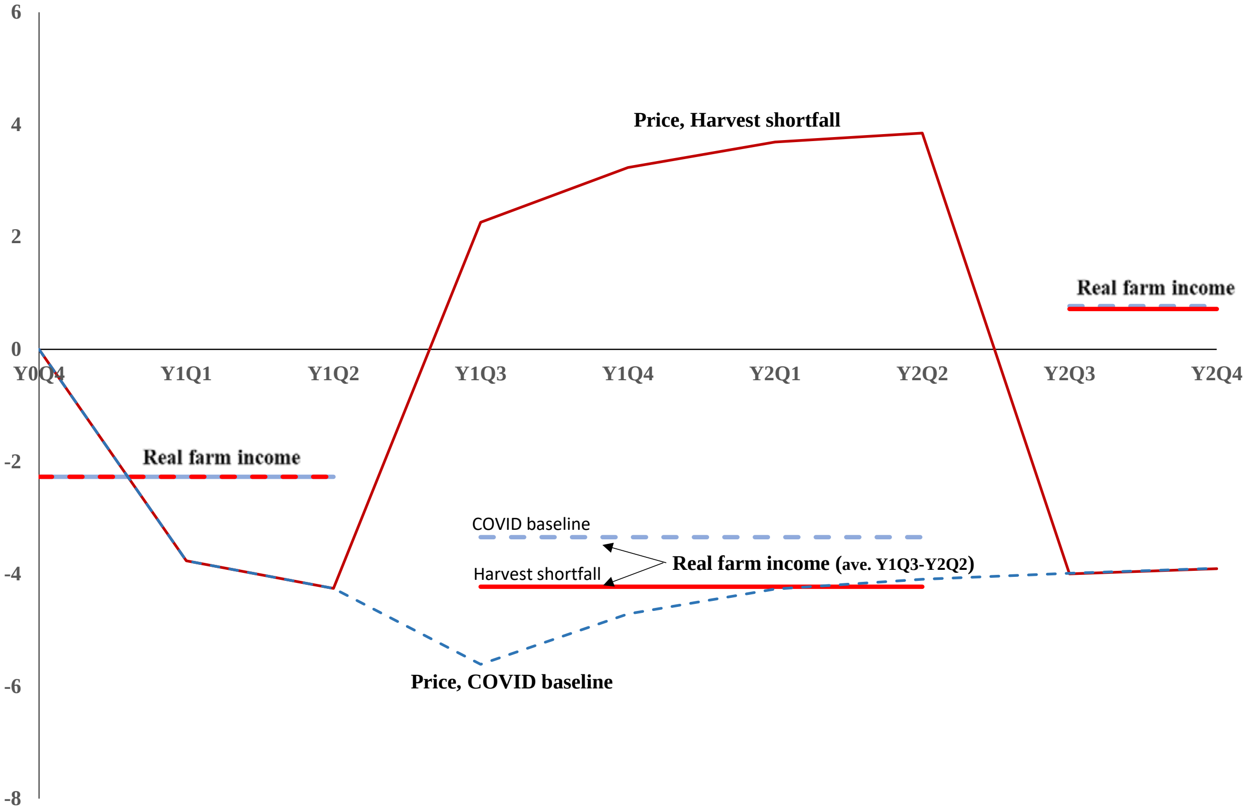
* In our simulations year 1 starts on March 1, 2020. ThusY1Q3 is the 3 months starting September 1, 2020 and Y2Q2 is the 3 months starting June 1, 2021. Similarly, Y1Q1 is the 3 months starting March 1, 2020 and Y1Q4 is the 3 months starting December 1, 2020.

Charts 3 and 4a&b show effects of the harvest shortfall on the Fruit & nut industry. By comparing the COVID-baseline and harvest-shortfall price deviations in Chart 3, we see that the harvest shortfall increases the price of domestically-produced Fruit & nut by about 8.3 per cent through the year from Y1Q3 to Y2Q2 (the average gap over this period between the price lines for harvest shortfall and COVID baseline). This implies a price elasticity of demand for U.S. Fruit & nut of about 1.2 (an 8.3 per cent increase in price restrains demand by 10 per cent in line with the reduction in supply). This price elasticity may seem high for a food item. However, the elasticity reflects relatively high trade exposure for Fruit & nut both as an import-competing and export commodity.

The price increase for Fruit & nut through the year Y1Q3 to Y2Q2 limits the effect on the real incomes of Fruit & nut farmers to about 1 per cent. This can be seen by comparing the real farm income results in Chart 3 for the harvest shortfall with those for the COVID baseline. While this is a mild reduction in real-farm income for the Fruit & nut industry in aggregate, it may hide a severe degree of hardship that could be suffered by individual farmers if their labour shortage is substantially more than the average shortage of 10 per cent.

