Conference paper

Enhancing Livestock Sector Simulation: Synergizing Dynmod and Multimarket Models with Female Sexed Artificial Insemination as a Policy Scenario

4 August 2024

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CGIAR
INITIATIVE ON
Sustainable Animal Productivity

Citation: Maruta, A.A., Bahta, S.T., Enahoro, D.K. and Baltenweck, I. 2024. *Enhancing Livestock Sector Simulation: Synergizing Dynmod and Multimarket Models with Female Sexed Artificial Insemination as a Policy Scenario.* Conferences paper presented at ICAE, New Delhi, India, 4 August 2024. Nairobi, Kenya: International Livestock Research Institute.

Acknowledgments
This work was conducted as part of the CGIAR Initiative on Sustainable Animal Productivity for Livelihoods, Nutrition and Gender inclusion (SAPLING). CGIAR research is supported by contributions to the CGIAR Trust Fund. CGIAR is a global research partnership for a food-secure future dedicated to transforming food, land, and water systems in a climate crisis.

Abstract

This study investigates the synergistic integration of two widely utilized economic models—Dynmod and the multi-market partial equilibrium model, SectorM—in the context of Tanzania's livestock sector. While Dynmod specializes in capturing detailed herd dynamics, SectorM excels in modeling economic factors such as supply, demand, and prices. Leveraging the complementary strengths of these models, the research employs the General Algebraic Modeling System (GAMS) software to establish a linkage between Dynmod and SectorM, thereby creating a more comprehensive and dynamic simulation framework for Tanzania's livestock sector.

As a critical test of the linkage, the study introduces a reproductive shock through Female-Sexed Artificial Insemination (FSAI), a proven tool for advancing genetic progress and enhancing herd management. FSAI emerges as a strategic intervention, increasing the proportion of female cattle in herds, which indirectly impacts meat supply by reducing the number of offtake animals in the short term. The results from the linked models reveal intuitive outcomes, including a short-term decrease in meat production due to reduced offtake and a subsequent supply shock in SectorM, leading to changes in meat prices and farmers' incomes. These findings underscore the value of model integration in capturing the complex interplay between biological and economic factors, offering actionable insights for policy interventions aimed at enhancing livestock productivity and improving the socioeconomic well-being of Tanzanian farmers. This research contributes significantly to livestock sector modeling and highlights FSAI's potential as a transformative policy tool for sustainable meat production.

Keywords: Modeling, Dynmod, Partial Equilibrium Model, Livestock Sector, Tanzania

I. Introduction

The livestock sector is vital to many economies, contributing significantly to food security, livelihoods, and economic growth (World Bank, 2021). In the field of economic modeling for the livestock sector, two prominent models have been widely utilized: the herd dynamic model, Dynmod, and the multi-market partial equilibrium model, SectorM (proposed by Bahta et al., 2021). Each model offers distinct strengths and faces specific limitations, presenting an opportunity for synergistic integration to overcome these challenges and improve the overall simulation framework.

Dynmod, a well-established model, excels in capturing intricate herd dynamics over time. It effectively represents factors such as parturition rate, offtake rate, mortality rate, age, sex, size, and various other demographic attributes of the livestock sector (Lesnoff, 2008). Additionally, Dynmod calculates and simulates economic variables, including income generated from various livestock products such as meat, milk, hides and skins, manure, draught power, and eggs.

However, it operates under the assumption of constant prices for livestock products, which are exogenously determined (i.e., without accounting for interactions between demand and supply within the model) over the simulation period. For instance, if the simulation period spans 20 years, Dynmod assumes constant prices for livestock products—a stark contrast to real-world scenarios where prices fluctuate significantly. These price variations are influenced by factors such as supply and demand dynamics, changes in feed costs, climatic conditions affecting production, market accessibility and transportation costs, policy changes such as subsidies or taxes, global trade fluctuations, and shifting consumer preferences for specific livestock products (e.g., Zhang et al., 2018). This highly variable pricing environment highlights the limitation of Dynmod’s static price assumption, which hinders its ability to reflect the dynamic economic conditions that characterize the real-world livestock sector.

Conversely, the SectorM model proficiently captures economic dynamics by treating prices and other economic variables as endogenous—determined through the interactions of demand and supply within the model—allowing them to fluctuate over time based on various influencing factors. While SectorM excels in economic intricacies, its representation of herd dynamics and demographic factors is less detailed compared to Dynmod. Specifically, data for livestock products in SectorM are sourced from secondary sources and lack disaggregation by sex and age of the animals, limiting the model's precision in demographic analyses.

Integrating the Dynmod and SectorM models presents a valuable opportunity to address each model's limitations by leveraging the strengths of the other. By linking these models, the exogenously determined constant prices in Dynmod can be replaced with the endogenously determined, variable prices from SectorM, enhancing the economic realism of the simulations. Conversely, the herd dynamic data from Dynmod can supplant the secondary, less detailed livestock data in SectorM, providing a more nuanced representation of herd demographics. This integration would result in a more comprehensive and accurate simulation framework for the livestock sector.

Building upon the complementary strengths of Dynmod and SectorM, this paper aims to integrate these models to create a more comprehensive and realistic simulation of the livestock sector. By combining Dynmod's detailed herd dynamics with SectorM's economic adaptability, we seek to address each model's limitations, thereby enriching simulation results and providing a more accurate depiction of the interplay between herd dynamics and economic factors. This integration is anticipated to yield valuable insights previously unattainable with individual models. To achieve this linkage, we utilize the General Algebraic Modeling System (GAMS) software, facilitating the seamless integration of the two models.

