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Peer Review File

The impact of Highly Pathogenic Avian Influenza H5N1 on US domestic and international dairy and beef markets

Corresponding Author: Professor Katharina Hauck

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Professor Hauck,

Your manuscript titled "The impact of Highly Pathogenic Avian Influenza H5N1 on US domestic and international dairy and beef markets" has now been seen by 3 original reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

In particular, for publication in Communications Earth & Environment, we request that you provide methodological details, especially regarding production factors, clarify assumptions and how it is modeled in scenarios, reframe the trade, and discuss sectoral disaggregation and how simulated outcomes correspond to the observed economic impacts as requested by reviewer 1 and 3.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Martina Grecequet, PhD
Senior Editor,
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

Reviewer's comments on COMMSENV-25-3087-T

General Comment
The paper "The Impact of Highly Pathogenic Avian Influenza H5N1 on US Domestic and International Dairy and Beef

Markets" examines the effects of H5N1 on the US economy and its trading partners using a global CGE trade model. The topic is potentially valuable for the journal's readership.
However, some results and their explanations raise concerns that are closely tied to the CGE model's methodological framework. I recommend that the authors (i) clearly acknowledge the limitations, (ii) avoid overemphasising potentially misleading findings, and (iii) ensure accessibility for both technical and non-technical audiences. The paper should strike a balance between transparency about model caveats (for modellers and economist) and a careful presentation of results that avoids confusion (for non-economists).
The comparison in Lines 140–146 with past real-world impacts supports the plausibility of the overall results.

Major Comment 1: Sectoral Disaggregation
The model disaggregates seven agricultural and food sectors (≈2% of US GDP), one manufacturing sector (<16%), and an aggregated "other sectors" category (≈79%). Shocks target the small agri-food sectors, and results focus on these, but translating their changes to the rest of the economy is challenging.
This aggregation may be justifiable given the weak links between major US sectors (services, health, trade, etc.) and agri-food, but it risks overstating indirect effects. The authors should note this in the discussion and explain how interactions between agri-food and the aggregated sectors should be interpreted.

Major Comment 2: Production Factors
I could not find information on the treatment of the production factor capital. It is unclear whether capital demand is fixed by sector or mobile between sectors.
Looking at the results, and without further information, I would conclude that capital is the production factor most likely to be reallocated. For example, Table D.9 shows a 0.03% decrease in manufacturing employment, while Table D.7 shows a 0.03% increase in manufacturing output and Table D.5 shows a 0.01% decrease in manufacturing prices—allowing trade to increase by 0.1% (Table D.6).
At present, I see three possible explanations:
(i) reallocation of labour types other than unskilled labour (unlikely),
(ii) reallocation of capital, or
(iii) an increase in total factor productivity (unlikely)
Of these, I consider the reallocation of capital the most likely. If capital is being reallocated from agri-food sectors to manufacturing and other sectors, the assumptions behind this should be explained. In particular, in a short-term scenario, such reallocation may require strong assumptions.
It would be helpful if the authors clarified how the production factor capital is modelled and how capital behaves in the scenarios.

Major Comment 3: Trade
Lines 100–103 report that US non-agri-food sectors gain competitiveness and increase exports following an agri-food shock. This finding may depend heavily on unclear factor reallocation assumptions and could be counterintuitive, potentially creating doubt.
Given the acknowledged limitations in trade representation (Lines 159–161), I recommend reframing this as a modelling artefact or caveat, rather than a main finding.

Detailed comments (partially repeating the general comments)

Line 46-47 : Comment: As done for the GDP, it could be useful to also inform about the relative share of total jobs. What is the importance of 3 M jobs, compared to the total employment in the US? The same for the wages. Since agriculture, cattle, dairy, food processing are capital intensive, the employment should not be too high. If the share of jobs of total number of jobs and wages appears too small, the authors could consider how to sell this. E,g, can it be still an argument because these jobs are mainly focussed in rural regions (so meaning farmers on the country side would suffer negative impacts). And should the employment serve as selling point for the study at all? For real life understanding one would see these jobs jeopardized by the shocks. However, in the model results, the agri-food employment partially even benefits from the shocks.

Line 59 : delete « (552 words »

Line 72-73: Check: "0.06% (95% high density 73 interval: -0.06% to -0.06%) of real GDP (Scenario S1, Fig. 1B)." the lower and upper bound of the interval are the same at -0.06%

Line 75: "Price shocks are highest for raw milk (5.58%) and dairy products (5.25%)," Comment: maybe indicate more clearly that 5.58% is the increase of raw milk price and 5.25% represents the production price increase of dairy products.

Line 78: "the economic loss to the USA is greater at 0.28%" Question: this refers to the loss of the whole economy or only to the dairy sector?

Line 79: "for the realistic scenario S2, and 0.91%" Question: this refers to the loss of the whole economy or only to the dairy sector?

Line 79-80: “with the output losses in the dairy sector estimated at 9.32% (-11.61% to -7.05%) and 20.6% (-25.06% to -16.42%), respectively.” Question: this refers to the loss of the dairy sector?

Line 94: “0.05% (-0.05% to -0.05%, S1), » Comment: upper bound of interval = lower bound
Line 122: “by $53.656 (-59.204 to -48.300) » Comment: dollar sign missing in the brackets

Line 159-162: “Third, some of the simulated export increases may appear significant in terms of percentage change; however, the quantities produced at the sectoral level remain within realistic adjustment ranges. In other words, while trade is increasing significantly, this increase can be accommodated by the sectors because it represents a relatively small share of total production.”
Comment: It somehow looks like that the results on trade described before are not interpretable.

Lines 100-103: “The modified terms-of-trade make the US economy more competitive internationally in non-agricultural goods and services, resulting in an increase of exports. This effect can compensate for the decrease in exports of directly affected agricultural products, resulting in an overall increase in US exports of 0.01% (0.01% to 0.01%), 0.11% (0.09% 103 to 0.13%), and 0.75% (0.59% to 0.95%), respectively.”
Comment: see major comment 3

Appendix page 5, Figure A.2: Sectors contribution to total Output Quantities (QO) shows the shares of output:
Other sectors 79%
Manufacturing 16.4%
Processed food 2.03%
Grains, crops, meats, dairy cattle, raw milk: each < 1% adding up to approximately 2%.
Comment: The authors might think about reflecting the fact that the agri-food sectors are very small compared to the two aggregates “manufacturing” and “Other sectors” and explaining the potential problems and limitations associated with it (see major comment 1).

Appendix page 11:
“This productivity shock increases the amount of labor required to maintain the same level of output. Since real wages are assumed to be fixed, the cost of employing additional workers does not rise, encouraging firms in these sectors to demand more labor to compensate for the productivity loss. However, the shock has also a negative impact on the rest of the economy’s employment levels. This decrease in productivity has negative spillover effects on the overall labour market conditions affecting both US household incomes and consumption of all goods and services in the USA.
Our findings suggest that aggregating all these impacts, consumption of goods and services overall decreases by 0.05% in the current situation, and 0.21% and 0.86% in S2 and S3. Lowered household incomes also reduce saving capacity, resulting in a reduction in sectoral investments in the USA, which is strongest in the dairy industry. Overall, investments into all sectors decrease by 0.04%, 0.19% and 0.67% across the scenarios.“
Question: does this mean, that the increase of the 3 million jobs (which maybe account for 2% of all jobs) impact the rest of the US labour market? This would be a very strong spill-over effect, which probably would not appear in reality. Especially, if most of the jobs are in service sectors.

Appendix page 11:
“Trade shifts occur indirectly in S1 and directly in S2 and S3, where a percentage reduction of traded quantities is implemented. Following the outbreak, the U.S. experiences an increase in the global export volume and value. This increase is driven by two main factors, first, the decrease in the price of U.S.-manufactured goods caused by the agricultural slowdown and the reallocation of domestic factors rendering US manufacturing more competitive. Second, U.S. trading partners agricultural sectors benefit from an increase in demand by US consumers for agricultural imports. They make up for the reduction in US dairy production, both to satisfy demand in their own domestic markets, and in other countries including the USA itself.“
Question: I understand that there is an increase in US exports, but find it difficult to bring align with the statement “Second, U.S. trading partners agricultural sectors benefit from an increase in demand by US consumers for agricultural imports.” Isn’t this referring to increasing imports? How these increasing imports can increase the exports? I am probably missing the link.

Reviewer #2 (Remarks to the Author):

Dear authors,
thanks for replying to my comments related to the paper "The impact of H5N1 on US domestic and international dairy markets".
All comments have been satisfactorily addressed.

Reviewer #3 (Remarks to the Author):

Thank you for addressing the feedback. I have two final comments:

1) "Here, a Computable General Equilibrium model is used to assess the short-to-medium term macro-economic impact...": I recommend rephrasing this as "is used to simulate..." to better reflect the nature of the modelling approach. Please also

ensure consistency throughout the manuscript in stating that the model simulates outcomes.

2) To what extent do the projected short-term effects align with real-world observations so far? If relevant reports or data are already available, please include a brief discussion on how well the simulated outcomes correspond to the observed economic impacts.

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Version 1:

Decision Letter:

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Dear Professor Hauck,

Your manuscript titled "The impact of Highly Pathogenic Avian Influenza H5N1 on US domestic and international dairy and beef markets" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Martina Grecequet, PhD
Senior Editor,
Communications Earth & Environment
Consulting Editor,
Communications Sustainability

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Dear Editors and Authors,
I have reviewed the revised version of the article “The Impact of Highly Pathogenic Avian Influenza H5N1 on US Domestic and International Dairy and Beef Markets” (COMMSENV-25-3087A) along with the authors’ rebuttal letter.
I truly enjoyed reading both. The authors have carefully addressed my previous comments and provided thoughtful responses. The manuscript now represents a strong and engaging piece of work that balances the complexity of a CGE model analysis with clear and accessible communication.
Congratulations to the authors on these revisions.

Reply to Reviewer comments for '*The impact of H5N1 on US domestic and international dairy markets*'

Reviewer #1 (Remarks to the Author):

Review NATFOOD-24112341A "The impact of H5N1 on US domestic and international dairy markets" for Nature Food.

The paper addresses a highly relevant issue, namely the economic consequences of livestock diseases and zoonotic risks. The research approach using the GTAP model is appropriate to capture the relevant impacts and interdependencies, and to derive meaningful net effects and identify underlying mechanisms. I appreciated the opportunity to read this paper and think that such work is very useful for the scientific discussion as well as for policy makers. However, I do have some concerns and comments, which I outline below, along with suggestions on how to address them.