The price increase for U.S. Fruit & nut caused by the harvest shortage strongly affects trade flows. This can be seen by comparing the harvest-shortfall and COVID-baseline export and import lines in Chart 4a, or more directly in in Chart 4b. The harvest shortfall reduces exports of Fruit & nut throughout the year Y1Q3 to Y2Q2 by about 15.5 per cent and increases imports by about 4.8 per cent. These deviations in trade flows limit the reduction in household consumption of Fruit & nut (a composite of domestic and imported product) to about 2 per cent (Chart 4b), despite the 10 per cent harvest shortfall.

Chart 3. Fruit & nut price and real farm income: percentage deviations from no-COVID baseline



4.2. A shutdown in processing facilities for pigs

Pigs take approximately two quarters from birth to slaughter. We assume that in each quarter pig farmers are producing two products, half-finished pigs and finished pigs (ready for slaughter). Assume that COVID-19 leads to an unexpected 10 per cent loss of meat processing facilities in Y1Q1 and that this leads to a 10 per cent loss in processed pig output in that quarter. On the demand side, assume that the loss of output of processed pigs in Y1Q1 causes a price adjustment to restrain demand to the available supply.

With regard to the price received by farmers for finished pigs in Y1Q1, we considered three possibilities. The first possibility is that farmers desperate to find processing facilities for their finished pigs accept a price lower than baseline (the situation without the problem in meat processing, but with COVID). The second possibility is that after the temporary loss in processing facilities, processors compete strongly for finished pigs to take advantage of higher prices for the processed product. In this case it is possible that farmers would receive a higher than baseline price on average over Y1Q1. The third possibility and the one we adopt is that there is no change in the price received by farmers from the COVID-baseline level.

In USAGE-Q, pigs are not identified as a separate farm commodity or industry, nor do we have a separate pig processing industry. Pigs are the principal product of the farm industry

Chart 4a. Fruit & nut trade volumes: percentage deviations from no-COVID baseline

