An economic assessment of U.S. ground beef in response to the introduction of plant-based meat alternatives[1]

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ABSTRACT: Red-meat has been criticized as detrimental to both the environment and human health, leading to a push in the U.S. for consumers to reduce red-meat consumption. Plant-based meat alternatives (MA) have been shown to have reduced environmental impacts compared to red-meat and have been presented as promising alternatives to red-meat. While MA may provide viable replacements for ground beef (GB), specifically, they do not replace the actual source of GB, cattle. Cattle production is a vital part of the U.S. food supply chain and plays an important role in the economy. As such, the goal of the present research was to perform a comprehensive assessment of the economic impacts associated with a reduction in GB consumption in response to increased MA consumption in the U.S. The Global Trade Analysis Project (GTAP) was used to model GB production in the U.S. While there was a cattle meat sector in GTAP, there was not a unique sector for GB. SplitCom was used to disaggregate the cattle meat sector into two sectors: (1) GB and (2) other beef products (OB). GTAP then was aggregated into 19 sectors, 3 regions (the U.S., primary U.S. beef import countries, and rest of world), and 6 factors of production. As the private household budget share for GB 0.31%, the investigated reductions in consumer demand (1, 5, 10, and 15%) did not greatly impact overall economic output. Even at 15% reduction in GB, most sectors experienced minor changes in terms of price or quantity demanded. Most notably, land use and price for cattle (CTL) was reduced by 2.89% and 4.78%, respectively. Agricultural labor and capital were reduced by nearly 10% each for GB and 4% each for CTL. While these results do not account for the economic effects of a corresponding increase in consumer demand for MA, it is unlikely that more significant changes would be observed. Further analysis on this topic is needed to understand the economic impacts of a reduction in GB paired with a corresponding increase in MA.

Key words: GTAP, multi-regional input-output, cattle, sustainability, protein

INTRODUCTION

Climate change is one of the greatest issues facing humanity today. Average global temperatures have increased by 1°C and the sea level has risen 0.19 m above pre-industrial levels (IPCC, 2014; IPCC, 2019). Anthropogenic greenhouse gas (GHG) emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have been the primary drivers of climate change (IPCC, 2014). More than half of anthropogenic GHG emissions have been produced in the past 40 years and despite policies and efforts to mitigate emissions from countries around the world, the largest absolute increases have been observed between 2000 and 2010 (IPCC, 2014). Climate change impacts have been observed across the globe, from the melting of polar ice caps to the changing of migration patterns, ranges, and seasonal activities of terrestrial and aquatic species (IPCC, 2014). Economic and population growth have been the greatest drivers of increased emissions, due to increases in CO_2 emissions from fossil fuel combustion; meanwhile, human food production, livelihoods, and health have been directly impacted by the resulting climate change (IPCC, 2014; IPCC, 2019). The United Nations Paris Agreement aims to address climate change by holding increases in global temperatures to below 2 °C above pre-industrial levels and to pursue efforts to limit temperature increase to 1.5 °C above pre-industrial levels (UN, 2015). If sizeable and sustained reductions in GHG emissions are not achieved, further warming will result in long-lasting and irreversible impacts on both people and ecosystems (IPCC, 2014; IPCC, 2019).

One strategy proposed to help address the climate crisis is for consumers to change their eating habits. In particular, there has been call for consumers to minimize beef consumption as a means of reducing their individual carbon footprints (John Reynolds et al., 2014; Westhoek et al., 2014; Hartmann and Siegrist, 2017; Poore and Nemecek, 2018; Springmann et al., 2018; Willett et al., 2019; Aiking and de Boer, 2020). Globally, livestock production contributes to 14.5% of human-induced GHG emissions, with beef cattle contributing to 41% of these emissions (Gerber et al., 2013). The short-lived climate pollutant, CH_4, emitted as a result of the digestion process of cattle is the primary source of GHG from cattle production (France and Dijkstra, 2005). Mitigation of CH_4 emissions by means of improved genetics, feeding efficiency, and feed additives have proven helpful in reducing the climate change impacts from cattle in the United States and the European Union plus the United Kingdom, where cattle contribute to 3.4% (2.16% for beef cattle, specifically) and 4.99% of national GHG emissions, respectively (EEA, 2021; EPA, 2021). However, this is not the case in many developing countries around the world where cattle producers often lack access to these advanced technologies. Cattle, as a result, require more resources, produce less beef per unit input, and emit more overall GHG, rendering them less sustainable and more GHG intensive than their U.S. or EU counterparts (Gerber et al., 2013; Gerber et al., 2015). Given these inconsistences, a growing global population and the rising demand for meat has called into question whether beef can remain a sustainable part of the human diet. Recently, (Willett et al., 2019) proposed a universal healthy reference diet with the goal of meeting worldwide nutritional needs while addressing climate change among five other primary environmental concerns associated with food production. Included in this universal diet is the recommendation to "limit red meat, by at least 50%, with a recommended daily combined intake of 14 g (in a range that suggests total meat consumption of no more than 28 g/day)."

As a result of calls to reduce beef and other red meat consumption, there has been an increase in research and development of meat alternatives (MA) – products made from plants, insects, and even cell culture that aim to mimic the look, texture, and taste of conventional animal proteins (Bonny et al., 2017; Kyriakopoulou et al., 2018; Lee et al., 2020; Santo et al., 2020). The idea being that MA made from plants, insects, or cell culture will require fewer resources and result in less GHG emissions than conventional animal sourced proteins (Candy et al., 2019; Chen et al., 2019; World Economic Forum, 2019; Aiking and de Boer, 2020; Santo et al., 2020; Smetana et al., 2020; Eisen and Brown, 2021). Meat alternatives made to substitute ground meat products, such as burger patties and sausages, have been the most successful in mimicking the look and texture of their conventional counterparts; however, there has been limited success in replicating the taste of animal proteins or the satisfaction consumers experience when eating meat (Hartmann and Siegrist, 2017; Davis et al., 2021). Impossible Foods and Beyond Burger are the first companies who claim to have successfully created a plant-based meat patty that not only successfully mimics the look and texture of a traditional ground beef (GB) patty, but also the taste and satisfaction of eating a GB burger. Both alternative patties contain technology that even allows these patties to "bleed" like a traditional beef patty. With the creation of the Impossible Burger (IB) and Beyond Burger (BB), these companies suggest that there is no longer a need for consumers to eat conventional beef and promote their products as the more sustainable food choice.

To demonstrate the sustainability of IB and BB, both Impossible Foods and Beyond Meat have commissioned life cycle assessments of their products compared to GB (Goldstein et al., 2017; Heller and Keoleian, 2018; Khan et al., 2019). According to these works, on a per kg product basis, both IB and BB use 96% and 93% less land, 87-97% and 99% less water, and produce 77-89% and 89% less GHG emissions, respectively, than U.S. produced GB (Goldstein et al., 2017; Heller and Keoleian, 2018; Khan et al., 2019). While both IB and BB are thought to be more sustainable than GB, this is based solely on environmental impacts and does not incorporate a full picture of sustainability. Sustainability can be defined with three key pillars: (1) the environment; (2) the economy; and (3) society (Dalampira and Nastis, 2020). With this definition in mind, for a food to be considered wholly sustainable it must be produced in an environmentally conscientious manner while being beneficial both for the economy and for human health (Dalampira and Nastis, 2020). In essence, sustainable food production is a balance, lending itself to tradeoffs and compromise in order to obtain the best outcome. Previous studies have assessed the environmental impacts of GB compared to IB or BB; however, these studies have not incorporated economic or health impacts, thus failing to provide a complete picture of the sustainability of these products.