First, the scope is too narrow. You focus on H5N1 and the US. I suggest i) including other countries (H5N1 occurs also elsewhere) and ii) including other diseases (e.g., African swine fever is also very relevant right now, to name just one). Your model can do both. A broader scope would be much more attractive for a journal like Nature Food. It would also be very relevant in terms of comparing impacts, and in terms of showing policy makers that this model and approach can be used to prioritize where to put what action. In its current form, the analysis seems to me to be too narrow to be as meaningful as this approach could be. In this sense, your ex-ante assessment could also be compared with similar events observed in the past. This would allow it to be put into perspective.

Thank you for this valuable suggestion. We appreciate the recommendation to broaden the scope of the analysis.

Regarding the inclusion of other diseases and countries, we understand the appeal of a broader comparative approach. However, our current focus on H5N1 in the United States was chosen deliberately due to the, currently, limited expanse of the pathogen in cattle, and the US's significant role in global agricultural markets and influence on international trade and policy. The U.S. is one of the world's largest producers and exporters of meat and other agricultural commodities, meaning that disruptions in its supply chains can have far-reaching global consequences. While our model is adaptable, incorporating other diseases or countries would require both disease and region-specific data and modelling frameworks that are not as richly available. A combined analysis of multiple diseases across diverse geographies would introduce substantial complexity and uncertainty, particularly when estimating cross-sectoral impacts (e.g., on hospitality and tourism). We agree that this is a promising direction for future research. We agree also that the model has broader applicability. We see this work as a foundation for future work that could include other diseases and international contexts.

On the point of retrospective comparisons, we acknowledge the value of benchmarking our ex-ante assessment against past events. Our modelling approach is already informed by historical data, which may introduce a degree of circularity if used for retrospective validation.

I invite the authors to be more explicit about the research and policy gap (what we don't know, but should, and why) that they address in the paper. More specifically, you can also use the supplementary material to summarize some related literature, in the field of

economics and policy, on i) livestock diseases, ii) similar cases with human health implications occurring in plants, e.g. the EHEC case in vegetables and lettuce, and iii) pests and diseases in crops. All of these also have implications for production, demand, trade and regulation, and indeed have similarities for policy responses. This would lift your paper from an ad hoc analysis to being embedded in a larger field of literature, and also allow further strengths in assumptions, methods, and policy options to be considered (see also below).

Thank you for the suggestion. With the higher word limit for the resubmission, we now have the scope to add an additional paragraph on research and policy gap in the introduction (page 2, line 45-53), and a section summarising related literature (page 9, line 140-153; page 13, line 284-304).

In the current setup, you look at different scenarios that consist of assumptions about impacts on production, consumption, trade, etc., as well as policy responses. I would suggest taking the policy part apart. This would mean that you would have, for example, 3 impact scenarios, all of which you would combine with a larger number of policy scenarios. This would allow you to see what are the best policy responses under what conditions. That gives policy makers a basis for what to do. I think that could be a key contribution of your work. In that sense, it wasn't clear to me why these policy options that are now being considered are actually being chosen. Please clarify. And: I felt there must be much more to consider, again looking at other literature (see areas listed above).

Thank you for this suggestion. We fully agree that, disentangling policy responses from impact scenarios would allow for a richer analysis and offer guidance for policymakers. However, in our current GTAP framework, the “policy” variables are embedded in the defined shock. Table 1 (page 12) lays out which policy measures are included in each scenario and what are their potential effect, and Table 2 then directly maps these choices into the GTAP variable to be shocked (qpa, aoall, qxs, to). As such, there is no separate “policy” dimension to vary independently. This can be partly explained by the lack of data and possibility for comparison between interventions. Indeed, GTAP treats epidemiology as exogenous. That means we cannot map different policy to distinct spread of the disease in cattle. Until an epidemiological-economic coupling is developed (which we flag as an important direction for future work), any policy variation would simply amount to arbitrary rescaling of productivity or demand shock.

Some of the results are so large that I wonder what the reality check on this gives. For example, Canada increases exports by 340%, is this possible, in what time frame and at what cost? I would like to see more discussion of the results, which means more space, see also my comments below.

We do agree with the reviewer that these estimates can be confusing because of their large size.

Within our updated scenarios and due to the change made to the model closure (SI, Table A.3), these values are much lower, with increases of 7.67%, 35.33%, and 165.06%. However, even if the values decreased these effects are still significant and large in percentage. This can be explained by different mechanisms. First, the quantity of dairy exported by Canada was not very large before the outbreak, as most production was aimed at meeting domestic demand. Therefore, any increase in export quantity can translate into high percentage changes, even if the absolute quantity change remains small relative to the total size of the sector. This is evident when looking at the corresponding changes in output quantities, which increase by only 0.65%, 1.29%, and 6.16%, respectively, figures we believe to be reasonable estimates. This shows that even if the exported quantities increased significantly in percentage terms, the increase in output produced by the sector is

very reasonable and meets realistic production capacity. We added this explanation Page 8, line 104-110.

From the short main text it was not possible to understand what was actually done, and not even the intuition of the main mechanisms was clear to me. I think such a paper deserves a bit more space (so the 2-page format may not be the best).
However, even the supplementary material was not sufficient to understand what was done, why and how. For example, many of the assumptions remain vague in terms of i) why these parameters are chosen to be affected, ii) how exactly these are parameterized and why iii) where the assumptions are taken from (Table A4 remains unclear where this is taken from). More generally, the whole modeling setup remains too ad hoc. I suggest that all of this be underpinned with literature, and for areas of high uncertainty and even unknowns, consider using tools such as scenario integration or Delphi analysis to synthesize knowledge from key experts.

We have substantially expanded the Methods section of the manuscript. This now includes a more detailed explanation of the GTAP model structure, the rationale for its use in this context, and how it captures the economic impacts of disease outbreaks (page 11). We have also clarified the process by which key parameters were selected and how they were implemented in the model (Pages 12-14; Table 2 and SI Section C.1).

To address concerns about the ad hoc nature of the modelling setup, we have also implemented a series of robustness checks. These include sensitivity analyses on key parameters to assess the stability of our results under alternative plausible assumptions (Arndt, Channing & Pearson, Ken, 1998 - https://www.gtap.agecon.purdue.edu/uploads/resources/download/1209.pdf). The outcomes of these checks are now reported in the supplementary material (Section E.1 and E.2).

I also invite authors to explain assumptions in much more detail. At one point you talk about demand being reduced by xx%, I was wondering what that means. How do you account for a shift in the demand curve (which is what you mean?)? How exactly does demand and the elasticity of demand change, what happens to cross-price elasticities, etc.? The current supplementary material was not sufficient to grasp the main ideas and assess whether this is well aligned.

Thank you for bringing this important point to our attention. Our choices to shock the demand are motivated by the literature on page 13-14, line 284-304. To make it clearer, we have now added a more detailed explanation of how demand shocks are implemented in the GTAP model in the revised Methods section (Page 13, 268-279) and SI (Section C.1). In short, GTAP demand elasticities are not specified directly. Instead, they are derived from the structure of the CDE expenditure function. This setup does not explicitly model cross-price elasticities, and it is now discussed on page 11, line 218-232.

If the analysis only requires a limited number of cross-price effects, as in the case we study, we can approximate these by adjusting the substitution parameters (SUBPAR), which influence how easily consumers switch between goods. However, reliable estimates for how SUBPAR values might change in response to an avian flu outbreak are difficult to estimate, and not well defined. Therefore, we conducted sensitivity analyses by slightly varying the SUBPAR values to assess the robustness of our results. Details of this analysis are provided in Section E of the Supplementary Information.

I missed a clear reflection on and explanation of the underlying dynamics for disease, policy, impacts, and how these dynamics are accounted for in your model and policy options. For such a highly dynamic livestock disease problem, the timing of interventions may be critical.

The model used in this analysis is a comparative-static model and does not incorporate dynamic changes over time. GTAP only assess the cross-sectoral and cross-country effects of different interventions that we design in our scenarios, and which are implemented with different exogenous shocks to demand, trade, and productivity based on past outbreaks estimate (Tables 1 and 2 and P. 13-14, line 284-304). We have added an explanation of the underlying dynamics of the model for the disease and policy impacts in the supplementary information (SI, Section A1 & A2). We acknowledge that policy timing is critical and emphasize that a dynamic epi-econ model is needed to capture these temporal interactions. Developing such a framework is a key objective for future work. Our study does not consider the impact on disease transmission. This could be done by embedding our companion paper Rawson et al. (2025 - https://doi.org/10.1038/s41467-025-59554-z) within an economic framework. However, this is beyond the scope of the current paper.

Reviewer #2

The authors examine the effects of H5N1 avian influenza in U.S. dairy cattle. For this, they employ the Global Trade Analysis Project (GTAP) model, which is a multi-region and multi-sector Computable General Equilibrium (CGE) model that simulates the economic behaviour of various economic agents (e.g. producers, consumers, government) and projects impacts across different economic dimensions. They assume three different scenarios: Scenario 1 describes the current situation; Scenario 2 assume that the outbreak escalates and government amplifies measures; Scenario 3 assumes a feasible worst case scenario in terms of the spread of the outbreak. Each scenario consists of different assumptions about the potential channels of impact, such as interventions, changes in demand, etc (as described in the Appendix).

Comment

My major comment stems largely from my limited familiarity with Computable General Equilibrium analysis and the characteristics of of US dairy sector: how robust are the results given the assumptions used to model the potential channels of impact in each scenario? Overall, the analysis appears to have been conducted meticulously. I recognise that choosing the right assumptions is far from trivial, and it sensible that the authors have grounded their assumptions in pas literature. However, as it is also stated in page 2, lines 82-84 the estimated results are conditional on the assumptions that have been used for each scenario. For this reason, I feel the paper would benefit from a more in-depth discussion about the sensitivity of the results, including their direction and magnitude, as well as sensitivity checks if possible, to clarify which channels of impact maybe more robust. This is relevant for policy makers seeking to prioritise policies for containing the spread of the outbreak.

We thank the referee for their supportive comments. To address the question of robustness, we implemented a comprehensive sensitivity analysis using GTAP, varying key elasticities and shock sizes (Page 14; line 306-314). We find that while the magnitude of impacts varies moderately across scenarios, the direction of key outcomes remains consistent. We follow the standard GTAP sensitivity procedure as outlined in Section E of the Supplementary Information. We believe that this additional analysis strengthens the policy relevance and credibility of our findings.