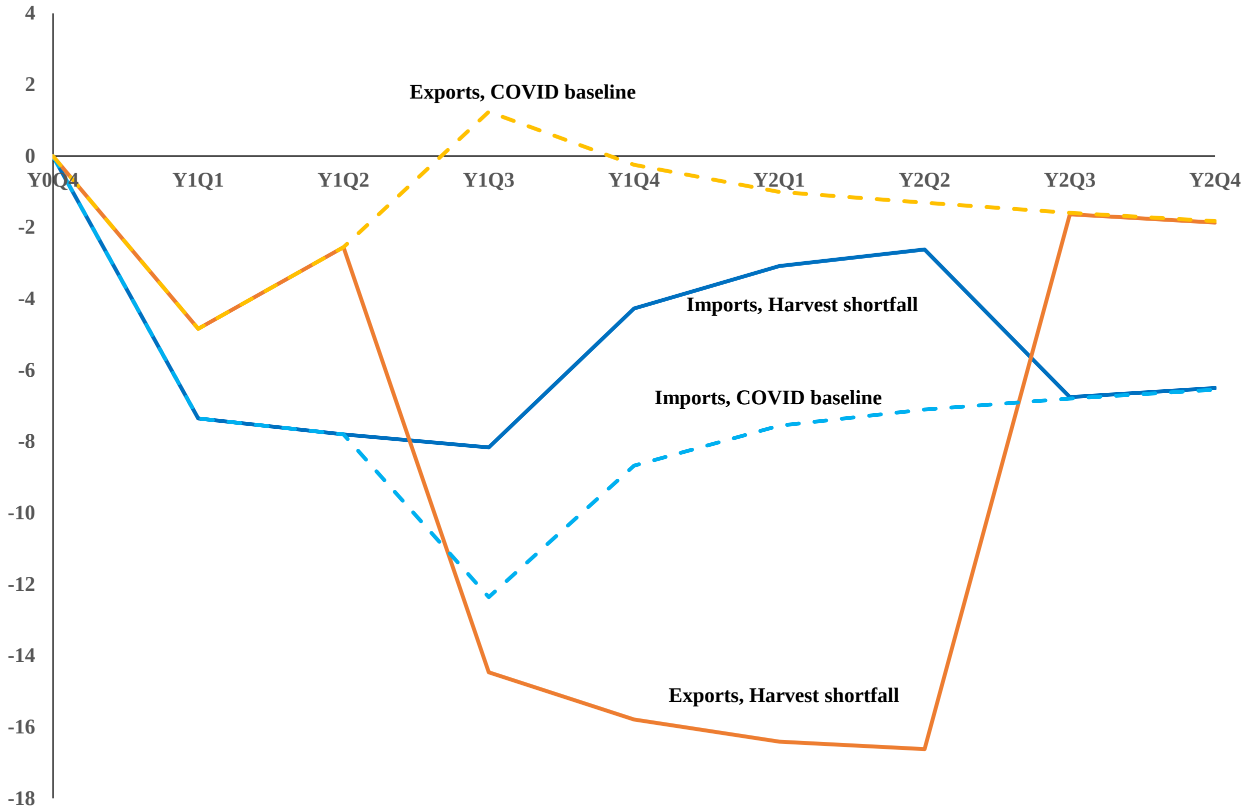
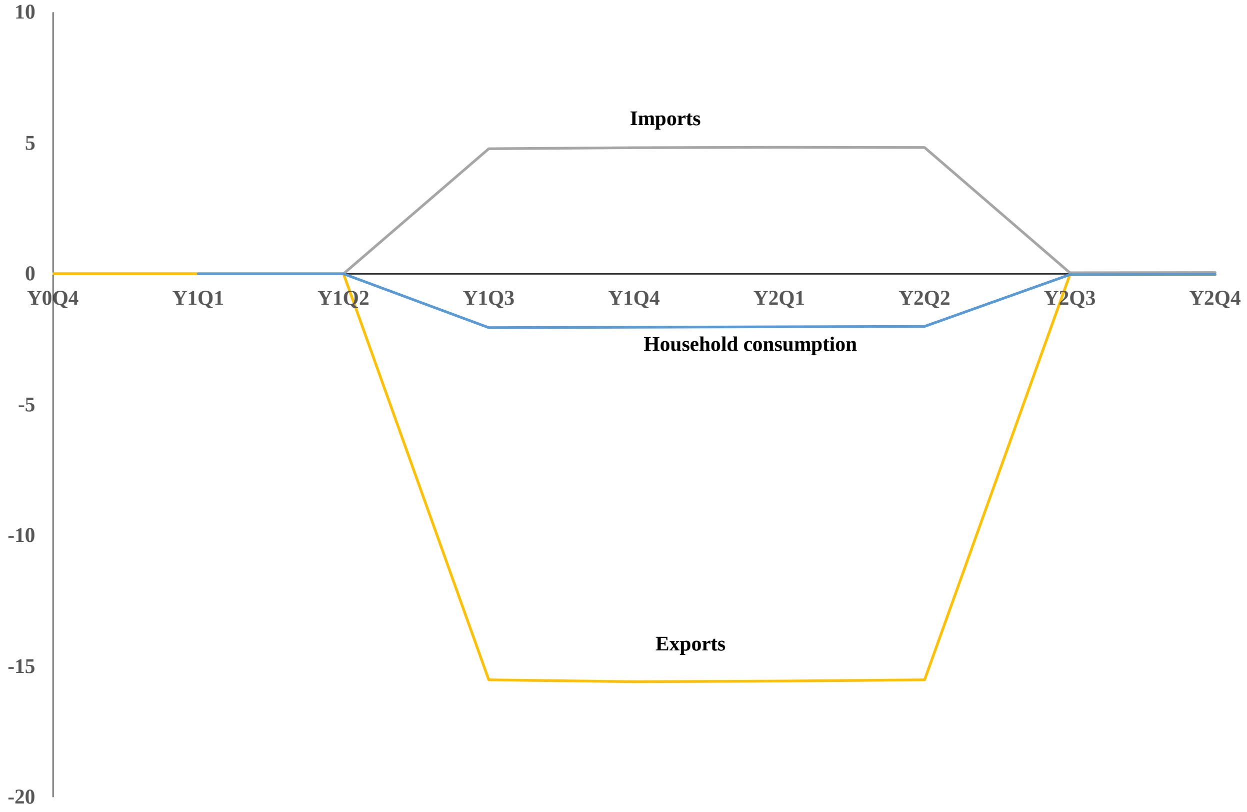


Chart 4b. Fruit & nut trade and consumption volumes: % deviations from COVID baseline, that is % deviations due to harvest shortfall



titled Other animal (OA). In the USAGE-Q database, 62.6 per cent of the output of OA is sold to an industry titled Animal processing (AP).[4] AP also purchases cattle for processing. The purchases from OA (mainly pigs) represents 29.5 per cent of the value of animal inputs processed in AP. Thus, we assume that the 10 per cent loss in pig processing capacity in AP represents a 2.95 per cent reduction in AP's output.

On the input side for AP, we introduce a 10 per cent reduction in their purchases from OA but a zero change in their purchases of animals from other farm industries such as Cattle ranching. For all other inputs to AP, we introduce a reduction of 1.475 per cent. In this way we recognize that the partial shutdown takes the AP industry by surprise and that it can make only a halfway adjustment in its labour and material inputs to match the 2.95 per cent reduction in its output.

Consistent with the loss of processing capacity being a surprise to the OA industry, we assume that there is no adjustment in its inputs in Y1Q1. Thus, in our USAGE-Q simulation OA suffers a decline in its output per unit of input in Y1Q1.