To obtain a more complete picture of the sustainability of GB compared to IB or BB, it is essential that economic impacts of these products be considered. While replacing GB has been the target of IB and BB, GB is just one component of cattle production. Whole muscle cuts (e.g., ribeye steaks, briskets, etc.), hides, tallow, edible and inedible offal, pharmaceuticals and many other by-products are also obtained from processed cattle (Marti et al., 2012). In total, cattle production is a $66 billion dollar industry, consistently ranking first in total cash receipts for agricultural commodities in the U.S. (USDA, 2021). Additionally, cattle production is an intricate process that supports a large segment of U.S. labor at each stage in the supply chain and is directly linked to several other U.S. sectors. Furthermore, the U.S. is the third largest exporter of beef, playing a large role in international markets. Previous analyses have not considered the role that GB plays in the broader economy and have thus only considered the sustainability of GB compared to IB and BB from one of the three pillars of sustainability. The objective of the present research is to gain a more complete picture of the sustainability of GB compared to IB and BB by assessing the national and international economic impacts of decreasing GB consumption in the U.S.

MATERIAL AND METHODS

GTAP Model

The Global Trade Analysis Project (GTAP) Model, a prevalent computational general equilibrium model, was used to assess the impact of reducing GB consumption in the U.S. on both U.S. and global economies (Aguiar et al., 2019). The tenth version of the GTAP Data Base used herein accounted for annual flows of 65 products and services (i.e., sectors) and 6 factors of production in 121 countries and 20 aggregate regions for the reference year 2014. The GTAP Data Base is comprised of country-based Input Output Tables (IOT) and describes global bilateral trade patterns which links individual countries and regions. As U.S. GB production is directly linked to U.S. cattle production, an internationally important sector of food production, the GTAP Data Base provides a unique opportunity to assess the impacts of reduced GB consumption in the U.S. not only on the U.S. economy but also on international trade for products and services associated either directly or indirectly with GB production in the U.S.

GTAP Data Base Aggregation

The 65 unique economic sectors from GTAP 10 were first aggregated into 18 sectors, with cattle meat and other relevant sectors isolated for more detailed analysis. In total, a 19-sector model was created for the present analysis, aggregated to represent GB production and sectors associated with other by-products from cattle production (Table 1). Sectors of particular interest included: ground beef (GB); other bovine meet (OB); cattle (CTL); animal fats and vegetable oils (F_O); vegetables and pulses (VEG); oil seeds (OIS); leather (LTH); and pharmaceuticals (PHA). The 141 countries/regions from GTAP 10 were aggregated into three regions: (1) the U.S. (USA); (2) Australia, Canada, Mexico, and New Zealand, import countries important to U.S. beef production (IMP); and (3) rest of world (ROW). Finally, six factors of production were classified, including: (1) agricultural labor, (2) skilled labor, (3) unskilled labor, (4) capital, (5) land, and (6) natural resources.

Creating a Ground Beef Sector in GTAP

While the GTAP Data Base contained a unique sector for cattle meat, this sector included data on all meat products from cattle, including GB, along with meat production from other ruminant animals. As such, the cattle meat sector in GTAP was disaggregated into two sectors: (1) GB and (2) OB. SplitCom software was used to perform this disaggregation as it accepted comprehensive data on splitting GTAP flows while it maintained the integrity of the Data Base IOT (Horridge, 2008). Within the SplitCom software there were four key equations which were modified in order to successfully split GB from the U.S. cattle meat sector: (1) trade weight for exports (TEXT); (2) national cross weight (XWGC); (3) national row weights (ROWC); and (4) national column weights (COLC).

The TEXP equation factored in both imports and exports of the original commodity (cattle meat) into the new commodities (GB and OB) in the U.S. as well as other regions. According to U.S. beef trade data, 72% of all U.S. beef imports in 2020 were lean trimmings which were used directly for GB production in the U.S. (National Cattlemen's Beef Association Member Newsletter, 1 May 2020). Of these lean trimmings, 83% were sourced from IMP (Australia, Canada, Mexico, and New Zealand) while the remaining 17% were from ROW. To determine the time relevant input for TEXP, these data were cross-referenced with the United Nations Comtrade Database for the year 2014 (UN, 2020). These values ensured that the splitting data remained consistent with the 2014 GTAP 10 Data Base used in the present work. From this data it was determined that 91% of lean trimmings were from IMP countries and 9% from ROW. This information was then used to populate TEXP with values that would most accurately reflect U.S. trade for GB.

The XWGC equation functioned to describe the interactions of the new commodities which resulted from the split. XWGC combined the new commodities (GB and OB) with their new industries in order to create a national matrix. For this equation, the new commodities were set to have minimal cross interaction, as GB would not move back into the OB sector once it was designated GB.

For the ROWC and COLC splitting equations, total U.S. GB production was first estimated. National survey data was used to determine the total number of cattle slaughtered in the year 2014 and average dressing percentages for each type of animal (i.e., heifer, steer, bull, or cow) were used to determine total kg of beef production (NASS, 2020). It was assumed that 100% of meat from slaughtered bulls and cull beef and dairy cows were used for GB while 30.9% of feed steer and heifer meat was used for GB (Bowling and Gwartney, 2015). Based on this information, 41.9% of U.S. produced beef was allocated to GB and 58.1% to OB, and the ROWC and COLC equations were populated accordingly.

With all four splitting equations populated, the GB sector was created in GTAP. To validate this split, several test runs of the GTAP model were performed to ensure that baseline trade data within the model was in line with the national and international trade databases. Additionally, analysis of sectors connected to GB and OB, such as cattle production, were evaluated to ensure that U.S. production values were accurate in the model.

Scenario Descriptions

The GTAP Data Base accounts for private household (i.e., consumer), government, and firm (i.e., intermediate) spending. With these designated spending accounts, it was possible to model specific changes to private household consumption of GB. To determine the economic impacts of a decline in GB consumption in the U.S., private household demand for GB was reduced in four set intervals. Reduction rates (i.e., scenarios) included: 1%, 5%, 10%, and 15%. The maximum reduction rate of 15% was selected based on market behavior related to U.S. dairy milk consumption in response to the introduction of alternative milks. According to Dairy Management Inc., retail sales of milk alternatives were 8.7% of the combined volume (gallons) of milk and milk alternatives in 2019 (Stewart et al., 2020). Meanwhile, The Good Food Institute (GFI) reported that milk alternatives were 15% of retail milk sales in 2020 (Gaan, 2021). However, if national milk production data is used with GFI milk alternative production data this value drops to 6% of combined milk and milk alternative sales in 2020 (NASS, 2020). Given that reported replacement rates of milk alternatives for milk are conflicting, the 15% maximum replacement rate for meat alternatives was chosen to encompass all possible options.