For instance, there is the assumption of 5% reduction in demand for beef in scenario 2. Would it be though more realistic instead to assume an increase in demand of beef due to

an increase in chicken price, given that supply of chicken is directly affected by H5N1 outbreak and at greated magnitude, i.e. chicken and beef are substitute commodities?

The suggestion that beef demand could increase due to a rise in chicken prices, given their substitutability, is well taken. Our assumption of a 5% reduction in beef demand in Scenario 2 is based on behavioural responses observed in past zoonotic outbreaks. That said, we acknowledge that this assumption may oversimplify the complex substitution dynamics in meat consumption. We have now clarified this limitation in the discussion section (Page 9; line 154-156). A more comprehensive treatment would require explicitly modelling the poultry sector and cross-price elasticities between meat types, which, while important, falls outside the scope of our current macroeconomic focus.

Similarly, in scenario 2 the assumption of the demand shock of 10% reduction in demand of pasteurised dairy products might be a bit high. Pasteurisation eliminates the spread of the milk, which could reassure consumers to maintain their milk consumption, particularly as milk is a low cost dietary option? As another example, how realistic are the estimated impacts under the current S1 scenario?

We agree that pasteurisation significantly reduces the likelihood of transmission. The 10% reduction in demand for pasteurised dairy products in Scenario 2 was informed by consumer behaviour observed during previous zoonotic outbreaks, such as Foot and Mouth or H1N1, where demand declined despite low actual transmission risk (Attavanich et al., 2011- https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2024.1338677/full). These reactions were often driven by perceived rather than scientific risk. To address this concern, we have added a sensitivity analysis assuming different range of shock on milk demand. The results show that the overall macroeconomic impact is very similar, and the direction of key outcomes remains unchanged. Similarly, for Scenario 1, we have clarified the basis for our assumptions in the Scenarios section (Page 12, line 253-254). Moreover, our Scenario 1 analysis is very robust to different value of the shock as shown in Section E of SI.

There are three described interventions. The moving of dairy cattle and testing of farm workers may not be so expensive because U.S. dairy farms may be able to "spread" the costs due to their large scale of production, and in addition, USDA reimbursements may at least partly offset these costs? The milking process in farms that positive cases were confirmed may be the expensive, but how many farms were confirmed with positive cases. Martin et al. (2024) mentions that positive cases were confirmed in 151 herds in 12 states between March and August 2024, with a probability that more cases exist. Taking these into account, is the estimated short- to midterm loss is estimated of $13bn a bit influenced upwards?

We agree with the referee that the estimates of costs of biosecurity in farms, and the impact on costs of production are highly speculative. To address the comment of the referee we have amended the model to allow for uncertainty in cost estimates. In a companion paper (https://doi.org/10.1038/s41467-025-59554-z) it is argued that the number of unreported cases of H5N1 in US herds is likely much higher that what has been reported and that current interventions are weak.

Other specific comments:

- *page 2, lines 47 of the manuscript mentions 0.05%, while appendix page 14 line 300 mentions the loss of 0.04% of GDP CORRECTED*
- *page 7, lines 132 in appendix "lactating dairy cattle that are moved between states need to be tested for influenza A1" does "moved" means bought? YES?*

- *page 7, lines 134 in appendix “It is recommended that all workers on affected farms are tested” all workers in all dairy U.S. farms, or those employed in farms that are moved between states? ALL*
- *page 8, lines 187-188 in appendix “The adverse impact on productivity are assumed to be 15% (raw milk), and 10% (pasteurised dairy and live cattle) and 5% 189 (beef).” is this estimated to be per farm that measures apply or the average impact on US dairy farming sector? AVERAGE*
- *page 13, lines 278-280 in appendix “Huang et al. (2017) analysed the Chinese chicken meat market's response to an H1N1 outbreak” I think the authors assessed the impact of avian influenza (HPAI) outbreaks, not H1N1 CORRECTED*
- *page 2, line 48: “There is a one-off increase in prices, because the outbreak and the mitigation measures increase the costs of production.“ One-off means a temporary increase in prices? If yes, what is the time-span for temporary? REMOVED*
- *page 2, lines 56-57: “Farmers in the US face two opposing effects: either increased employment to compensate for the loss in productivity in affected sectors, or reduced employment to adjust to lowered demand and output” but appendix, page 14 line 309 states: “and needs more labour to compensate for the lost productivity and maintain production in the shocked sectors.” the latter statement seems to be contradict partly from the former. CORRECTED*
- *page 19 appendix “Table A9: Projected impact on employment of unskilled labour, by scenario, sector, and country, % reduction compared to pre-H5N1 situation” I am not sure how interpret the results: in S1 for Australian cattle sector there is a 0.67% reduction and in S1 Australian other sector there is a 0.01% increase? Or maybe it should be “change” instead of “reduction”? CORRECTED*

Thank you for highlighting these points, which we have addressed as part of the paper's revision.

References

Martin, N.& Trmcic, A. & Alcaine, S. (2024). Hot topic: Avian influenza subtype H5N1 in US dairy—A preliminary dairy foods perspective. JDS Communications. 5. S4-S7. 10.3168/jdsc.2024-0634.

Reviewer #3

Dear authors. please find below my comments related to the paper "The impact of H5N1 on US domestic and international dairy markets"

Key results

The paper shows that the recent outbreak of H5N1 in US cattle will have impact on the US macroeconomic indicators (GDP, trade and employment) with minimum spillover to partner countries. The impact of the results are affected by the severity of measures modelled in three different scenarios with increasing severity.

Validity
The data employed for the study is the world-wo=ide recognized GTAP database. The database is consistent and robust and well placed for this type of analysis. The authors should report the version and the base-year used, at least in the appendix
Nevertheless, the way in which the database has been aggregated could create issues with the result interpretations. The database is employed with a very rough level of aggregation. This impedes to understand some key economic issues. For example, authors cannot report the impacts of the shocks on the feed sectors and all other agricultural production that might be affected by the shocks. Secondly, results on consumption are also biased as consumers are substituting meat and dairy products (whose price is increasing) with an aggregate sector which is including 61 remaining sectors.

We thank the referee for their thoughtful feedback. The study employs the globally recognized GTAP database, which is well-suited for macroeconomic impact analysis. As requested, we have now explicitly reported the version and base year of the GTAP database in the Methods section (Page 11, line 210 & 233) and SI (Section A.1; Figure A.2). Regarding the level of sectoral aggregation, we acknowledge that a more detailed disaggregation, particularly within the agricultural and food sectors, could provide additional insights. However, the primary objective of this study is to inform national policy responses to H5N1 by providing high-level projections on key macroeconomic indicators such as GDP, trade, employment, household income, and consumption. A detailed sectoral analysis, while valuable, falls outside the scope of this work. That said, we have taken steps to improve the granularity of our analysis. Specifically, we have further disaggregated the food sectors to better capture substitution effects in consumption. A detailed table (SI Section A.1 - Table A.1; Figure A.2) outlining the disaggregation structure is now included on page 4 of the Supplementary Information section (SI) to improve the clarity and robustness of our analysis.

Data and methodology

In general, the methodology employed is well recognized in the literature. The authors employ an of off-the-shelf model without providing any novelty from the methodological point of view.

The authors should clarify why the results they report can be considered short to medium term as typically, results from a comparative static simulation without any specific change should be considered medium to long run impacts of a shock. this is particularly true if the authors did not modify the level of elasticities of the standard model but nothing is mentioned about this in the paper.

We appreciate the reviewer's insightful comment regarding the temporal interpretation of our results. As noted, comparative static simulations typically reflect medium- to long-term impacts unless specific assumptions are made to constrain factor mobility and price

flexibility. In our original analysis, the results were intended to reflect medium-term impacts. To address the reviewer's concern and enhance the robustness of our findings, we modified the model to analyse a short to medium term time-horizon. This was implemented by reducing transformation elasticities (ETRAE) and by fixing wages, in line with standard practices in the literature (see Supplementary Information, page 4 and page 7 Tables A.3). These adjustments reflect the limited flexibility of factor markets and nominal rigidities typically observed in the short run (Countryman and McDonnell, 2025 - https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf; Burfisher, 2021 - https://doi.org/10.1017/9781108780063)

The authors should also provide (in the appendix) a more detailed elaboration on the model closure rule, particularly on the labor market to make the interpretation of the job results easier.

We thank the reviewer for this valuable suggestion, which has helped us improve the transparency of our modelling approach. In response, we have included a comprehensive table in the SI (Table A.3) detailing the closure rules applied in each scenario, including all deviations from the standard GTAP model. Regarding the labour market specifically, we endogenize labor quantities while holding real wages constant, allowing unskilled-labor endowments to adjust. We adopt this modelling choice to capture short- to medium-term dynamics, during which wages are typically rigid (Burfisher, 2021 - https://doi.org/10.1017/9781108780063). This reflects short-term wage rigidities and is consistent with established practices in the CGE literature. A more detailed discussion of this labour market specification and its implications for interpreting employment results is now included in the Supplementary Information (Section D; Page 11).

On the pure modelling approach, the authors should better defend the translation of the scenarios in modelling code. Achieving a reduction of consumption via increase of taxes, for instance, has an impact on the government budget and on overall results.

We thank the reviewer for highlighting this important modelling consideration. We agree that the method used to implement consumption reductions can significantly influence the model's fiscal and macroeconomic outcomes.

To address this, we revised the model closure by endogenizing the consumption tax rate. This allows the model to adjust the tax rate to achieve the desired reduction in consumption, rather than imposing a direct quantity constraint (SI, Table A.3). This approach ensures that the fiscal implications (specifically, the increase in government revenue) are captured within the model framework. The additional tax revenue is reflected in the government budget and subsequently affects the income of the global household. This fiscal feedback mechanism may partially offset the negative income effects of the H5N1 shock, thereby influencing the overall results however this effect is small. This modelling strategy is consistent with established practices in the CGE literature (OECD, 2020 - https://doi.org/10.1787/f6a9ef88-en.; Maliszewska et al., 2020 - https://ssrn.com/abstract=3573211, de Menezes et al., 2024 - 10.22004/ag.econ.342181), and a more detailed explanation is now included in the Supplementary Information (SI, Page 11).

The same holds for modelling imports ban from third countries via import taxes. Alternative techniques, implementing preference shift of consumers or third countries (see Philippidis G, Hubbard L. A Dynamic Computable General Equilibrium Treatment of the Ban on UK Beef Exports: A Note. J Agric Econ. 2005;56(2):307–312.) should have a less distortive impact on the results.