Ideally, we should set the reduction in OA's output per unit of input in Y1Q1 at 3.13 per cent: recall that in each quarter, OA produces equal amounts of half-finished and finished pigs and that the cut in demand from AP is a 6.26 per cent reduction in demand applying only to finished pigs (a 10 per cent cut applying to 62.6 per cent of sales). However, from the point of view of modelling the effects of OA's loss of sales, the important consideration is that OA loses 6.26 per cent of a quarter's productive effort. Half this effort was devoted to finished pigs in Y1Q1 and half to half-finished pigs in the previous quarter. We simplify the simulation by allowing the reduction in OA's output in Y1Q1 to be 6.26 per cent. In effect, we assume that all of the lost inputs occurred in Y1Q1.

Column (2) of Table 2 shows macroeconomic effects of the pig processing disruption. The details of the calculations are in Appendix 2. Here we note that the GDP effect for the pig processing disruption over the year starting Y1Q1 is -0.0073 per cent, a loss of about $1.4 billion. This is much smaller than the GDP effect in the Fruit & nut simulation (a GDP loss of 0.034 per cent for the year starting Y1Q3 or about $6.5 billion, see Section 4.1). The GDP results in the two experiments are driven by resource wastage assumptions, which then lead to multiplier effects through reductions in labor and capital input. In broad terms, the resource wastage from the processing disruption is 6.26 per cent of a quarter's OA output, or 1.57 per cent of a year's OA output, plus minor wastage in the AP industry. In total these wastages are much smaller than a 10 per cent loss of the annual Fruit & nut crop.

Reflecting our assumption that the processing disruption does not affect the price received by farmers for their pigs, Chart 5 shows coincident price-deviation paths for pigs in the with- and without-disruption cases. However, the loss of sales of pigs has a strongly negative effect on real farm income, averaged over the year starting Y1Q1. No further effects for the OA industry are visible beyond year 1.

Chart 6 shows a 4.78 per cent price spike for the animal processing product in Y1Q1. This constrains the demand for the product to match the 2.95 per cent reduction in output. Thus,

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[4] The rest of the output of Other animal is exported, sold directly to households or sold as an intermediate input to the Other animal industry.

Chart 5. Other animal (mainly pigs) price and real farm income: % deviations from no-COVID baseline