To achieve the desired consumer reduction of GB in GTAP, private household demand (*qpd*) for GB in the U.S. was swapped for consumption tax (*tpd*) in the model closure and the shock, *qpd*("GB","USA"), was applied at -1%, -5%, -10%, and -15%. In utilizing this method, consumer demand specifically in the U.S. was targeted. To avoid possible effects from a tax distortion, the endogenous variable, *del_ttaxr* (change in the ratio of taxes to income), was made exogenous by swapping with the variable *tp* (tax on private consumption). This provides redistribution of the tax revenues from spending on GB back to consumers so that they have the same income but choose to spend it on items other than GB. To ensure total U.S. consumer demand for GB was reduced by the intended rate in each scenario, substitution between imported and domestic products was eliminated by setting the substitution parameter, ESUBD, for GB to 0. Each of the four reduction scenarios (1%, 5%, 10%, and 15%) were compared against the GTAP baseline scenario (i.e., the unaltered USA, IMP, and ROW economies).

RESULTS

Economic Effects in USA

When considering the quantity output (*qo*) of each USA sector in response to reduced consumer demand for GB, the sectors most affected were GB and CTL, while other sectors of interest were minimally affected (Table 2). As the budget share for GB in USA private household domestic consumption was determined to be 0.31%, a shift in consumer demand for GB was not expected to greatly impact the output from other sectors. Outside of GB, CTL was the only sector that observed any noted changes, with *qo* reduced by a maximum of 3.76% when consumer demand for GB was reduced by 15%. Other sectors of interest (OB, F_O, VEG, OIS, and LTH) had slight increases in *qo*; however, even at the 15% GB reduction rate, no sector experienced more than 0.38% increase in *qo*. Pharmaceuticals was the only sector of interest which experienced a decline in *qo*, with a maximum reduction of 0.02% when consumer demand for GB was reduced by 15%.

While *qo* of GB decreased substantially with reduced consumer demand, USA *qo* of GB did not change at an equivalent rate to that of the consumer demand. Quantity output is a function of three entities: government, private household (i.e., consumer), and firm. When consumer demand was reduced, only private household demand was reduced by the set rate. Meanwhile, firm demand for GB was only slightly reduced and government demand increased slightly in each reduction scenario.

Overall, changes in response to reduced USA consumer demand for GB were most pronounced at the 15% reduction rate. As such, further discussion of results will focus on this scenario. Table 3 presents results for factors related to consumer demand in USA. Overall, the cost of GB increased substantially, which resulted in the intended reduced demand (15%) and a similar reduction in the total budget share of GB (15.19%). While total demand was reduced, total expenditure for GB increased by 3.59% because of the increased price. Across all other sectors of interest, minor changes were observed in terms of price, quantity demanded, expenditure, or budget share.

Regional Analysis

The model predicts a slight positive impact on USA real gross domestic product (GDP), increasing by 0.009%; while the IMP and ROW regions face slight reductions in GDP, declining by 0.016% and 0.001%, respectively. When reviewing the GDP expenditure differences between the updated GTAP output (15% reduction in GB) and the original GTAP output (baseline), the changes to GDP become clearer (Table 4).

In USA, consumption, investment, and government expenditures grew, while export and import expenditures declined. The domestic decline in GB consumption was overcome by increases in consumption of SER, O_I, MFG, and OTF. Additionally, the higher domestic private household consumption tax of GB led to greater government earning which in turn led to the observed increase in government spending. These increases in consumption and government spending are the primary drivers for GDP growth in USA. The inverse is true for IMP and ROW - consumption, investment, and government expenditures decreased. There was a pronounced decline in IMP exports of GB, CTL, and GRA to USA which was recovered by slight increases in IMP exports of OTM, GB, LIV, CTL, F_O, GRA and VEG to ROW. The result of these changes in exports resulted in the slight decline in GDP observed in IMP. In addition, IMP spending on imports decreased as a result of a reduction in the regional private consumption expenditure which affected overall domestic consumption. While ROW exports grew as a result of the slight increase in its biggest exported commodity, MFG, to both USA and IMP, there were overall declines in consumption, investment, and government expenditures. In addition, the import of meat and agricultural commodities to ROW increased along with most other sectors, contributing to the overall decline in ROW GDP.

Equivalent variation (EV) measures consumer welfare as the difference between consumer spending required to obtain the new level of utility (from the experiment) at baseline prices and spending prior to the experimental change (Huff and Hertel, 2000). In the case of the present work, this was the change in total consumer spending in each region which resulted from the reduction to USA GB consumption, based on the baseline model prices. The GTAP welfare decomposition feature facilitates the analysis of changes to EV, which are presented in Table 5. It was estimated that USA and ROW would experience overall welfare gains (positive EV value), while IMP an overall welfare loss (negative EV value) as a result of the 15% reduction in USA consumer demand for GB. Three components contributed to the observed EV effects: allocative efficiency, goods and services terms of trade, and savings-investment terms of trade.

Gains in allocative efficiency are the result of improved allocation of resourced to more productive sectors. In the present work, all three regions experienced allocative efficiency gains For USA, even though the increased tax on GB resulted in a negative allocative efficiency gain of -220.31 million USD, this loss was absorbed by gains in other sectors, mainly SER, MFG, OTF, and O_I. While IMP experienced slight changes in allocative efficiency across all sectors, negative allocative efficiencies were most pronounced in O_I, GB, and SER and these losses were absorbed primarily with gains in O_G. In ROW, all sectors except O_I experienced gains in allocative efficiency. Most notably, GRA had a gain of 35.26 million USD while GB had a gain of 5.99 million USD.

Terms of trade for goods and services impact EV as a result of changes in export and import prices for a country. If a country’s exports prices increase relative to imports then that country has the ability to buy greater quantity of imports while keeping the quantity of exports constant, resulting in greater welfare for that country. Small gains in terms of trade for goods and services were found for USA and ROW at the expense of IMP – both USA and ROW gained on their exports while IMP substantially lost as a result of reduced exports. Most of USA goods and services welfare gain was from the MFG and SER sectors, in addition to small gain from the GB sector. For IMP, the reduced demand for GB in USA had an impact on exports of lean trimmings (i.e., GB) from IMP. Additionally, CTL, GRA, VEG, MFG, O_I, and SER were reduced as a result of the reduced demand for GB in USA. Welfare gains in goods and services for ROW were predominantly due to gains in the agricultural sectors, most notably OTM, GRA, VEG, OIS and OAG. While there were losses to industrial related sectors, these were not large enough to affect the overall gain in terms of trade for goods and services for ROW. Finally, positive savings-investment terms of trade in USA indicates an increase in USA purchasing power for capital goods (a proxy for future consumption), while both IMP and ROW experienced a loss savings-investment.

Although the USA experienced an overall welfare gain, it still experienced a 545.61 million trade balance deficit (Table 5). Despite a positive trade balance of 591.06 million USD from GB, the result of the decline in domestic consumption, an overall trade deficit could not be avoided. This was primarily the result of a 1222.06 million USD trade balance deficit from MFG. Conversely, both IMP and ROW experienced positive trade balances in the new economy. For IMP, the trade balance deficit of 464.47 million USD caused by the reduction in GB exports was overcome by the positive trade balance of 479.45 million USD from MFG along positive balances from most other sectors. While ROW experienced 111.74, 160.36 and 107.90 million USD trade deficits from GB, GRA, and OAG, respectively, this was overcome by the positive trade balances of 725.76 and 209.43 million from MFG and SER, among most other sectors.