We thank the reviewer for this insightful comment, which has helped us refine our approach to modelling the import ban. In our baseline scenario, we implemented the ban using high import tariffs. However, we acknowledge that this approach may introduce distortions. To address this, we have incorporated an alternative specification in our sensitivity analysis that simulates a change in the Armington elasticities, in other word a preference shift change. This approach is consistent with the method proposed by Philippidis and Hubbard (2005-https://doi.org/10.1111/j.1477-9552.2005.00006.x). Details of this implementation are provided in Section E.2 of the Supplementary Information. The outcome of this sensitivity analysis shows the robustness of our results.

Additionally, we note that the large percentage changes in export quantities observed in some scenarios are partly due to the low baseline levels of exports in the pre-H5N1 period. In absolute terms, these changes represent a relatively small share of total production and should be interpreted accordingly. This mechanism can be observed in the relatively small change in output quantities (SI, Table D.6).

Clarity and context

The text is clear and results have been provided with sufficient consideration of previous works.
To improve the linkages between introduction and model results, I would suggest to expand the first paragraph of the main text adding some more figures on the current outbreak of H5N1 on cows as authors do not report any figures related to the impact of the outbreak on cows in the USA so that readers could better understand why this current outbreak is different from previous ones ("dairy cattle have not been identified as a host fort e H5N1. virus previously").

Answer: Introduction of the main text has been extended to clearly state the timeline and magnitude of the outbreak. We also want to refer to our companion paper (https://doi.org/10.1038/s41467-025-59554-z) which describe in great depth H5N1 spread.

References
A possible missed reference is the following:
Philippidis G, Hubbard L. A Dynamic Computable General Equilibrium Treatment of the Ban on UK Beef Exports: A Note. J Agric Econ. 2005;56(2):307–312.

Remarks on code availability
The results of the paper should be easily reproducible by users owning a license to use the GTAP database. The code to reproduce the shocks can be used the community but does not contain any relevant novelties but rather the application of standard shocks.

Reviewer #4

General comments

In the paper "The impact of H5N1 on US domestic and international dairy markets" the authors use the GTAP model to simulate the impact of the H5N1 outbreak in the US. The authors simulate different scenarios of production and trade shocks resulting from the H5N1 outbreak and draw conclusions on the impacts on the domestic sectoral economy and international trade.

Employing the multi-country global trade model GTAP to simulate trade shock resulting from a epidemic outbreak is in general OK. However, in this study I found too many issues making me doubt that this paper is suitable for a publication in Nature Food.

My general concerns:

1st: Suitability of the GTAP model:

I wonder if the GTAP world trade model is suitable for analysing the impact on the dairy market, which accounts according to the authors for only 3% of the domestic GDP. With 3% of GDP the sector is very small, so the results found for the whole model could be not the best reliable, especially if the rest of the sectors are aggregated in one residual sector. Institutions analysing scenarios for agricultural markets (e.g., FAO/OECD) are using PE models for scenario analysis. PE models allow for a better detailed representation of agricultural sectors.

We thank the reviewer for raising this important point regarding model suitability, which we carefully considered during the design of our study. While the dairy sector accounts for approximately 3% of domestic GDP, the potential impacts of an H5N1 outbreak extend far beyond this sector. These include disruptions to labour markets, household income and trade- effects that cannot be fully captured by a partial equilibrium (PE) model.

At the outset, we evaluated the merits of using a PE versus a general equilibrium (GE) model. Given the nationwide scale of the outbreak that we simulate (particularly in Scenario 3, which is comparable in scope to the BSE crisis), we determined that a GE framework was necessary to capture the economy-wide spillovers. This approach is consistent with previous studies that have analysed similar shocks using CGE models (e.g., McDonald & Roberts, 1998 - https://doi.org/10.1111/j.1477-9552.1998.tb01285.x
; Philippidis & Hubbard, 2005 - https://doi.org/10.1111/j.1477-9552.2005.00006.x). Moreover, Beutels et al. (2008 - https://doi.org/10.1002/hec.1339) argue that PE models are inadequate for assessing the broader economic consequences of health-related shocks and policy interventions. To further support our modelling choice, we have added a discussion in the Methods section of the main text quantifying the broader economic footprint of the dairy supply chain based on a USDA note (Page 10, line 204-209 - https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy) including upstream and downstream linkages. This shows that the sector's indirect effects substantially reinforce the relevance of a GE approach for this analysis.

2nd: Plausibility of the results

Although the paper tells an economic story, the results are in many points not plausible and convincing. A critical discussion of the observed results is missing. And some results will be surprising the reader, e.g., the observation that in a short-mid term scenarios the labour force set-off from the agricultural sectors migrate to the other sectors (represented as one

big residual). As a result of the labour migration and the decrease of salaries other sectors gain competitiveness. In reality, this scenario would mean: the (very small) beef/dairy sector contracts and helps other sectors growing.

We appreciate the reviewer's observation regarding the plausibility of some of our simulated results, particularly the labour reallocation from the agricultural sector to "other sector". We agree that, without sufficient context, these dynamics may appear counterintuitive. In the standard GTAP framework, labour is assumed to be mobile across sectors, and wages adjust flexibly to equilibrate supply and demand. As a result, when agricultural sectors contract due to the H5N1 shock, labour reallocates to other sectors, which (due to wage decrease) gain competitiveness. However, we recognize that aggregating diverse industries into a single residual sector can obscure sector-specific dynamics and may hinder the interpretation. To address this, we have restructured the sectoral aggregation to include 9 distinct sectors across 10 countries (SI, Table A.1), allowing for a more detailed labour and output analysis. Additionally, we implemented wage stickiness by modifying the model closure (Table A.3), and we reduced the elasticity of transformation ('ETRAE') to match that of land, thereby introducing sluggish labour reallocation between sectors. These adjustments reflect short-term labour market frictions and improve the realism of our results. These modifications are grounded in established CGE modelling practices (Burfisher, 2021 - https://doi.org/10.1017/9781108780063;
Countryman & McDonnell, 2025 - https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf
). We believe these changes enhance the credibility and interpretability of our findings.

MAIN TEXT

1 Title: The impact of H5N1 on US domestic and international dairy markets
Comment: maybe in the title the acronym H5N1 can be replaced by a more popular term (e.g., by avian influenza). The non-expert does not gain any information from H5N1. DONE

Thanks to the reviewer's comment, we have now updated our title to:
"The impact of Highly Pathogenic Avian Influenza H5N1 on US domestic and international dairy and beef markets"

6 economic sustainability of farming, and global food systems. Using a Computable General Equilibrium model, we assess short-to-medium-term impacts on Gross Domestic Product, trade, and employment under varying scenarios. We project economic losses ranging from $14bn to $164bn.
Comment: with a CGE model one cannot project or forecast, one can simulate a shock but not forecast. Also indicating absolute monetary values for losses is normally avoided in CGE modelling, since the result are based on a SAM of a certain base year and absolute figures only inform if one knows the reference values. Therefore, most common CGE results are reported in percentage change compared to a reference. And even here: non-experts of the US economy, will not be able to evaluate how important the losses of $14bn to $164bn are.

We also acknowledge the concern about presenting absolute monetary losses. While such figures can help convey the scale of impacts, they can be misleading without proper context. To address this, we now report percentage changes relative to the baseline, which is standard practice in CGE modelling. However, we also express the welfare change in dollar terms, enabling us to provide a monetary estimate of H5N1 cost. This dual presentation aims to enhance interpretability for both expert and non-expert audiences. We also clarify that all monetary values are expressed in 2017 USD, consistent with the base year of the GTAP

database used in this study. This has been noted in the main text and in the Supplementary Information to avoid misinterpretation (Methods Page 11, line 210, SI Figure A-2).

14 The recent outbreak of H5N1 avian influenza in dairy cattle across at least 15 US states
Comment: maybe indicate a concrete time, that later reader can identify when this happened.

We have revised the Introduction to include specific dates for the recent H5N1 outbreak in dairy cattle and provide clearer temporal context for readers.

33 … The US dairy sector makes up about 3% of US GDP,
Comment: 3% of GDP is not very big. For a CGE model application this share of GDP could be considered even as critically low to execute simulations with, since impacts on other bigger sectors might be more relevant in scenarios. This might raising the readers first question: why using an economic wide CGE model to simulate impacts on a sector which accounts only for 3% of the GDP? The intersectoral impacts from the small sector might be limited. A Partial Equilibrium model was the better choice.

We thank the reviewer for raising this point regarding the relative size of the dairy sector and the appropriateness of using a CGE model. While the dairy sector alone accounts for approximately 3% of US GDP, the broader set of affected agricultural sectors, including cattle and beef, contributes significantly more. According to a recent USDA report (2024 - https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy), these sectors collectively contribute 5.5% to GDP and provide 10% of national employment. Additionally, food expenditures represent 12.9% of household budgets. Given the scale and interconnectedness of these sectors even a medium-sized shock, such as an H5N1 outbreak, can generate substantial spillover effects across the economy. These include changes in labour allocation, trade flows, and household income, which are best captured within a general equilibrium framework. While partial equilibrium models offer detailed sectoral insights, they are limited in their ability to account for such economy-side feedback. For this reason, we believe a CGE model is the most appropriate tool for this analysis as now discussed in the Methods section of the main text (Page 11, line 190-209).

44 We project that the short- to midterm loss associated with the current H5N1 outbreak is about $13.7bn in the US (based on 2023 GDP) or 0.05% of GDP (Scenario S1, figure 1B).
Comment: the loss of less 0.05% of GDP is so small, that also this very small change could be at the threshold of being interpretable. One cannot project with a CGE model, on can simulate. The figures could be different with a different base year or data base and the GTAP 11 base year is different than from 2024. Thus, the results observed cannot be projections.

We thank the reviewer for this thoughtful and important comment regarding the interpretation and presentation of our results. We agree that CGE models are not forecasting tools, but rather simulate counterfactual scenarios based on a given set of assumptions. Accordingly, we have revised the terminology throughout the main text and supplementary material to use ‘estimate’ instead of ‘project’ to more accurately reflect the nature of the results. We clarify that our simulations are based on the GTAP 11C database, which uses 2017 as its base year (SI, Figure A-2; Methods, Page 11, line 210).

We acknowledge the reviewer's point that a 0.05% change in GDP is extremely small. This only happens under Scenario S1 where the H5N1 outbreak is very limited. Scenario 3 has an impact of about 1 % of GDP, which aligns with other studies using similar approaches, as noted in the discussion section (page 9, lines 140–153).