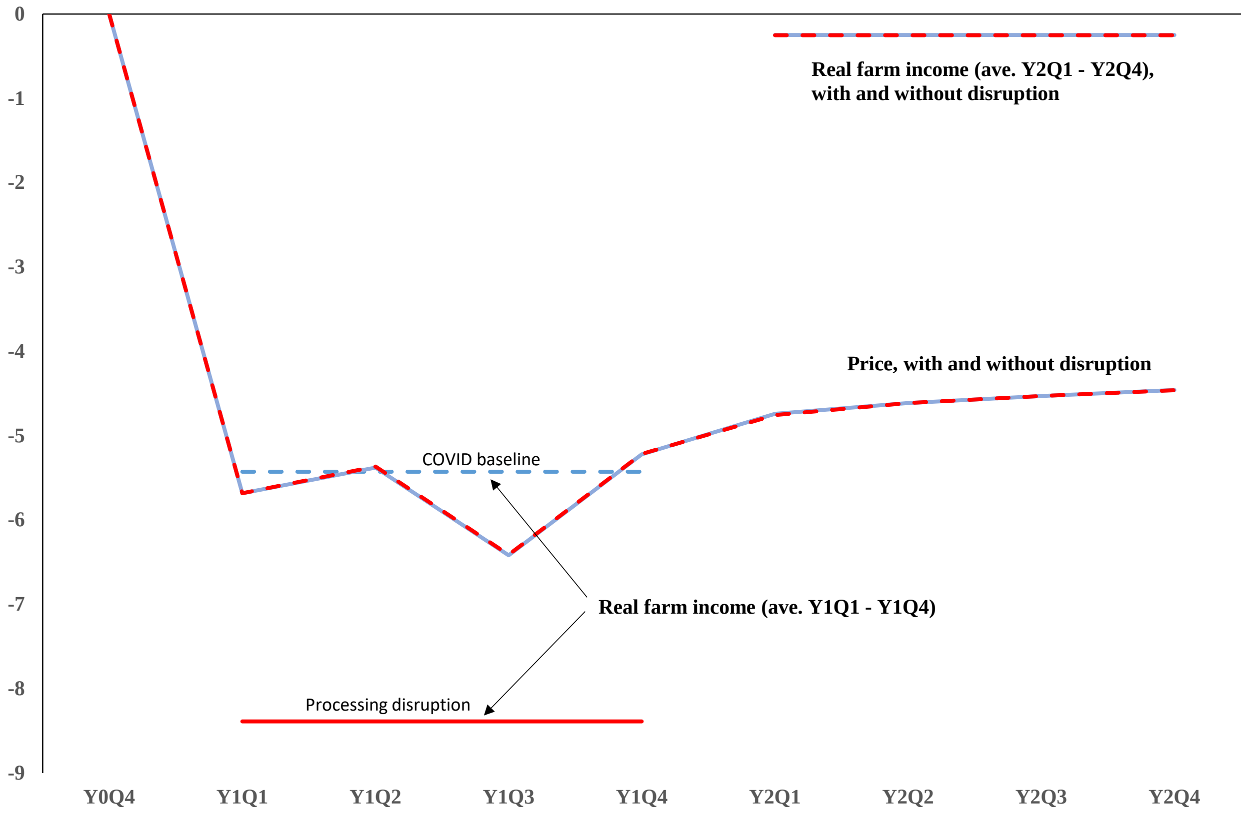
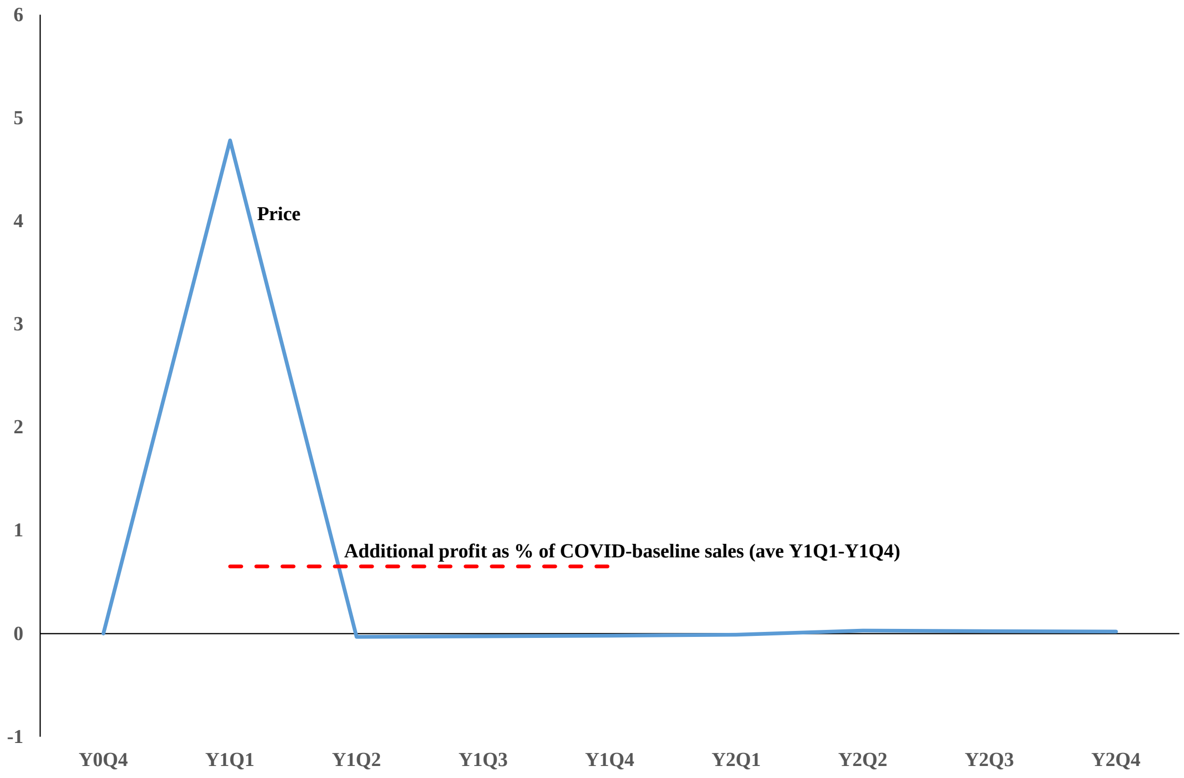


Chart 6. Animal processing price and profitability: % deviations from COVID-baseline, that is % deviations due to processing disruption



the implied price elasticity of demand is 0.62 (= 2.95/4.78). This is about half the Fruit & nut elasticity (1.2, see Section 4.1). Compared with Fruit & nut, AP has low trade exposure both as an import competitor and exporter.

The relatively low demand elasticity for AP generates a sufficiently high price spike to allow AP profits to increase despite the reduction in sales. As shown in Chart 6, profits in AP are higher on average through the year starting Y1Q1 by 0.76 per cent of the COVID-baseline value of sales.

The increase in the AP price in Y1Q1 reduces exports and generates increased imports. As shown in Chart 7, these movements in trade volumes restrict the reduction in household consumption of AP products (combined domestic and imported) to 2 per cent, noticeably less than the reduction in domestic output of 2.95 per cent.