Factors of Production

In GTAP, factors of production (land, labor, capital, and natural resources) are in a fixed supply, falling under the resource constraints assumption. Capital and labor are assumed to be imperfectly mobile, or sector-specific, as the transformation of existing machinery and equipment for use in different industries is rarely possible and labor requires time and training in order to move between industries. Results suggest that the 15% reduction to GB may lead to large declines in labor (i.e., rises in unemployment) in both USA and IMP regions for GB and sectors closely linked to GB (Table 6). In USA, labor in GB and CTL sectors were most impacted, with employment dropping by 9.98% and 4.10%, respectively. While not as large of reductions, IMP regions also experienced declines in labor for GB and CLT sectors, with employment decreasing by 2.22% and 1.19%, respectively. Most other sectors linked to GB experienced minimal changes in both USA and IMP regions while labor in ROW remained virtually unaffected.

Land is specific to agricultural sectors in GTAP and is assumed to be fully mobile, which allows for it to be rented by another industry within the agricultural sectors until its rent differential disappears. Natural resources are specific to limited GTAP sectors, which are aggregated in O_G and OTL sectors in the present analysis. Percent changes to the quantity of land used (i.e., land use) and prices of land (i.e., land rent) for livestock and other agricultural sectors in USA and IMP are presented in Table 7. Changes to ROW were negligible and thus not reported herein. In USA, land use for CTL was reduced by 2.89%, while land use for OAG, OIS, VEG, and LIV increased. In addition, the price of land declined for all sectors, with the largest decline or 4.78% observed in CTL. In IMP, there was a slight increase in land use for all sectors, except CTL in which there was a 0.8% reduction. Moreover, the price of land declines slightly for all sectors, with the largest decline of 1.57% observed in CTL.

Systematic Sensitivity Analysis

While the present research has assumed a maximum of a 15% reduction in USA consumer demand for GB as a response to the introduction to plant based meat alternatives, it is not possible to predict the true effect the introduction of meat alternatives will have on consumer demand for GB. As such, a sensitivity analysis was performed, using the GTAP systematic sensitivity analysis (SSA) tool to test a range of replacement rates for GB. Ground beef accounts for just 0.03% of private household spending and for 0.20% of total domestic spending. With GB contributing minimally total USA economic output, performing the SSA with 100% variation (±15% shock to *qpd*), will provide the opportunity to gain more insight into the impacts of replacing GB with meat alternatives. Additionally, it provides a means of testing what might happen if MAs end up replacing GB at a greater share than currently anticipated. With the GTAP SSA tool, the mean and standard deviation of the model results for each variable were estimated for reduction rates ranging from 0 to 30% for GB. A 95% confidence interval was constructed using Chebyshev's theorem, which describes the minimum proportion of results that exist within a range of one standard deviation around the mean, for a variety of model results.

When assessing *qo* of goods, most changes were observed in the meat and agricultural sectors, though most changes were minimal (Figure 1). The *qo* for GB experienced the most variability, with the upper limit of the 95% confidence interval is 8.23% while the lower limit was -28.19%. The cattle sector was similarly variable, with results between 3.1% and -10.19%. The greater confidence intervals for GB and CTL indicate that their reported changes to *qo* are most affected by a shock to consumer demand for GB, which further highlights the strong connection between the two sectors. Conversely, all other agricultural sectors display relatively small confidence intervals, indicating that changes in *qo* of these sectors are least likely to be impacted by changes to GB *qpd*.

The effect of the SSA on EV indicates that welfare changes in all three regions are likely to be robust in response to changes in GB *qpd* (Figure 2). For the USA, the resulting SSA 95% confidence interval falls between 650.47 and -189.94 million USD. Meanwhile, IMP and ROW regions confidence intervals fall between 132.37 and -453.32 million USD and 734.16 and -214.38 million USD, respectively. These results indicate that, when consumer demand for GB is reduced at a greater rate (30%), an overall welfare gain can be expected across all three regions. This change in EV can be attributed to the increased tax on GB, meaning that if the cost of GB had remained the same after the reduction in consumer demand, then consumers would have been able to spend less money overall to achieve the same utility of GB.

Results from the SSA indicate that changes to GDP for USA and IMP as a result of reduced consumer demand for GB are strong (Figure 3). The confidence interval falls between 0.15 and -0.05% for the USA and 0.01 and -0.04% for IMP. Meanwhile, the standard deviation for ROW region is zero, indicating that this region was not affected by the modeled range of change to GB demand.

For the USA, the confidence interval for trade balance falls between 249.95 and -855.99 million USD (Figure 4). For IMP and ROW regions, the confidence intervals fall between 345.21 and -100.8 million USD, and 510.78 and -149.15 million USD, respectively. These results suggest that the trade effects resulting from a greater range of demand for GB are less certain, in some instances it may be possible that each region experiences a surplus and in other instances each region may experience a deficit. However, when running the model at a 30% reduction in GB, we find that the trends in terms of trade remains consistent with the maximum reduction of 15%: the USA experiences an overall deficit while IMP and ROW experience trade surpluses.

DISCUSSION

While GB represents a relatively small percent of total USA economic output, reducing consumer demand for GB did result in changes both nationally and internationally; impacting welfare across regions and altering trade between regions. While many of these changes were relatively small, they highlight that GB consumption in USA does play a role in both national and international economies. Although the present research was not able to assess the introduction and substitution of MAs for GB within the GTAP framework, these results suggest that replacement of GB with MA may not provide comparable economic benefits to USA or global economies. As such, further discussion will focus on the possible economic effects that may arise from the introduction of MA in USA based on the reported economic effects of reducing GB in USA.

Total economic output for USA was reduced by 0.014% when GB was reduced by 15%. Mukhopadhyay and Thomassin (2012) found that reducing meat by 20% in Canadian diets lead to a 0.2% reduction in total economic output. Furthermore, when a 50% increase in vegetables and fruits in Canadian diets was added to this meat reduction, the authors still found a 0.12% reduction in total economic output. These results support the conclusion that while a replacement of GB with MA may add to economic output, it is not likely to replace the loss observed from reducing GB. Mukhopadhyay and Thomassin (2012) also found that reducing meat by 20% in Canadian diets led to a 0.12% reduction in GDP and when a 50% increase in vegetables and fruits in Canadian diets was added to this meat there was a 0.05% reduction in GDP. This suggests that, as with GB in the USA, meat plays an important role in the Canadian economy.

When reducing GB by the maximum of 15%, the quantity output of most goods was minimally affected, though GB and CTL sectors in both USA and IMP regions experienced reductions. In line with the present work, Mukhopadhyay and Thomassin (2012) found that reducing meat by 20% in Canadian diets led to 2.3% and 9.5% reductions in cattle and meat products sector outputs, respectively. When a 50% increase in vegetables and fruits in Canadian diets was added to this meat reduction, the authors report mixed results, but indicate that the increase in fruits and vegetables is not enough to offset the negative economic effects of meat reduction.