60 The outbreak and its impact on agriculture has knock-on effects on economic sectors that are not directly affected.
Comment: how can this be concluded if the all the other sectors except mild/dairy/beef/cattle are aggregated as 61sectors in one residual?

We agree that this information was not clearly presented in the original results. The new aggregation, along with revised tables and graphs in both the main text and supplementary information along with added explanation, now provides a clearer understanding of this phenomenon (SI, Section A-2; Methods, page 10, line 240-247).

62 they search for employment elsewhere.
Comment: how realistic is it that agricultural crisis sectors, where workers are probably mainly on the country side, create an economy wide labour migration (to the sectors in urban areas). Wouldn't agricultural labour would stay in agricultural/rural sectors, as they are often unskilled and not able to be hired in any sector?

We agree that large-scale migration of agricultural labour, particularly from rural areas to urban-based sectors, may be limited, especially in the short term, due to skill mismatches and geographical constraints. However, our analysis is for the short to medium-term context, where some degree of labour reallocation is plausible. However, to better capture the limited mobility of agricultural labour, we have reduced the elasticity of transformation (ETRAE) in our model (See SI, Section A.2). This parameter controls the substitutability of input across sectors, and lowering it introduces frictions that slow down sectoral labour reallocations. This adjustment aligns the model more closely with real-world labour market dynamics, particularly for unskilled rural workers. Such approach is consistent with practices in the CGE literature imperfect labour mobility (Countryman and McDonnell, 2025 - https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf
).

73 USA itself. For example, dairy exports from Canada are expected to increase by 7.5%, 52.7%, and 340% for
Comment: how to interpret the 340%, especially, if these results are short-/mid term? How does it change the trade production in Candada?

We thank the reviewer for this observation regarding the interpretation of large percentage changes in Canadian dairy exports. We acknowledge that the previously reported 340% increase may appear implausible, particularly in a short- to medium-term context. This figure however reflects a very low absolute baseline level of Canadian dairy exports, as most production is typically consumed domestically. As a result, even a small absolute increase in export volume can translate into large percentage changes. To provide additional context, we now discuss the corresponding changes in total dairy output, which are much smaller, 0.65%, 1.29%, and 6.16%, across the scenarios (SI, Table D.6). These figures suggest that while export volumes rise sharply in percentage terms, the overall production response remains within realistic bounds.

Following revisions to our scenario assumptions the export increases are now more modest: 7.67%, 35.33%, and 165.06% respectively. We believe these updated figures are more

plausible and better reflect short- to medium-term trade dynamics. This explanation has been added to Section D of the supplementary Information and to the main text (page 8, line 105-110).

Supplementary material

7 “We have chosen the GTAP model because it describes the agricultural sector in greater detail than other CGE models.“

Comment: Wouldn’t some specialised PE models be better suitable to simulate the impacts on the dairy/milk market (incl., milk, milk powder, cheese, butter). The dairy/milk market like other agricultural markets are very complex and institutions like FAO/OECD for their outlook use PE models to estimate impacts for their baselines under simulated scenarios. So the benefit of the CGE model is the representation of the whole economy (also non-agricultural commodities), but in this studies these non-agricultural commodities are aggregated. So the usage of the GTAP model could be better be exploited.
Isn’t one of the driving motivation to be mention should be that the GTAP model represents international trade between countries and regions and thus is suitable to simulate trade shocks examined in this paper.

We thank the reviewer for this constructive comment. We agree that partial equilibrium (PE) models are highly effective for detailed analysis of specific agricultural markets, and we appreciate the opportunity to clarify our rationale for using a CGE model in this study. While PE models are commonly used by institutions such as FAO and OECD for agricultural outlooks, they are limited in their ability to capture intersectoral linkages, labour market dynamics and macroeconomic feedback. Given the potential for H5N1 to affect not only the dairy markets but also employment, trade and household income, we believe a CGE model is more appropriate for capturing the broader economic implications of such shock. The GTAP model offers a robust and widely used representation of global trade flows, making it especially suitable for simulating international trade shocks, such as export restrictions of shifts in import demand, that are central to scenarios. Moreover, we have refined our sectoral aggregation to better distinguish key agricultural and food sectors, thereby improving the model’s ability to trace sector-specific impacts. We have revised the manuscript to more clearly articulate the aggregation in the Methods section and in subsection A.1 of the supplementary Information. We have included a full discussion justifying our use of the GTAP model in the Methods section of the main text (page 10, lines 190–200).

20 Table A1: Regions, sectors and factors of production in the GTAP model
United States (US) --- Raw milk --- Unskilled Labor (UnSkLab)
Canada (CND) --- Dairy Products --- Skiller Labor (SkLab)
Mexico (MEX) --- Meats Products --- Capital (Capital)

Comment: what does this table express? In the US in the Raw Milk sector only unskilled labourers are working? In Mexico in meat production only capital is the primary production factor?

This table presents the global GTAP aggregation used in the paper. We have now revised the presentation by dividing it into three separate parts to highlight that these components are not related with each other (SI Table A.1).

27 Table A2: Economic sector descriptions

Comments: I am sceptical concerning the aggregation of the sectors. The 4 dissagregated sectors milk, dairy, beef and cattle are on the one hand the sectors of interest, but the other 61 sectors are aggregated to one residual. Like this no information is provided about the intersectoral impacts and reactions of important key sector (e.g., food processing industry are missed). Furthermore, concerning the reallocation of production factors, the factors (e.g., labour) offset from the four sectors will be absorbed by a big residual assuming that the whole rest of the economy will absorb the agricultural labour forces. This might not correspond to the reality since big parts of the rest of the economy are demanding semiskilled labour.

We thank the reviewer for this important observation regarding sectoral aggregation and labour reallocation, which has helped us improve the robustness and interpretability of our results. In response, we have revised the aggregation structure to include 9 distinct sectors across 10 countries. This revised structure disaggregates key food-related industries, including food processing and distribution, that were previously grouped into a residual category. This allows us to better capture intersectoral linkages and the downstream effects of shocks originating in the dairy and livestock sectors (See SI, Figure A.2).

We also recognize the reviewer's concern that displaced agricultural labour may not be easily absorbed by the broader economy, particularly in sectors requiring semi-skilled or urban-based labour. To reflect this, we have reduced the elasticity of transformation (ETRAE), which governs the substitutability of labour across sectors. This adjustment introduces frictions that better reflect real-world labour market segmentation and limits unrealistic reallocation of rural labour into unrelated sectors. This approach is consistent with recent CGE modelling practices (Countryman & McDonnell, 2025 - https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf
). A comprehensive description of the new aggregation and labour market assumptions is provided in the Supplementary Information (SI, section A.1 and Figure A.2).

40 The GTAP model assumes a constant elasticity of substitution (CES) production function. The elasticity of substitution is capturing how easy it is to substitute an input for the other. For example, on a dairy farm, …
Comment: This way of explaining is illustrative but not correct there are no production processes for cattle in the model (like grazing or stable feeding) represented in the CGE model, there are no number of workers represented in the model, only pay-slips in the CGE model. There is a pay-off between making it easy and illustrative to understand for the reader and to create a wrong impression of the CGE model.

We agree that our original discussion of the CES production function may have unintentionally oversimplified the model's structure and created the impression that GTAP includes detailed production processes or labour headcounts, which it does not. Our intention was to provide an intuitive explanation for a broader audience, but we recognize the importance of maintaining technical accuracy. In response, we have revised the description in Section A.1 of the Supplementary Information and in the main text (Section Methods, page 10, line 198-200) to more accurately reflect the role of the CES production function in the GTAP model. The updated text now reads:

"A CES production function describes how a firm combines inputs like capital and labor to produce output, allowing for a constant degree of substitutability between those inputs. The CES function allows you to control the ease of substituting one input for another by adjusting

a single parameter. This makes it useful for modelling economies where inputs aren't perfectly interchangeable."

65 "The GTAP model also separately represents countries interconnected by trade, to account for the global economy. Apart from the USA, we analyse Canada, Mexico, and Australia because they are the US's biggest trading partners for dairy products3 and beef4. All other countries are aggregated into 'Rest of the World'.
Comment: wouldn't it have been useul to destangle the RoW a bit more? What is with China, Brazil, India and Europe, as particarily these regions could change their trade relations of dairy/bbef products. If we want to see the trade related impacts, we would give the model a changes to switch trade to other partners.

We agree that disaggregating the 'Rest of the World' category is important for capturing potential trade reallocation effects, particularly involving major global players such as China, Brazil, India, and the European Union. Our initial regional disaggregation focused on the U.S.'s immediate neighbours (Canada, Mexico, and Australia) based on USDA trade data (https://www.fas.usda.gov/data/commodities/dairy-products), highlighting their strong bilateral trade in dairy and beef. However, we recognize that this approach may have limited the model's ability to simulate broader trade diversion effects. In response, we have expanded the regional disaggregation to include 10 countries and regions, now explicitly incorporating China, the EU, Brazil, and India. This allows the model to better simulate shifts in trade flows and substitution patterns in response to U.S. supply shocks. A detailed description of the updated regional structure is provided in Section Methods (Page 12, line 242-247).

68 From all components, the model derives an equilibrium where all demand equals all supply,…
76 ….. workers can seek employment in other sectors, up to a degree. The GTAP model considers this interconnectedness.
Comment: please be more precise to what extend the GTAP model considers these interconnectedness. Only some elements described here, are represented in the GTAP model. Testing time for dairy famers are not considered explicitly in the GTAP model, but a reader not familiar with the model could have the impression.

We thank the reviewer for this important clarification. We agree that our original wording may have unintentionally implied that the GTAP model explicitly represents micro-level interventions such as testing protocols or mask-wearing. This is not the case. The GTAP model operates at a macroeconomic level and does not include detailed representations of production processes, health interventions, or individual labour units. Instead, it uses representative agents and value flows derived from Social Accounting Matrices (SAMs).

Our approach is scenario-based: we draw on insights from past outbreaks and relevant literature to construct plausible macroeconomic shocks such as reductions in productivity, changes in trade flows, or shifts in consumer demand, which are then implemented within the GTAP framework. This allows us to assess the broader economic implications of such shocks without modelling the interventions themselves. We have revised the manuscript to clarify this distinction and avoid any potential confusion by expanding the Methods section more thoroughly (Page 11 & 12). A more accurate explanation is also now included in the main text and in Supplementary Information Section A.1 & A.2, and the literature supporting this approach is reviewed in Section C.2.