5. Concluding remarks

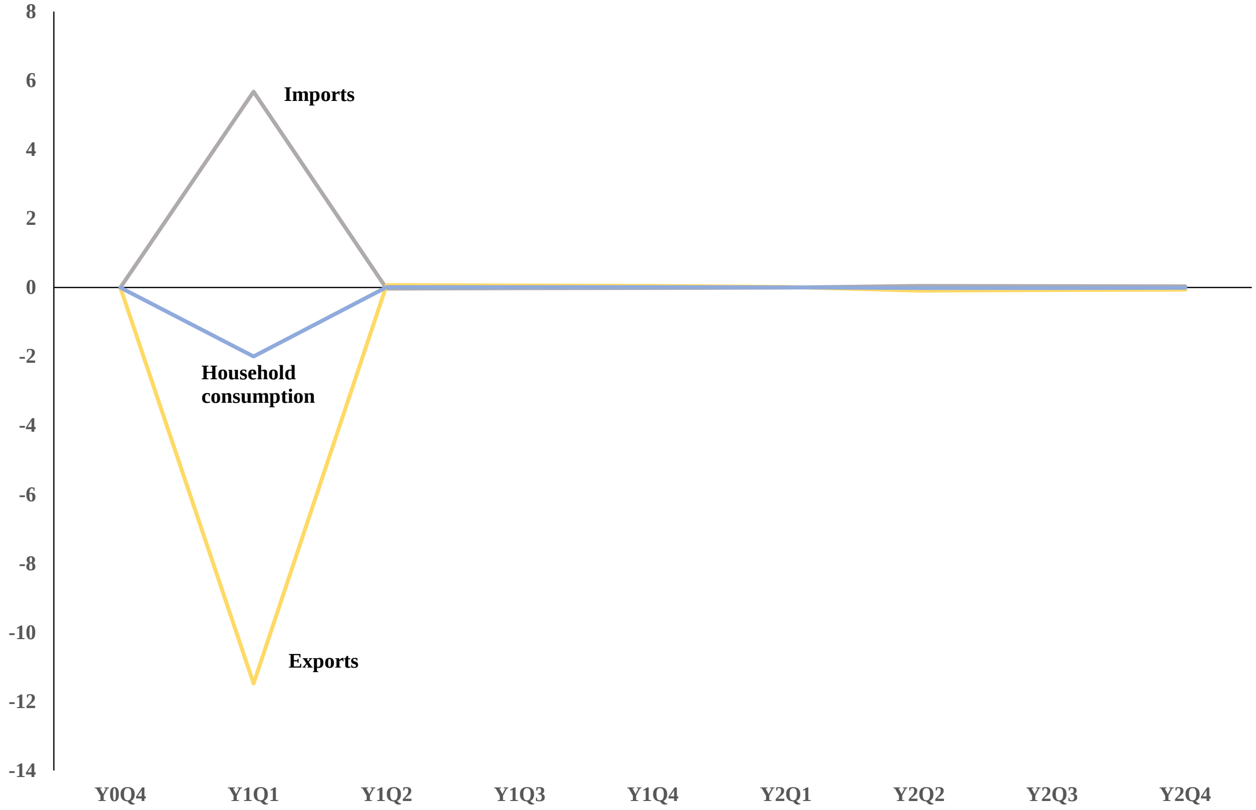
Supply-chain problems in U.S. agriculture leading to euthanizing of livestock and destruction of crops received widespread media coverage in April and May of 2020, and are a tragedy for the affected farmers. However, data on farm outputs for beef, pork, corn and many other crops (see FAPRI-MU, 2020) indicate that supply-chain problems did not have a noticeable effect on farm income or on delivered supplies of agricultural products. This seems consistent with results from our CGE simulation on pig processing in Section 4.2 which showed mild impacts on farm incomes and on output, consumption and prices of meat products from a 10 per cent loss of pig processing capacity in one quarter. The choice of a 10 per cent shock was arbitrary, but we judge it to be large relative to what was experienced in the U.S. in the initial stages of the COVID pandemic, see for example Wiener-Bronner (2020).

Similarly, in our harvest-shortfall simulation for Fruit & nut in Section 4.1, we applied an arbitrary 10 per cent labor-related loss of output. Again, the simulation did not indicate serious problems in satisfying food requirements in the U.S. In light of the high unemployment situation in the U.S. and the constructive response by the U.S. administration to potential labor-shortage problems in agriculture [see USDA (2020)], we judge that a labor-related harvest loss of as much as 10 per cent for Fruit & nut is unlikely.

As illustrated in this paper, CGE modeling is a practical technique for projecting the effects at a disaggregated level of shocks to the economy. CGE studies are commissioned by government departments throughout the world to assist them in policy advising. Guidance from CGE modelling is particularly valuable for policy decisions on the many issues for which the historical record is thin.