Observed reductions in sector outputs resulted in rather large declines in labor for USA and smaller declines in labor for IMP. Mukhopadhyay and Thomassin (2012) found that reducing meat by 20% in Canadian diets led to a 0.13% reduction in employment and when a 50% increase in vegetables and fruits was added to meat reduction, the authors still found a 0.05% reduction in employment. As labor is not easily mobile across industries, this suggests that when new labor is needed for MA production (from growing crops for patties to the factory work to manufacture the patties) it will not be automatically sourced from the lost labor in the CTL and GB sectors. More resources and training will be necessary if such a shift is to be accomplished.

Land use is a topic that is often brought up when discussing environmental impacts of GB compared to MA, but it has yet to be considered from an economic perspective. The present work found that both land use and the price of land were reduced for the USA CTL sector in response to GB reduction. Because GTAP allows for land to be mobile across agricultural sectors, a corresponding increase in land use is observed or other agricultural sectors. Even with this replacement of land use, there is an overall 0.8% reduction in land use in the USA. However, it is important to note that this assumes that the land no longer used for CTL could be used for other agricultural purposes. While ideally this would be the case, it is very unlikely that land no longer used for cattle would be able to directly transfer into any other type of agricultural use. The majority of land used for cattle production (35% of total USA land area) in USA is marginal land, land that is too hilly, has minimal access to water, or has poor soil quality and thus cannot be used to produce crops (USDA, 2016; Bigelow and Borchers, 2017). For land that is converted from range or grasslands to croplands, land productivity must also be considered. While the reduced land used for CTL may be used to grow crops for MA on, it is likely that yields on these converted lands will be lower than established crop lands, thus resulting in less value gained from the land (Lark et al., 2020).

A final consideration is how replacing GB with MA in USA will impact the consumer. While the present study resulted in a reduction of consumer spending on GB, the current costs of MA are not equivalent to replace GB – IB and BB are 3.8 and 2.7 times the cost of GB, respectively. This means that consumers would need to choose either: (1) to maintain the same level of spending and thus reduce their overall food intake; or (2) to maintain the same level of consumption and thus increase their food budget share to maintain the same level of food intake. If consumers chose option 1, they would be consuming about 11% or 9.5% less food to eat IB or BB instead of GB, respectively. While with this option consumers are not effected financially, they are nutritionally, a consideration that is not addressed herein but is nonetheless important to note. Alternately, if consumers chose option 2, they would be spending about 41.6% or 25.7% more to eat IB or BB instead of GB, respectively. This means that consumers now have to reallocate funds to afford the MAs and give up spending in some other area of their budget. In this sense, MAs become a luxury product that consumers have to decide whether they are willing to spend money on or not. For many Americans, this may not be a pressing concern, but this does become a bigger issue in lower income households and lower income countries.

Further analysis on this topic is needed to more completely understand the economic impacts of a reduction in GB consumption paired with a corresponding increase in MA. However, the present work provides a first look into the sustainability of MA compared to GB from the economic standpoint. Paired with current work comparing the environmental impacts of MA and GB the decision to choose one product over the other becomes more challenging. With a growing global population, it may prove to be more essential for future research to investigate how to produce both GB and MAs sustainably. Furthermore, there exists an untapped opportunity for the two products to develop a more symbiotic relationship – the pea and soy pulp which results from formation of MAs is a feasible feedstuff for beef and dairy cattle. This means that the by-products of MA production have the potential to support cattle production, helping to mitigate some of the competition for feeds/food between the two industries while simultaneously increasing the global protein supply.

LITERATURE CITED

Aguiar, A., M. Chepeliev, E. Corong, R. McDougall, and D. van der Mensbrugghe. 2019. The GTAP Data Base: Version 10. Journal of Global Economic Analysis. 4:1–27. Available from: https://www.gtap.agecon.purdue.edu/databases/v10/v10_doco.aspx

Aiking, H., and J. de Boer. 2020. The next protein transition. Trends in Food Science and Technology. 105:515–522. doi:10.1016/j.tifs.2018.07.008.

Bigelow, D. P., and A. Borchers. 2017. Major Uses of Land in the United States, 2012. Available from: www.ers.usda.gov

Bonny, S. P. F., G. E. Gardner, D. W. Pethick, and J.-F. Hocquette. 2017. Artificial meat and the future of the meat industry. Animal Production Science. 57:2216–2223. Available from: https://doi.org/10.1071/AN17307

Bowling, R., and B. Gwartney. 2015. Beef 101. Agricultural Marketing Service of the U.S. Department of Agriculutre. Available from: https://www.ams.usda.gov/reports/beef-101

Candy, S., G. Turner, K. Larsen, K. Wingrove, J. Steenkamp, S. Friel, and M. Lawrence. 2019. Modelling the food availability and environmental impacts of a shift towards consumption of healthy dietary patterns in Australia. Sustainability (Switzerland). 11:1–27. doi:10.3390/su11247124.

Chen, C., A. Chaudhary, and A. Mathys. 2019. Dietary change scenarios and implications for environmental, nutrition, human health and economic dimensions of food sustainability. Nutrients. 11:1–21. doi:10.3390/nu11040856.

Dalampira, E. S., and S. A. Nastis. 2020. Back to the future: simplifying Sustainable Development Goals based on three pillars of sustainability. International Journal of Sustainable Agricultural Management and Informatics. 6:226. doi:10.1504/ijsami.2020.10034327.

Davis, S. G., K. M. Harr, S. B. Bigger, D. U. Thomson, M. D. Chao, J. L. Vipham, M. D. Apley, D. A. Blasi, S. M. Ensley, M. D. Haub, M. D. Miesner, A. J. Tarpoff, K. C. Olson, and T. G. O'Quinn. 2021. Consumer Sensory Evaluation of Plant-Based Ground Beef Alternatives in Comparison to Ground Beef of Various Fat Percentages. Kansas Agricultural Experiment Station Research Reports. 7. doi:10.4148/2378-5977.8036.

EEA. 2021. National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. European Environmental Agency. Available from:

https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-17

Eisen, M. B., and P. O. Brown. 2021. Eliminating Animal Agriculture Would Negate 56 Percent of Anthropogenic Greenhouse Gas Emissions Through 2100 Modeling the elimination of animal agriculture. bioRxiv. 1–27. doi:https://doi.org/10.1101/2021.04.15.440019.

EPA. 2021. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. Available from: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

France, J., and J. Dijkstra. 2005. Volatile Fatty Acid Production. In: J. Dijkstra, J. M. Forbes, and J. France, editors. Quantitative aspects of ruminant digestion and metabolism. 2nd ed. CABI International, Oxfordshire, UK. p. 157–175. Available from: https://www.cabi.org/cabebooks/ebook/20053225686

Gaan, K. 2021. State of the Industry Report: Plant-Based Meat, Eggs, and Dairy. (C. Bushnell, A. Crawford, B. Friedrich, E. Ignaszewski, M. Gosker-Kneepkens, L. Specht, and S. Voss, editors.). The Good Food Institute.