84 We project the economic impacts of three hypothetical scenarios, i
Comment: consider replacing the term "project" by "we simulate". Non CGE model experts, might not know that a CGE model cannot be used to do projections or forecaststst, and this is a often occurring confusion, that readers expect a CGE model to provide projections. The baseyear of GTAP11 are (if I am not mistaken) the years 2015-2017. So the baseyear represents another ecoconomic situation, than it was in 2009 or in

Thank you for the careful reading. We have corrected the occurrences of the word "project" in both the main text and the supplementary information. The revised wording now uses "estimates."

238 Suppl B Economic shocks
Comment: it would be interesting to know more how the model was technically shocked, which should be only an additional column to the table, e.g., where scales or elasticity parameters were shocked and maybe be how much? This information would allow other modellers to repeat the exercise for other studies.

We have now provided more technical detail on how the model was shocked (summarised in an expanded Table 2). This addition allows readers to clearly understand how each scenario was operationalized within the GTAP framework. To further support reproducibility, we have made available detailed replication materials on our GitHub repository.

253 Table A4: Assumed short-to-medium term shocks of H5N1 on the US dairy and cattle beef sectors
Comment: The decrease of input productivity by 1%, 5% and 10% is indicated as "Authors estimation". How were these decreases estimated? While, the other scenario parameters are empirically funded and based on historical data. the change of factor productivity seem to be defined ad-hoc. As productivity shocks are very effective on scenarios, here more explanations would be good, based on which assumptions the authors assume productivity decreases by 1%, 5% and 10%. If kept as ad-hoc, a sensitivity analysis would be helpful to show at what point of change the variation of the input factors will change the overall results.

A full sensitivity analysis has been added for both the shocks and parameters. We explore a ±25% variation around our baseline shock values and define an uncertainty range for our results based on twice the standard errors. This approach follows the methodology adopted in the GTAP literature (Arndt, Channing & Pearson, Ken, 1998 - https://www.gtap.agecon.purdue.edu/uploads/resources/download/1209.pdf). Results are display in SI Appendix E with tables and different plots.

317 At the same time, skilled and unskilled labour become cheaper as they produce less.
Comment: how is unemployment covered in the model. Probably in GTAP model the full employment assumption is used. However, is this realistic in the farming sector in the USA, especially in crisis times? Would workers employed in the dairy sector be fired and aren't the workers from the agricultural sector less easily absorpt by other sectors (e.g., technical or service sectors)?

We agree that the full employment assumption in the standard GTAP model limits its ability to capture labour market disruptions, particularly in crisis contexts such as the agricultural sector during an H5N1 outbreak. To partially address this limitation, we implemented a model closure in which real wages are fixed, and employment adjusts endogenously. This allows the model to simulate changes in employment levels rather than assuming perfect

wage flexibility. While this does not fully capture unemployment, it provides a more realistic approximation of labour market stress in the short to medium term. The resulting employment changes are reported in Supplementary Information Section D. This approach is consistent with CGE modelling practices that aim to approximate labour market frictions without explicitly modelling unemployment (Burfisher, 2021 - https://doi.org/10.1017/9781108780063
).

328 Demand shocks are implemented through taxation on different goods to capture a certain lowering
329 of total demand and a preference shift.
Comment: I am wondering if the simulation of demand shocks is legitimate to be done by modifying the taxes. As policy instruments, taxes are used to steer the market (supply and demand). Varying the taxes to simulate a decrease in demand caused by customer preferences might technically work but does not seem to be plausible. Maybe in GTAP application, it is legitimate to vary taxes to simulate demand shocks. The meaning applying "taxation on different goods". First, which are these goods, and doesn't this create a multiple commodity shock, which is moving the model from a multiple angel, which should not be changed, as the commodities (and their markets) should react to the sector specific shocks. Furthermore, what happens with the tax income of the taxes of the "different goods"? If multiple commodities, could a change in tax income be expected. Making the government richer or poorer?

We agree that using taxes to simulate demand-side shocks, particularly those driven by changes in consumer preferences, requires careful justification. In CGE modelling, it is common to use taxes or subsidies as proxies for demand shifts (OECD, 2020 - https://doi.org/10.1787/f6a9ef88-en.; Maliszewska et al., 2020 - https://ssrn.com/abstract=3573211). This approach allows us to simulate a reduction in demand for specific goods (e.g., dairy and beef) in a controlled and quantifiable way (de Menezes et al., 2024 - 10.22004/ag.econ.342181). Regarding the fiscal implications, the additional tax revenue is reflected in the government budget and subsequently affects the income of the global household. This fiscal feedback mechanism may partially offset the negative income effects of the H5N1 shock, thereby influencing the overall results however this effect is small. To address concerns about economic plausibility, we have conducted a sensitivity analysis on key elasticities to directly capture changes in individual behaviour (SI, Section E.2).

341 outbreak in their own dairy and beef industries. We assume that some countries ban the import of US agricultural products, but even without these mandates, US dairy products and cattle are less
Comment: how is the import ban of the US agricultural products modelled in the GTAP model, and which countries are these explicitly? Is the "ad valorem tax" used to reduce the import demand by other countries?

We thank the reviewer for this important question regarding the modelling of the U.S. agricultural export ban and the countries involved. In the revised version of the model, we simulate the export ban by endogenizing the export tax rate. This allows the model to determine the level of taxation required to reduce export quantities to a specified target, rather than imposing a fixed ad valorem tax. This approach provides a more flexible and accurate representation of trade restrictions and is consistent with standard CGE modelling practices.

361 demand for all non-agricultural imported goods, benefiting in turn US manufacturing

sectors. In GTAP, the Armington elasticities play an important role in this phenomenon by representing the substitution rate between imported and domestic goods.
Comment: shouldn't it be the Armington elasticity be varied to simulate demand shocks turning it from the consumption of local to the consumption of imported commodities?

The Armington elasticities play a key role in determining how easily consumers and producers can shift between local and foreign products in response to price or policy changes. While we agree that modifying Armington elasticities could be a useful way to simulate demand shocks, we chose not to alter them in the core scenarios due to the high degree of uncertainty surrounding their appropriate values in the context of an H5N1 outbreak. There is currently limited empirical guidance in the literature to support specific adjustments. Instead, we conducted a sensitivity analysis in which we varied the Armington elasticities by ±25% around their GTAP baseline values. This approach allows us to assess the robustness of our results without introducing speculative assumptions. The analysis, presented in Section E.2 of the Supplementary Information, shows that the impact of these variations is minimal in Scenarios 1 and 2, but becomes more noticeable in Scenario 3, where trade disruptions are more substantial.

360 For the key trading partners, this boost in economic activity and income increases their consumers'demand for all non-agricultural imported goods, benefiting in turn US manufacturing sectors.
Comment: This seemed to be a plausible model reaction, in a CGE model if labour can migrate from agricultural to non-agricultural sectors. However, how much would we expect such a reaction in reality? A crisis for the agricultural sector, helps boosting the non-agriucltural sectors, or wouldn't the contraction of the agricultural sector negatively influence the downstream sectors and the input providiers?

We agree that the extent to which a crisis in the agricultural sector could generate positive spillovers in non-agricultural sectors depends critically on labour mobility and the structure of intersectoral linkages. In the standard GTAP framework, labour is assumed to be mobile across sectors, which can lead to optimistic reallocation effects. To better reflect real-world frictions such as skill mismatches and geographic immobility, we reduced the elasticity of transformation (ETRAE), which governs the substitutability of input across sectors. This adjustment introduces more realistic constraints on labour mobility, particularly in the short to medium term, and is consistent with recent modelling practices (Countryman & McDonnell, 2025 -https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf

). Even with reduced labour mobility, the model still shows modest gains in non-agricultural sectors, primarily due to improved terms of trade and increased demand from key trading partners. In Scenario 3, for example, the net gain in trade is approximately 0.75%.

We do acknowledge that the contraction of the agricultural sector negatively affects upstream and downstream industries, such as input suppliers and food processors. However, the two opposite effects can be non-exclusive. Indeed, it is important to consider the structural composition of the U.S. economy. Manufacturing and services account for a large share of GDP, so even small relative changes in these sectors can outweigh larger percentage changes in smaller sectors like agriculture and related industries. This helps explain the aggregate results observed in the model.

369 Table A5: Aggregate economic impacts of H5N1 for the USA, Canada, Australia and Mexico
Comment: What does the "" indicate in the table?*

$ value

396 Table A6: Projected impact on output prices … and Tables A7 to A10
Comment: Consider replacing the word "projected" by "simulated". A CGE model simulation is not a projection or forecast.
Furthermore "% reduction compared to pre-H5N1 situation" isn't "change/variation" meant here? Or what do the negative and positive percentages in the table mean?
How do we need to interprete figure >100 in the table, for example in Table A7 cell: (S3 Raw milk: Canada) = 1150%. Is here a change from a net importer to a net-exporter the reason for this enormous increase? Can this figure be interpreted?

Indeed, the observed increases are very large, and the main contributing factors to this outcome are the following: first, domestic US demand shifts toward international goods, and the relative size of the U.S. economy compared to Canada amplifies the effect; second, the initial value of exported agricultural quantities is small, so any changes have a large percentage impact. These two factors help explain the pronounced reaction observed for Canada.
We also want to underline that our updated results are less extreme than in the previous version, although the effects remain substantial. Finally, we redirect the reviewer to the previous discussion, on the size of exported quantities relative to the size of the output quantities produced by the industry showing that the overall adjustment is quite small and remains inside production capacities. This concern is now briefly discussed in the main text (Results, Page 8, lines 104-110).

408 Table A9:
Comment: in S3 in the USA the employment for unskilled labour in the Dairy sector decreases by 24.8% and it increases in the Raw milk sector by 54.2%, which looks like that workers fired from the dairy sector move to the raw milk sector. How can this be explained in reality? If the dairy sector contracts, the raw milk sector should contract, too. Hiring more labour in the contracting raw milk sector seems not plausible, also because this sector is probably highly capital intensive (machines for milk processing) and these machines might not be used at their capacity limits, if milk supply is reduced. So there is no need for more workers on the machines.