In academic circles, CGE modelling is subject to two common criticisms. The first is black-boxism. The specification of a detailed CGE model such as USAGE-Q requires thousands of lines of computer code. This makes it impossible to set out the entire model in a standard length paper. In these circumstances, academics often feel that they are not being told enough to understand what is going on. Our response is to provide back-of-the-envelope (BOTE) calculations to explain and support CGE results. Such calculations help us understand orders of magnitude and economic mechanisms. For example, in this paper we found that a 10 per cent loss of Fruit & nut harvest would reduce GDP by 0.034 per cent ($6.5b) and a 10 per cent loss of pig processing capacity in one quarter would reduce GDP by

Chart 7. Animal processing trade and consumption volumes: % deviations from COVID-baseline, that is % deviations due to processing disruption



0.0073 per cent ($1.4b). To check that these results are believable, we derived a BOTE estimate of GDP effects. In these BOTE calculations, we considered the direct loss of output from the agricultural disruptions under consideration and then factored in multiplier effects generating reductions in employment and capital in use (see Table 2).

The second aspect of CGE modelling that sometimes worries academics is the perception that the field lacks theoretical novelty: that the theory was worked out long ago. In fact, we find that almost every new project poses a theoretical challenge. In this paper, the challenge was to work out how to accommodate the pattern of agricultural activities across a year. Solving this theoretical problem was essential for gaining insights from the CGE model on the likely effects of COVID disruptions occurring at different points in the agricultural supply chain.

Appendix 1. Setting up the perturbation runs described in Section 4

A.1. A labor shortage in the harvest season for Fruit & nut

To help us work out how to implement the Fruit & nut harvest-shortfall scenario in USAGE-Q, we use Table A1.1. This is a simplified version of our quarterly model, using stylized data.

In Table A1.1 we assume in the baseline (with COVID) that effective activity in Fruit & nut is 25 units a quarter. In terms of USAGE-Q this is the output of Fruit & nut, reflecting inputs adjusted by technology (productivity) variables. In USAGE-Q we assume that baseline demand for Fruit & nut in each quarter is 25 units, matching output. In reality, inputs

Table A1.1. Conceptualizing Fruit & nut output and demand in a quarterly model

	Y1Q3	Y1Q4	Y2Q1	Y2Q2	Total
Baseline					
Effective activity[1]	25	25	25	25	100
Demand for finished F&n[2]	25	25	25	25	100
Implicit supply of finished F&n	100	0	0	0	100
Implicit inventory movement in finished F&n	75	-25	-25	-25	0
Perturbation					
Effective activity[1]	22.5	25	25	25	97.5
Demand for finished F&n[2]	22.5	22.5	22.5	22.5	90
Implicit supply of finished F&n	90	0	0	0	90
Implicit inventory movement in finished F&n	67.5	-22.5	-22.5	-22.5	0

[1] In the non-seasonal quarterly model, this is the level of output. It is also the level of inputs adjusted for changes in their effectiveness introduced by technology variables.

[2] This is sales to intermediate users, exports and households. It excludes inventory accumulation.

accumulate over a year to produce finished Fruit & nut in the harvest quarter (100 units in Table A1.1) and demand is only for the finished product (25 units in each quarter). Formally, there is no distinction in USAGE-Q between finished Fruit & nut and partially developed Fruit & nut. Implicitly, USAGE-Q allows for inventory flows of finished Fruit & nut. As shown in the table, there is implicit inventory accumulation of 75 units in the harvest quarter (Y1Q3) and decumulation of 25 units in each of the next three quarters. These inventory flows reconcile implicit demand and supply for finished Fruit & nut.

Our stylized representation in Table A1.1 of the perturbation run (with harvest loss) shows a 10 per cent reduction in effective activity in the Fruit & nut industry in Y1Q3. This is a reduction from 25 units in the baseline to 22.5 in the perturbation run. Because activity in Y1Q3 is devoted to the finished product, the 10 per cent loss of activity reduces the supply of the finished product by 10 per cent, from 100 units to 90 units. We assume that the shortfall of finished product requires contraction of 2.5 units in demand for finished product in Y1Q3 and each of the subsequent three quarters. The implicit inventory flows to reconcile demand and supply for finished Fruit & nut are now 67.5, -22.5, -22.5 and -22.5, still adding to zero.

Notice that the 10 per cent loss of output in one quarter translates to a 2.5 per cent loss in effective activity for the year, from 100 units to 97.5 units. However, the contribution of the industry to GDP and economic welfare has been reduced by 10 per cent. The loss of effective activity in the harvest quarter not only wastes resources in that quarter, but it also destroys 10 per cent of the contribution of resources used in the Fruit & nut industry in the three quarters leading up to the harvest quarter.