Gerber, P. J., A. Mottet, C. I. Opio, A. Falcucci, and F. Teillard. 2015. Environmental impacts of beef production: Review of challenges and perspectives for durability. Meat Science. 109:2–12. doi:10.1016/j.meatsci.2015.05.013. Available from: http://dx.doi.org/10.1016/j.meatsci.2015.05.013

Gerber, P. J., H. Steinfeld, B. Henderson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci, and G. Tempio. 2013. Tackling climate change through livestock : a global assessment of emissions and mitigation opportunities. Rome. Available from: http://www.fao.org/3/i3437e/i3437e.pdf

Goldstein, B., R. Moses, N. Sammons, and M. Birkved. 2017. Potential to curb the environmental burdens of American beef consumption using a novel plant-based beef substitute. PLoS ONE.

12:1–17. doi:10.1371/journal.pone.0189029. Available from: http://dx.doi.org/10.1371/journal.pone.0189029

Hartmann, C., and M. Siegrist. 2017. Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. Trends in Food Science and Technology. 61:11–25. doi:10.1016/j.tifs.2016.12.006. Available from: http://dx.doi.org/10.1016/j.tifs.2016.12.006

Heller, M. C., and G. A. Keoleian. 2018. Beyond Meat's Beyond Burger life cycle assessment: A detailed comparison between a plant-based and an animal-based protein source. Center for Sustainable Systems Univeristy of Michigan. 1–42. Available from: http://css.umich.edu/publication/beyond-meats-beyond-burger-life-cycle-assessment-detailed-comparison-between-plant-based

Horridge, M. 2008. SplitCom: Programs to dissaggregate a GTAP sector. Available from: https://www.gtap.agecon.purdue.edu/resources/splitcom.asp

Huff, K. M., and T. W. Hertel. 2000. Decomposing Welfare Changes in the GTAP Model. Available from: http://www.agecon.purdue.edu/gtap/,

IPCC. 2014. Climate Change 2014 : Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Core Writing Team, R. K. Pachauri, and L. A. Meyer, editors.). IPCC, Geneva, Switzerland.

IPCC. 2019. Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S.

Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield, editors.). IPCC, Rome, Italy. Available from: www.environmentalgraphiti.org

John Reynolds, C., J. David Buckley, P. Weinstein, and J. Boland. 2014. Are the dietary guidelines for meat, fat, fruit and vegetable consumption appropriate for environmental sustainability? A review of the literature. Nutrients. 6:2251–2265. doi:10.3390/nu6062251.

Khan, S., J. Dettling, J. Hester, and R. Moses. 2019. Comparative Environmental LCA of the Impossible Burger With Conventional Ground Beef Burger. Quantis. 1–64.

Kyriakopoulou, K., B. Dekkers, and A. J. van der Goot. 2018. Plant-based meat analogues. In: Sustainable Meat Production and Processing. Elsevier. p. 103–126.

Lark, T. J., S. A. Spawn, M. Bougie, and H. K. Gibbs. 2020. Cropland expansion in the United States produces marginal yields at high costs to wildlife. Nature Communications. 11. doi:10.1038/s41467-020-18045-z. Available from: https://doi.org/10.1038/s41467-020-18045-z

Lee, H. J., H. I. Yong, M. Kim, Y. S. Choi, and C. Jo. 2020. Status of meat alternatives and their potential role in the future meat market - A review. Asian-Australasian Journal of Animal Sciences. 33:1533–1543. doi:10.5713/ajas.20.0419.

Marti, D. L., R. J. Johnson, and K. H. Mathews. 2012. Where’s the (Not) meat? Byproducts from beef and pork production.

Mukhopadhyay, K., and P. J. Thomassin. 2012. Economic impact of adopting a healthy diet in Canada. Journal of Public Health (Germany). 20:639–652. doi:10.1007/s10389-012-0510-2.

NASS. 2020. National Agriculutral Statistic Services Quick Stats Database. NASS of the United States Department of Agriculture. Available from: https://quickstats.nass.usda.gov/

Poore, J., and T. Nemecek. 2018. Reducing food’s environmental impacts through producers and consumers. Science. 360:987–992. doi:10.1126/science.aaq0216.

Santo, R. E., B. F. Kim, S. E. Goldman, J. Dutkiewicz, E. M. B. Biehl, M. W. Bloem, R. A. Neff, and K. E. Nachman. 2020. Considering Plant-Based Meat Substitutes and Cell-Based Meats: A Public Health and Food Systems Perspective. Frontiers in Sustainable Food Systems. 4:1–23. doi:10.3389/fsufs.2020.00134.

Smetana, S., B. Oehen, S. Goyal, and V. Heinz. 2020. Environmental sustainability issues for western food production. Elsevier Inc. Available from: http://dx.doi.org/10.1016/B978-0-12-813171-8.00010-X

Springmann, M., M. Clark, D. Mason-D’Croz, K. Wiebe, B. L. Bodirsky, L. Lassaletta, W. de Vries, S. J. Vermeulen, M. Herrero, K. M. Carlson, M. Jonell, M. Troell, F. DeClerck, L. J. Gordon, R. Zurayk, P. Scarborough, M. Rayner, B. Loken, J. Fanzo, H. C. J. Godfray, D. Tilman, J. Rockström, and W. Willett. 2018. Options for keeping the food system within environmental limits. Nature. 562:519–525. doi:10.1038/s41586-018-0594-0.

Stewart, H., F. Kuchler, J. Cessna, and W. Hahn. 2020. Are Plant-Based Analogues Replacing Cow’s Milk in the American Diet? Journal of Agricultural and Applied Economics. 52:562–579. doi:10.1017/aae.2020.16.

UN. 2015. Paris Agreement. United Nations, Paris, France.

UN. 2020. UN Comtrade Database. Department of Economic and Social Affars of the United Nations. Available from: https://comtrade.un.org/data/

USDA. 2016. Overview of the United States Cattle Industry.

USDA. 2021. Cattle & Beef: Sector at a Glance. Economic Research Service of the United States Department of Agriculture . Available from: https://www.ers.usda.gov/topics/animal-products/cattle-beef/sector-at-a-glance/

Westhoek, H., J. P. Lesschen, T. Rood, S. Wagner, A. de Marco, D. Murphy-Bokern, A. Leip, H. van Grinsven, M. A. Sutton, and O. Oenema. 2014. Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Global Environmental Change. 26:196–205. doi:10.1016/j.gloenvcha.2014.02.004. Available from: http://dx.doi.org/10.1016/j.gloenvcha.2014.02.004

Willett, W., J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, D. Tilman, F. DeClerck, A. Wood, M. Jonell, M. Clark, L. J. Gordon, J. Fanzo, C. Hawkes, R. Zurayk, J. A. Rivera, W. de Vries, L. Majele Sibanda, A. Afshin, A. Chaudhary, M. Herrero, R. Agustina, F. Branca, A. Lartey, S. Fan, B. Crona, E. Fox, V. Bignet, M. Troell, T. Lindahl, S. Singh, S. E. Cornell, K. Srinath Reddy, S. Narain, S. Nishtar, and C. J. L. Murray. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. 393:447–492. doi:10.1016/S0140-6736(18)31788-4.

World Economic Forum. 2019. Meat: The Future Series - Alternative Proteins. Available from: http://www3.weforum.org/docs/WEF_White_Paper_Alternative_Proteins.pdf

Tables and Figures

Table 1. GTAP sectors.