We agree that the increase in employment in the raw milk sector, despite a contraction in dairy processing, appears counterintuitive and needs clarification. In our model, this outcome is driven by a Hicks-neutral productivity shock applied to the raw milk sector, which reduces the efficiency of all inputs. As a result, firms increase labour demand to maintain output levels. However, we acknowledge that this mechanism may not fully reflect real-world dynamics, particularly in capital-intensive sectors like milk production, where underutilized machinery and fixed input-output relationships may limit the need for additional labour. It is also important to note that the raw milk sector is relatively small in employment terms, so even modest absolute increases in labour can result in large percentage changes. This helps explain the 54.2% increase, which may overstate the real-world significance of the shift. To address concerns about unrealistic labour reallocation, we have reduced the elasticity of transformation (ETRAE), which limits the substitutability of input across sectors. This adjustment introduces frictions that better reflect real-world labour market constraints. A detailed discussion of these changes is provided in Sections A.1 and D of the Supplementary Information.

Bibliography

Arndt, C., & Pearson, K. R. (1998). How to carry out systematic sensitivity analysis via Gaussian quadrature and GEMPACK. *GTAP technical paper*, (3). https://www.gtap.agecon.purdue.edu/uploads/resources/download/1209.pdf

Arriola, C., P. Kowalski and F. van Tongeren (2022), "Understanding structural effects of COVID-19 on the global economy: First steps", *OECD Trade Policy Papers*, No. 261, OECD Publishing, Paris, https://doi.org/10.1787/f6a9ef88-en.

Attavanich, W., McCarl, B. A., & Bessler, D. (2011). The effect of H1N1 (swine flu) media coverage on agricultural commodity markets. *Applied Economic Perspectives and Policy*, *33*(2), 241-259. https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2024.1338677/full

Beutels, P., Edmunds, W. J., & Smith, R. D. (2008). Partially wrong? Partial equilibrium and the economic analysis of public health emergencies of international concern. *Health Economics*, *17*(11), 1317-1322. https://doi.org/10.1002/hec.1339

Burfisher, M. E. (2021). *Introduction to Computable General Equilibrium Models* (3rd ed.). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108780063

Countryman, A. M., & McDonnell, A. (2025). *Modelling the Global Economic Impact of Antimicrobial Resistance in Humans* (No. 713). https://www.cgdev.org/sites/default/files/modelling-global-economic-impact-antimicrobial-resistance-humans.pdf

Maliszewska, Maryla and Mattoo, Aaditya and van der Mensbrugghe, Dominique, The Potential Impact of COVID-19 on GDP and Trade: A Preliminary Assessment (April 10, 2020). World Bank Policy Research Working Paper No. 9211, Available at SSRN: https://ssrn.com/abstract=3573211

McDonald, S., & Roberts, D. (1998). The economy-wide effects of the BSE crisis: A CGE analysis. *Journal of Agricultural Economics*, *49*(3), 458-471 https://doi.org/10.1111/j.1477-9552.1998.tb01285.x

Philippidis G, Hubbard L. A Dynamic Computable General Equilibrium Treatment of the Ban on UK Beef Exports: A Note. J Agric Econ. 2005;56(2):307–312. https://doi.org/10.1111/j.1477-9552.2005.00006.x

USDA Data: https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/ag-and-food-sectors-and-the-economy

Rawson, T., Morgenstern, C., Knock, E.S. *et al.* A mathematical model of H5N1 influenza transmission in US dairy cattle. *Nat Commun* **16**, 4308 (2025). https://doi.org/10.1038/s41467-025-59554-z

Reviewer #1 (Remarks to the Author):

Reviewer's comments on COMMSENV-25-3087-T

General Comment

The paper "The Impact of Highly Pathogenic Avian Influenza H5N1 on US Domestic and International Dairy and Beef Markets" examines the effects of H5N1 on the US economy and its trading partners using a global CGE trade model. The topic is potentially valuable for the journal's readership.

However, some results and their explanations raise concerns that are closely tied to the CGE model's methodological framework. I recommend that the authors (i) clearly acknowledge the limitations, (ii) avoid overemphasising potentially misleading findings, and (iii) ensure accessibility for both technical and non-technical audiences. The paper should strike a balance between transparency about model caveats (for modellers and economist) and a careful presentation of results that avoids confusion (for non-economists).

The comparison in Lines 140–146 with past real-world impacts supports the plausibility of the overall results.

Response to Reviewer's comment

We thank the reviewer for the constructive suggestions. To address the feedback, we have added a paragraph to the discussion section of the main text (line 144ff), and extended the discussion of limitations (line 174ff). Specifically, we now discuss the risks of sectoral aggregation bias, clarify the treatment of capital and production factors mobility, and reframe the trade results as plausible but largely model-dependent mechanisms. To improve accessibility for non-technical audiences, we contextualize job figures with US employment data, explaining compensation vs output effects in labor markets. We believe that these revisions strengthen transparency for technical readers while ensuring a careful and accessible presentation for non-economists. We address the comments in detail below.

Major Comment 1: Sectoral Disaggregation

- *The model disaggregates seven agricultural and food sectors (≈2% of US GDP), one manufacturing sector (<16%), and an aggregated "other sectors" category (≈79%). Shocks target the small agri-food sectors, and results focus on these, but translating their changes to the rest of the economy is challenging.*
  This aggregation may be justifiable given the weak links between major US sectors (services, health, trade, etc.) and agri-food, but it risks overstating indirect effects. The authors should note this in the discussion and explain how interactions between agri-food and the aggregated sectors should be interpreted.

Answer: We agree with the reviewer that the GTAP database aggregation and inter-sectoral linkage are complex matters. We chose this aggregation because it provides a sufficient level of detail for the agricultural sectors that are the main focus of the study, while allowing non-agricultural sectors to adjust. We acknowledge the potential risk of aggregation bias and have now addressed this in the discussion section (see line 186 of the main text) as well as in the supplementary information (SI – page 5, section A.1). However, our results are broadly consistent with the relevant existing literature, as noted by the reviewer. In terms of interaction between sectors (agricultural vs non-agricultural), we identify two main direct pathways and one more indirect pathway through which the food sectors can impact the non-food sectors:

1. Household budget substitution effect, captured through income elasticity (INCPAR) and substitution elasticity (SUBPAR).
2. Production-side adjustments, specifically changes in prices and quantities of production factors, can affect certain nested production functions in the food sectors, leading to factor reallocation that may influence our results.
3. Indirect trade effects, adjustment in the terms of trade and output costs, which can indirectly impact non-food sectors.

The consequences of these effects are relatively small compared to the sectoral impact of H5N1 on agricultural sectors, very rarely crossing 2% even in the reasonable worst-case scenario S3 (Table D.5 to D.9). We now provide a detailed explanation on page 5, section A.1 of the Supplementary Information.

Major Comment 2: Production Factors

- *I could not find information on the treatment of the production factor capital. It is unclear whether capital demand is fixed by sector or mobile between sectors. Looking at the results, and without further information, I would conclude that capital is the production factor most likely to be reallocated. For example, Table D.9 shows a 0.03% decrease in manufacturing employment, while Table D.7 shows a 0.03% increase in manufacturing output and Table D.5 shows a 0.01% decrease in manufacturing prices—allowing trade to increase by 0.1% (Table D.6).*

  At present, I see three possible explanations:

  (i) reallocation of labour types other than unskilled labour (unlikely),

  (ii) reallocation of capital, or

  (iii) an increase in total factor productivity (unlikely)

  Of these, I consider the reallocation of capital the most likely. If capital is being reallocated from agri-food sectors to manufacturing and other sectors, the assumptions behind this should be explained. In particular, in a short-term scenario, such reallocation may require strong assumptions.

It would be helpful if the authors clarified how the production factor capital is modelled and how capital behaves in the scenarios.

Answer: We agree with the reviewer that we could improve the explanation of the underlying assumptions. To clarify, in the GTAP model, all factors of production can, in principle, be reallocated. However, this reallocation is highly constrained because we specify the transformation elasticities for production factors (ETRAE), which determine how easily a sluggish factor can move from one sector to another. Importantly, there is no increase in TFP as it is treated as exogenous. Consequently, only the first two adjustment mechanisms are observable, and even then, at a very low rate due to the short- to medium-term time horizon of the analysis.

We directly shock the productivity of non-skilled workers, as they represent a substantial share of the agricultural sector's total workforce according to Aguiar et al. (2022) (page 9 - https://jgea.org/ojs/index.php/jgea/article/view/181/221). However, this does not preclude the possibility of other factors adjusting in response to the shock. We include this explanation in the Supplementary Information (Section A.2, Page 6) and briefly mention it in the main text (line 241) in the Methods section.

Major Comment 3: Trade

- *Lines 100–103 report that US non-agri-food sectors gain competitiveness and increase exports following an agri-food shock. This finding may depend heavily on unclear factor reallocation assumptions and could be counterintuitive, potentially creating doubt.*
  Given the acknowledged limitations in trade representation (Lines 159–161), I recommend reframing this as a modelling artefact or caveat, rather than a main finding.

Answer: We agree that these results may appear too strong and somewhat counterintuitive. Our simulations suggest an improvement in the terms of trade: when agricultural and food exports contract, relative price adjustments within the trade bloc led to higher export prices compared to imports (ToT=P_x/P_i). This mechanism can help explain why non-agri-food sectors appear more competitive. Specifically, as agricultural goods lose competitiveness, the cost reallocation channel becomes active: production factors are reallocated, reducing production costs and then lowering prices, which improves competitiveness (see Table D.5 in SI).

However, we acknowledge that this effect is largely driven by the modelling assumptions, particularly on trade elasticities (Armington elasticities) and factors reallocation mechanism (nested production function, ETRAE) so that its magnitude may be overstated. Following your suggestion, we present this outcome as plausible but potentially model-driven and add further discussion to highlight its limitation (main text – discussion line 178-184). The supplementary information has also been updated in response to the referee's comments (page 11 and 12).

Detailed comments (partially repeating the general comments)

- *Line 46-47 : Comment: As done for the GDP, it could be useful to also inform about the relative share of total jobs. What is the importance of 3 M jobs, compared to the total employment in the US? The same for the wages. Since agriculture, cattle, dairy, food processing are capital intensive, the employment should not be too high. If the share of jobs of total number of jobs and wages appears too small, the authors could consider how to sell this. E,g, can it be still an argument because these jobs are mainly focused in rural regions (so meaning farmers on the country side would suffer negative impacts). And should the employment serve as selling point for the study at all? For real life understanding one would see these jobs jeopardized by the shocks. However, in the model results, the agri-food employment partially even benefits from the shocks.*

Answer:

We thank the reviewer for this comment. To provide context, 3 million jobs represent about 1.88% of total U.S. employment (3/159,539 – see https://fred.stlouisfed.org/series/PAYEMS), and this figure only accounts for jobs in the dairy sector. However, agriculture and its related industries contribute approximately 10.4% of U.S. employment, according to a USDA report (https://ers.usda.gov/sites/default/files/_laserfiche/publications/108461/AP-121.pdf?v=65301). This suggests that the entire food supply chain could be affected, with broader implications for the U.S. labor market as our analysis is not limited to dairy. We have added this clarification to the introduction of the main text (line 47).