With Table A1.1 in mind, we implemented the harvest shortfall scenario in USAGE-Q by:

(a) exogenizing Fruit & nut output in Y1Q3 in the perturbation run at 10 per cent below its baseline level. Correspondingly, we endogenized a phantom tax/subsidy on the dproduction of Fruit & nut to produce a price consistent with a 10 per cent reduction in demand to match the reduction in output.
(b) shocking the all input using technical change variable (a naturally exogenous variable) for Fruit & nut by 10 per cent in the perturbation run in Y1Q3. This generates a 10 per cent increase in all inputs per unit of output in Fruit & nut in perturbation relative to baseline.
(c) exogenizing the input to Fruit & nut of hired labor in Y1Q3 in the perturbation run and shocking it to 21.67 per cent below baseline. Correspondingly we endogenized a labor-saving technical change variable in Fruit & nut. Together (a) to (c) leave all inputs to Fruit & nut on their baseline levels except for hired labor which is down by 21.67 per cent.
(d) exogenizing Fruit & nut sales in Y1Q4, Y2Q1, Y2Q2 in the perturbation run at 10 per cent below their baseline levels. Correspondingly we endogenized a phantom tax/subsidy on the production of Fruit & nut in these three quarters to produce prices consistent with the 10 per cent reductions in demand.
(e) exogenizing Fruit & nut output in Y1Q4, Y2Q1, Y2Q2 in the perturbation run at baseline levels. Correspondingly we endogenized a phantom accumulation of Fruit & nut inventories in each of these three quarters.
(f) adjusting the results for real farm income in Fruit & nut in all quarters to exclude the effects of phantom subsidies and taxes introduced in (a) and (d).
(g) adjusting the results for real farm income in Fruit & nut and real GDP in Y1Q4, Y2Q1 and Y2Q2 to exclude the revenue derived by the phantom accumulation of Fruit & nut inventories introduced in (e).

A1.2. A loss of capacity in the meat processing industry

In one way, setting up the meat processing scenario in USAGE-Q was simpler than setting up the harvest-shortfall scenario for Fruit & nut. In another way, it was more complex. It was simpler because the meat processing shocks are introduced in a single quarter. It was more complex because it involved two industries, the farm industry OA and the processing industry AP.

To generate the desired perturbation effects in both the AP and OA industries, we:

(a) exogenize output for AP in Y1Q1 at 2.95 per cent below the COVID baseline. Correspondingly, we endogenize a phantom tax on the production of AP to create a price movement compatible with the reduction in the supply of domestically produced AP.
(b) exogenize AP’s inputs of OA at 10 per cent below the COVID baseline; exogenize AP’s inputs of Cattle ranching at their COVID-baseline level; and exogenize all other intermediate inputs and labor at 1.475 per cent below COVID baseline. Correspondingly we endogenize technology variables in AP affecting all of the exogenized inputs.
(c) shock the all-input-using technology variable in the OA industry in Y1Q1 to 6.26 per cent above its COVID-baseline level. Combined with the reduction in sales to the AP industry, this shock leaves OA’s inputs at approximately their COVID-baseline levels.

(d) exogenize the farm-gate price of OA at its COVID-baseline level. With OA technology in place via (c), we need an endogenous a phantom subsidy on the production of OA to accommodate the standard CGE assumption of zero pure profits. Collection of the phantom subsidy is excluded from the calculation of farm income in the OA industry.

Appendix 2. Explanation of Column (2) in Table 2

A 10 per cent loss in pig-processing capacity in Y1Q1 raises the price of AP products. This reduces real incomes generally, with a depressing effect on consumer demand and a negative flow-on to both employment and capital in use. Labour input and capital in use for the whole economy fall 0.0045 and 0.0028 per cent below their no-COVID baseline levels, column (2) Table 2.

In combination, the reductions in labour and capital input imply a 0.0038 per cent reduction in primary-factor input. This is approximately a 0.0038 per cent loss in real GDP. There is also a direct loss in productivity in the OA and AP industries. For OA, the loss is 6.26 per cent for one quarter or 1.57 per cent on an annual basis. Taking account of the size of the OA industry, the loss of 1.57 per cent of its inputs reduces GDP by about $430 billion. For AP, there is a 2.95 per cent reduction in output in Y1Q1. But there is also a reduction in inputs: 10 per cent for inputs of OA and 1.475 per cent for other inputs except Cattle ranching. Using the input data for AP in the COVID baseline for Y1Q1, we calculated that the aggregate reduction in AP inputs was 2.18 per cent. Thus, in the AP industry there was an increase in inputs per unit of output in Y1Q1 of 0.79 per cent [= 100*((1-2.18/100)/(1-2.95/100)-1)]. On an annual basis this is 0.20 per cent. Taking account of the size of the AP industry, a 0.20 per cent loss of productivity in AP translates into a GDP loss of $337 billion. In total, the productivity losses in the two industries reduce GDP over the year from Y1Q1 to Y1Q4 by $767 billion, which is about 0.0041 per cent of GDP. This leads to -0.0079 per cent [= -0.0038-0.0041] as a back-of-the-envelope (BOTE) estimate of the GDP effect of the processing disruption. The simulated effect is -0.0073. In dollars, this is about $1.4 billion.

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