Number	Sector	Description	Comprising
1	OTM	Other Meat	Meat products n.e.c.[1]; dairy products
2	GB	Ground Beef	Ground beef
3	OB	Other Bovine Meat	Bovine meat products (excl. ground beef)
4	LIV	Livestock and Raw Milk, Non-Bovine	Animal products n.e.c.; raw milk
5	CTL	Cattle	Bovine cattle, sheep and goats
6	F_O	Animal Fats and Vegetable Oils	Vegetable oils and fats
7	GRA	Grains	Paddy rice; wheat; cereal grains n.e.c.
8	VEG	Vegetables and Pulses	Vegetables, pulses, and fruits
9	OIS	Oil Seeds	Oil seeds
10	OAG	Other Agricultural Products	Sugar cane, sugar beet; plant-based fibers; crops n.e.c.; wool, silk-worm cocoons
11	OTF	Other Processed Foods	Processed rice; sugar; food products n.e.c.; beverages and tobacco products
12	LTH	Leather	Leather products
13	PHA	Pharmaceuticals	Basic pharmaceutical products
14	RUB	Rubber	Rubber and plastic products
15	O_G	Fuels	Coal; oil; gas; petroleum, coal products; gas manufacture, distribution
16	OTL	Other Land Use Industries	Forestry; fishing; minerals n.e.c.
17	MFG	Manufacturing	Textiles; wearing apparel; wood products; paper products, publishing; chemical products; mineral products n.e.c.; ferrous metals; metals n.e.c.; metal products; computer, electronic and optic; electrical equipment; machinery and equipment n.e.c.; manufactures n.e.c.; electricity
18	O_I	Other Industries	Water; construction; trade; accommodation, food and service activities; transport n.e.c.; water transport; air transport; warehousing and support activities
19	SER	Services	Communication; financial services n.e.c.; insurance; real estate activities; business services n.e.c.; recreational and other service; public administration and defense; education; human health and social work; dwellings

[1]Not elsewhere classified.

Table 2. Changes is quantity output from selected sectors when U.S. consumer demand for ground beef was reduced by 1%, 5%, 10%, and 15%. Values reported as percent change from baseline.

	Reduction Scenario			
Sector	1%	5%	10%	15%
Ground Beef (GB)	-0.665	-3.326	-6.653	-9.979
Other Beef (OB)	0.014	0.068	0.137	0.205
Cattle (CTL)	-0.251	-1.253	-2.505	-3.758
Fats and Oils (F_O)	0.002	0.009	0.017	0.026
Vegetables (VEG)	0.011	0.053	0.107	0.160
Oil Seeds (OIS)	0.025	0.126	0.252	0.378
Leather (LTH)	0.004	0.022	0.044	0.065
Pharmaceuticals (PHA)	-0.002	-0.008	-0.015	-0.023
19 Sector Total	-0.853	-4.255	-8.512	-12.769

Table 3. Changes to factors of consumer demand for selected sectors when U.S. consumer demand for ground beef was reduced by 15%. Values reported as percent change from baseline.

	Factors of Consumer Demand			
Sector	Price	Quantity Demanded	Expenditure	Budget Share
Ground Beef (GB)	18.59	-15.00	3.59	-15.19
Other Beef (OB)	-0.26	0.21	-0.05	0.01
Cattle (CTL)	-0.50	0.41	-0.09	-0.04
Fats and Oils (F_O)	-0.12	0.09	-0.03	0.03
Vegetables (VEG)	-0.24	0.00	-0.24	-0.19
Oil Seeds (OIS)	-0.25	0.00	-0.25	-0.20
Leather (LTH)	-0.07	0.06	-0.01	0.04
Pharmaceuticals (PHA)	-0.06	0.06	0.00	0.05

Table 4. Gross domestic product (GDP) expenditure differences between updated GTAP output (15% reduction in ground beef) and original GTAP output (baseline). Results displayed in units of million USD.

Region	Consumption	Investment	Government	Export	Import	Total
USA	1175.0	799.8	157.5	-428.1	-117.5	1586.6
IMP	-480.3	-267.1	-132.6	3.6	136.9	-739.5
ROW	-450.0	-459.0	-39.0	470.0	-66.0	-544.0

Table 5. Equivalent variation (EV) and trade balance in each GTAP region as a result of a 15% reduction in USA consumer demand for ground beef. Results reported in million USD.

Region	Allocative Efficiency	Terms of Trade: Goods and Services	Terms of Trade: Savings-Investment	EV	Trade balance
USA	142.84	76.70	65.95	285.48	-545.62
IMP	3.53	-156.44	-7.38	-160.29	140.40
ROW	205.07	79.74	-58.57	226.25	405.22

Table 6. Changes to labor for selected sectors in USA and IMP regions when USA consumer demand for ground beef was reduced by 15%. Values reported as percent change from baseline.

	Labor	
Sector	USA	IMP
Ground Beef (GB)	-9.983	-2.223
Other Beef (OB)	0.202	-0.001
Cattle (CTL)	-4.095	-1.189
Fats and Oils (F_O)	0.024	0.090
Grains (GRA)	-0.552	-0.096
Vegetables (VEG)	0.057	0.002
Oil Seeds (OIS)	0.288	-0.073
Other Agricultural Products (OAG)	0.417	0.047
Leather (LTH)	0.062	0.093
Pharmaceuticals (PHA)	-0.024	0.036

Table 7. Changes to the quantity used and price of land for livestock (LIV) and other agricultural sectors in USA and IMP regions as a result of a 15% reduction in consumer demand for ground beef in the USA. Values reported as percent change from baseline.

	Land Quantity		Land Price	
Sector	USA	IMP	USA	IMP
Livestock (LIV)	0.32	0.13	-1.57	-0.64
Cattle (CTL)	-2.89	-0.80	-4.78	-1.57
Grains (GRA)	-0.06	0.07	-1.95	-0.69
Vegetables (VEG)	0.43	0.15	-1.46	-0.61
Oil Seeds (OIS)	0.61	0.09	-1.27	-0.67
Other Agricultural Products (OAG)	0.71	0.19	-1.17	-0.58