We agree that the employment results (and production factors more broadly) may appear counterintuitive and require clearer explanation in both the main text and the SI. We have now expanded the discussion in the limitations section of the main text (line 174-178 – section discussion) and provided a detailed explanation in the SI (Page 11). In summary, two mechanisms are at play:

1. Compensation effect, as more labor is employed to compensate for the decrease in productivity;
2. Output effect, as reduced output lowers labor demand.

In our case, the first effect often dominates, leading to an increase in labor in the shocked sectors. We recognize that the outcome may seem counterintuitive, which is why we have explicitly explained the underlying mechanism in the main text (line 92-93) and the SI (page 11).

- *Line 59: delete « (552 words »)*

Answer: Thanks for the careful reading this has been removed.

- *Line 72-73: Check: "0.06% (95% high density 73 interval: -0.06% to -0.06%) of real GDP (Scenario S1, Fig. 1B)." the lower and upper bound of the interval are the same at -0.06%*

Answer: This is due to rounding, there is actually a very small difference between the two values, but when rounded to two digits after the decimal point, they appear to be the same value.

- *Line 75: "Price shocks are highest for raw milk (5.58%) and dairy products (5.25%)," Comment: maybe indicate more clearly that 5.58% is the increase of raw milk price and 5.25% represents the production price increase of dairy products.*

Answer: We have slightly revised the sentence framing (line 76) as follows: *"We observe a 5.58% increase in the production price of raw milk and a 5.25% increase for dairy products"*

- *Line 78: "the economic loss to the USA is greater at 0.28%" Question: this refers to the loss of the whole economy or only to the dairy sector?* And *Line 79: "for the realistic scenario S2, and 0.91%" Question: this refers to the loss of the whole economy or only to the dairy sector?*

Answer: This refers to total economic loss. We now have added the word "total" line 79 to clarify for the reader. We also added sectoral line 81 to make it clearer.

- *Line 79-80: "with the output losses in the dairy sector estimated at 9.32% (-11.61% to -7.05%) and 20.6% (-25.06% to -16.42%), respectively." Question: this refers to the loss of the dairy sector?*

Answer: Yes, this refers to sectoral economic loss. We rephrase it to make it clearer (line 81).

- *Line 94: "0.05% (-0.05% to -0.05%, S1), » Comment: upper bound of interval = lower bound*

Answer: Thank you for your comment. This is due to rounding, there is actually a very small difference between the two values, but when rounded to two digits after the decimal point, they appear as the same value.

- *Line 122: "by $53.656 (-59.204 to -48.300) » Comment: dollar sign missing in the brackets*

Answer: Thanks for the careful reading. It is now corrected.

- *Line 159-162: "Third, some of the simulated export increases may appear significant in terms of percentage change; however, the quantities produced at the sectoral level remain within realistic adjustment ranges. In other words, while trade is increasing significantly, this increase can be accommodated by the sectors because it represents a relatively small share of total production." Comment: It somehow looks like that the results on trade described before are not interpretable.*

Answer: Thank you for the comment. With this sentence, we aim to convey that these results should be interpreted with caution as they may appear very large. However, they are unlikely to have a significant economic impact at the overall level due to the low initial value. We have now expanded our explanation to clarify this point, as we believe it is important (see line 178-184 in main text - discussion).

- *Lines 100-103: "The modified terms-of-trade make the US economy more competitive internationally in non-agricultural goods and services, resulting in an increase of exports. This effect can compensate for the decrease in exports of directly affected agricultural products, resulting in an overall increase in US exports of 0.01% (0.01% to 0.01%), 0.11% (0.09% 103 to 0.13%), and 0.75% (0.59% to 0.95%), respectively."*
  Comment: see major comment 3

Answer: See answer to major comment 3. Further details have been provided starting line 178 of main text and SI, pages 11-12.

- *Appendix page 5, Figure A.2: Sectors contribution to total Output Quantities (QO) shows the shares of output:*
  Other sectors 79%
  Manufacturing 16.4%
  Processed food 2.03%
  Grains, crops, meats, dairy cattle, raw milk: each < 1% adding up to approximately 2%.
  Comment: The authors might think about reflecting the fact that the agri-food sectors are very small compared to the two aggregates "manufacturing" and "Other sectors" and explaining the potential problems and limitations associated with it (see major comment 1).

Answer: We now address this issue in the Supplementary Information, on page 5 section A.1.

- *Appendix page 11: "This productivity shock increases the amount of labor required to maintain the same level of output. Since real wages are assumed to be fixed, the cost of employing additional workers does not rise, encouraging firms in these sectors to demand more labor to compensate for the productivity loss. However, the shock has also a negative impact on the rest of the economy's employment levels. This decrease in productivity has negative spillover effects on the overall labour market conditions affecting both US household incomes and consumption of all goods and services in the USA.*
  Our findings suggest that aggregating all these impacts, consumption of goods and services overall decreases by 0.05% in the current situation, and 0.21% and 0.86% in S2 and S3. Lowered household incomes also reduce saving capacity, resulting in a reduction in sectoral investments in the USA, which is strongest in the dairy industry. Overall, investments into all sectors decrease by 0.04%, 0.19% and 0.67% across the scenarios."
  Question: does this mean, that the increase of the 3 million jobs (which maybe account for 2% of all jobs) impact the rest of the US labour market? This would be a very strong spill-over effect, which probably would not appear in reality. Especially, if most of the jobs are in service sectors.

Answer: The GTAP labor market follows standard neoclassical assumptions, meaning it is highly reactive and adjusts rapidly. As emphasized in the paper, we introduce more realistic features into the model to account for this limitation. Acknowledging these constraints, we primarily discuss employment at the sectoral level and rather than making it a central focus of the paper.

Our results show the following employment changes: -0.09% (S1), -0.39% (S2), and -1.24% (S3). These are reasonable values when considering the full supply chain which accounts for 10.4% of total US employment according to USDA figures. This corresponds to a loss of approximately 600,000 jobs in Scenario 2, and around 2.1 million in the worst case. While some jobs are preserved by the compensation effect of productivity loss (as previously described), the overall macroeconomic trend is a decline in total employment.

Regarding spillover effects across sectors, Table D.8 in the SI shows that most sectors experience a negative impact, with the exception of a few agricultural sectors facing large productivity declines. The same Table indicates that the spillover effect remains limited as "other sectors" experience only a 1.44% reduction in unskilled worker supply. (See SI, page 11)

- *Appendix page 11:*

"Trade shifts occur indirectly in S1 and directly in S2 and S3, where a percentage reduction of traded quantities is implemented. Following the outbreak, the U.S. experiences an increase in the global export volume and value. This increase is driven

by two main factors, first, the decrease in the price of U.S.-manufactured goods caused by the agricultural slowdown and the reallocation of domestic factors rendering US manufacturing more competitive. Second, U.S. trading partners agricultural sectors benefit from an increase in demand by US consumers for agricultural imports. They make up for the reduction in US dairy production, both to satisfy demand in their own domestic markets, and in other countries including the USA itself.“ Question: I understand that there is an increase in US exports, but find it difficult to bring align with the statement “Second, U.S. trading partners agricultural sectors benefit from an increase in demand by US consumers for agricultural imports.” Isn’t this referring to increasing imports? How these increasing imports can increase the exports? I am probably missing the link.

Answer:

We agree with the reviewer that the original wording may have been confusing and have revised the section for clarity. As detailed on page 12 of the SI, the text now more clearly distinguishes between the two distinct effects. The first is the internal reallocation of domestic factors, which enhances U.S. manufacturing competitiveness. The second is an income feedback effect, where trading partners, benefiting from increased U.S. import demand, experience increased economic activity that in turn boosts their own demand for U.S. goods. These clarifications are now fully incorporated into the SI page 12.

Reviewer #3 (Remarks to the Author):

Thank you for addressing the feedback. I have two final comments:

1) "Here, a Computable General Equilibrium model is used to assess the short-to-medium term macro-economic impact...": I recommend rephrasing this as "is used to simulate..." to better reflect the nature of the modelling approach. Please also ensure consistency throughout the manuscript in stating that the model simulates outcomes.

Answer: Thanks for this comment, we do agree that this makes things clearer. All occurrences of “assess” have been removed and replaced by “simulate”.

2) To what extent do the projected short-term effects align with real-world observations so far? If relevant reports or data are already available, please include a brief discussion on how well the simulated outcomes correspond to the observed economic impacts.

Answer: Given the time since the initial submission, we now have additional data. Unfortunately, it is questionable whether reporting is reliable under the current administration. As of July 7, the CDC has changed from weekly reporting to monthly. The USDA reported zero new cases for the past 30 days on September 5 (https://www.aphis.usda.gov/livestock-poultry-disease/avian/avian-influenza/hpai-

detections/hpai-confirmed-cases-livestock). This is unlikely to be true given available research evidence on projected spread amongst cattle [4]. We have added a section in the discussion comparing our results with last available USDA reports and a New York Times article addressing the H5N1 outbreak.

We have added the following to the discussion (lines 144-157):

“According to [24], U.S. milk production declined by approximately 8.5% between March 2024 and February 2025, falling from 18,800 to 17,200 million pounds. This outcome is broadly consistent with our simulation, which projects short- to medium-term output losses in the dairy sector ranging from 3.4% under the current situation (S1) to 9.3% under the realistic scenario (S2). However, this pattern does not hold for scenario S3, as milk production began to recover from February 2025 onward.

Several factors may explain this difference. First, we know now that cows exhibit a relatively long immunity period [25], making re-infection over our projection horizon unlikely. Moreover, recent evidence suggests that states with large dairy sectors have passed the peak of their epidemics by early 2025 [4]. This implies that the outbreak subsided more quickly than anticipated, allowing many animals to recover and boosting production. Second, reports suggest that the new U.S. administration adopts a laissez-faire approach towards the H5N1 outbreak and implements drastic cost-cutting measures in public health, resulting in a reduction in the federal workforce controlling the outbreak [26]. The likely reduction in surveillance, biosecurity measures and sub-optimal data collection likely result in a smaller shock to production costs compared to our assumption. Finally, sparse government communication on the outbreak likely leads to lower attention in the U.S. media, thereby reducing the adverse shift in consumer behaviour compared to our assumed shock [26].“