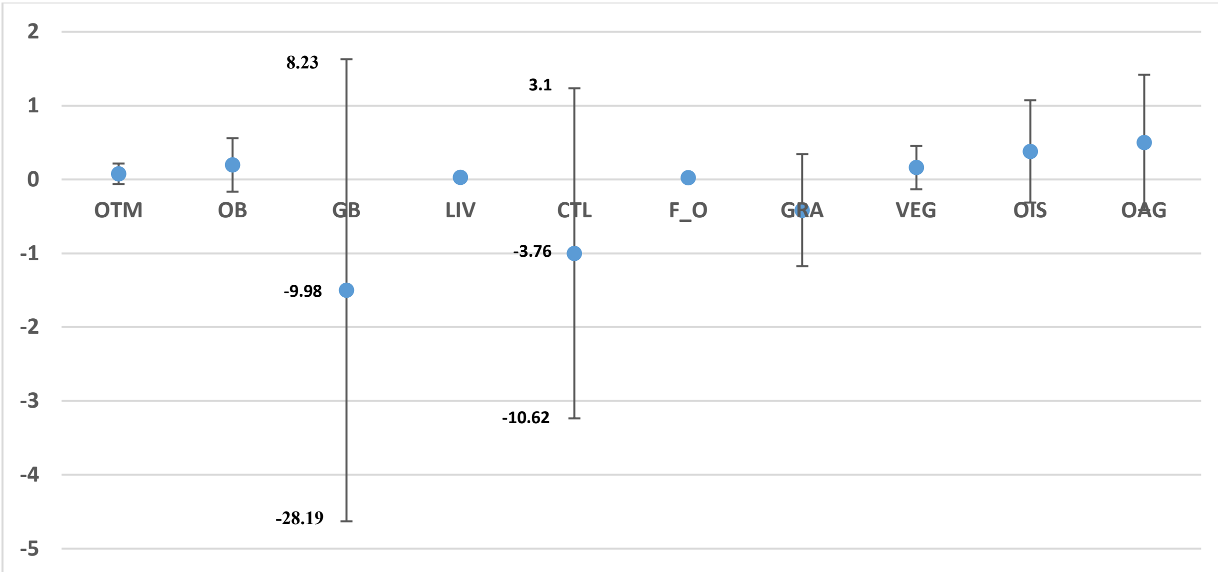

Figure 1. 95% confidence intervals[1] for the quantity output of select sectors[2] as a result of performing a systematic sensitivity analysis on consumer demand for GB.

[1]Note: values for GB and CTL fall outside of the range presented in this chart. In order to see the much smaller changes in the other sectors, these error bars have been modified to fit within the range of the current chart.

[2]OTM = other meat; OB = other beef; GB = ground beef; LIV = livestock; CTL = cattle; F_O = fats and oils; GRA = grains; VEG = vegetables; OIS = oil seeds; OAG = other agricultural products.

Figure 2. 95% confidence intervals for equivalent variation (EV) in USA, IMP, and ROW regions[1] as a result of performing a systematic sensitivity analysis on consumer demand for ground beef (GB).

[1]USA =United States; IMP = import countries important to USA GB (Australia, Canada, Mexico, New Zealand); ROW = rest of world.

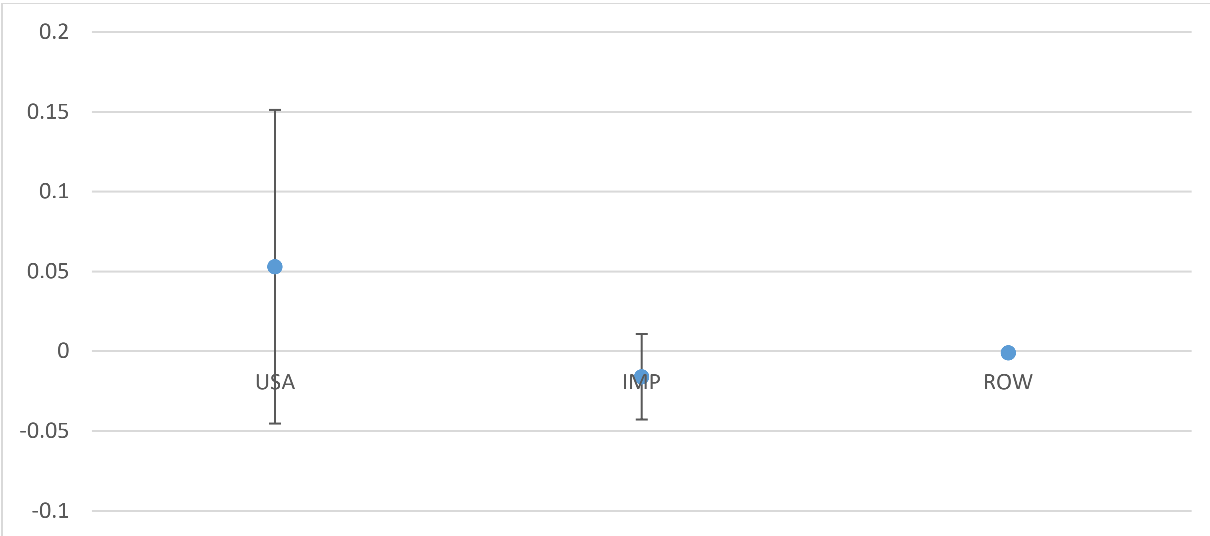

Figure 3. 95% confidence intervals for changes in gross domestic product (GDP) for USA, IMP, and ROW regions[1] as a result of performing a systematic sensitivity analysis on consumer demand for ground beef (GB).

[1]USA =United States; IMP = import countries important to USA GB (Australia, Canada, Mexico, New Zealand); ROW = rest of world.

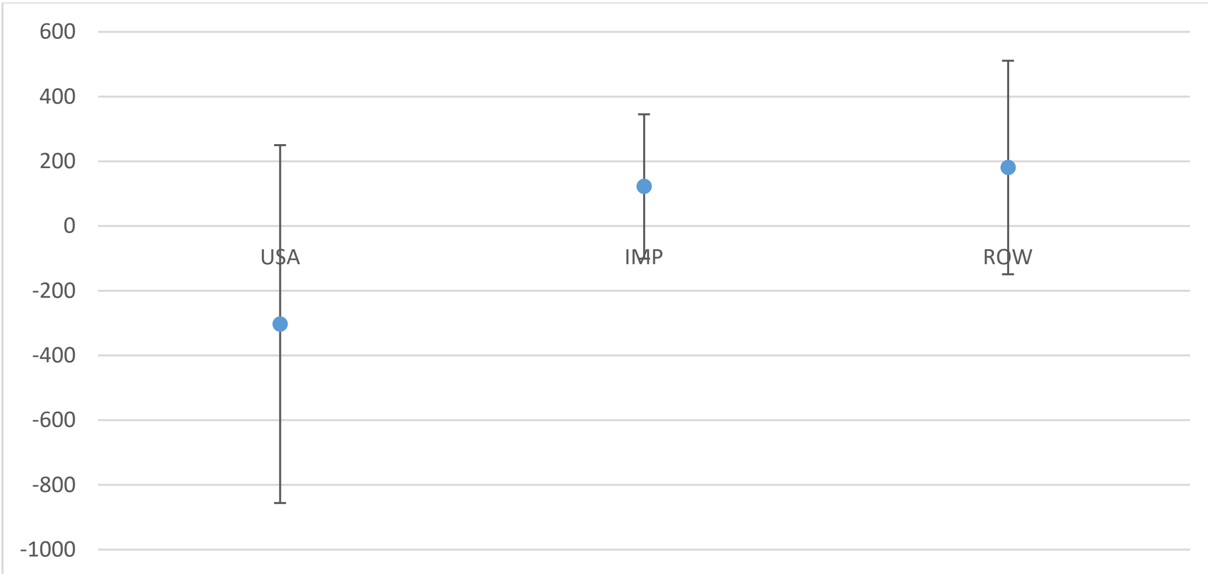

Figure 4. 95% confidence intervals for trade balance in USA, IMP, and ROW regions[1] as a result of performing a systematic sensitivity analysis on consumer demand for ground beef (GB).
[1]USA =United States; IMP = import countries important to USA GB (Australia, Canada, Mexico, New Zealand); ROW = rest of world.