To evaluate the efficiency of the linkage and accuracy of the simulation, we use Tanzania's cattle sub-sector as a case study, selected for its comprehensive and well-collected data from the Tanzania Livestock Master Plan (Michael et al., 2018). To test the linked model's consistency with real-world conditions, we introduce a shock in the Dynmod model related to reproductive dynamics—specifically, female-sexed artificial insemination (FSAI). FSAI is pivotal in increasing the number of female animals in the herd, thereby boosting overall herd size and livestock product output. We focus on its impact on meat production and income from meat in the linked model. Additionally, we compare whether the trends in meat supply align more closely with real-world conditions in the linked model than in the standalone models.

The paper demonstrates that the linked models produce more intuitive results than the standalone models. The introduced FSAI shock in the Dynmod model causes a short-term decrease in the number of offtake animals, as farmers retain more females to boost offspring, leading to reduced meat production. This reduction creates a meat shortage, driving up prices and consequently increasing income from meat, consistent with real-world conditions where shortages result in higher prices and producer incomes, assuming constant demand. In contrast, the standalone models fail to capture these economic relationships effectively.

The remainder of the paper is organized as follows. Section 2 presents a brief literature review offering insights into various approaches employed for modeling linkages between different models. Section 3 provides an overview of the two models, Dynmod and SectorM, highlighting both their commonalities and distinctions. This comparative analysis serves as a foundation for identifying key points for model linkage. In Section 4, the rationale behind the model linkage is provided, delving into the technical implementations of this process. Section 5 presents the pre-linkage and post-linkage results, analyzing the enhanced modeling approach through the application of FSAI as a shock. Finally, Section 6 offers a conclusion.

II. Literature Review

The literature underscores two primary arguments in support of model linking as opposed to integrating models into a singular "super-model." First, it highlights the importance of preserving the unique strengths and comparative advantages of individual model types, particularly regarding resolution, response time, result quality, and implementation efficiency. This approach ensures that each model continues to perform optimally within its specific domain of expertise. Second, it emphasizes the value of maintaining flexibility in methodological and technical frameworks, parameterization, and the utilization of diverse data sources. This adaptability facilitates more robust model development, application, and ongoing maintenance, thereby enhancing the overall utility and scalability of the linked models (Britz, 2008).

The literature identifies two primary approaches to model linking: soft-linking and hard-linking. Wene (1996) characterizes soft-linking as a user-controlled process in which the transfer of information relies on subjective judgment, whereas hard-linking is defined as a more formalized method where information processing and transfer are executed through automated computer programming. Krook-Riekkola et al. (2017) further refine these definitions, describing soft-linking as an iterative interaction between models until convergence and hard-linking as the simultaneous integration of models. This study adopts a hard-linking approach, which is particularly advantageous for global analyses with subordinate regional details. By maintaining the Dynmod and SectorM models at a country-level resolution, this method preserves the essential details of each model, thereby ensuring analytical rigor and consistency (Böhringer and Rutherford, 2008).

Moreover, Delzeit et al. (2020) provide a distinction between one-way and two-way model linkages, emphasizing their structural and functional differences. In a one-way linkage, the outputs of one model serve as exogenous inputs or shocks to another, with the direction of information flow determining whether the approach is top-down or bottom-up. Conversely, a two-way linkage incorporates bidirectional feedback between models, fostering enhanced convergence through iterative interactions. For recursive-dynamic models such as Dynmod and SectorM, a two-way linkage employs an iterative solution process, whereby information is exchanged between models until a predefined convergence threshold is achieved. This study employs a two-way linkage approach, enabling systematic information exchange across simulated time periods to ensure alignment and consistency between Dynmod and SectorM.

III. Overview of the Models

This paper utilizes the recursive-dynamic Dynmod model, developed by Lesnoff (2008), to simulate ruminant livestock populations. Dynmod captures population size, annual animal production, live weights, and by-products such as meat, milk, hides, skins, and manure, while generating financial estimates for economic analysis under fixed price assumptions. The model incorporates herd dynamics driven by births, mortality, offtake, and intake rates, with feed requirements set at 3% of an animal's total live weight.

The SectorM model is a recursive-dynamic, deterministic partial equilibrium model for Tanzania's agricultural sector, employing a mixed complementarity problem (MCP) framework to calculate equilibrium values. Dividing Tanzania into seven regional units, it includes commodities such as maize (also used as animal feed) and bovine meat from smallholder, fattening, and peri-urban systems.

While both Dynmod and SectorM share attributes like a recursive-dynamic nature and one-year projection time steps, they differ significantly in type, objectives, and scope. Dynmod, a growth model, excels in representing production systems, animal age categories, and herd dynamics but adopts a more aggregated approach. SectorM, a partial equilibrium model, calculates prices internally and focuses on regional specificity but lacks explicit herd dynamics. Linking these models leverages their strengths, providing a more robust analytical framework. Table 1 highlights the key distinctions and commonalities between Dynmod and SectorM.

Table 1: Comparative Analysis of Dynmod and Sectorm Models

	Dynmod	SectorM
Model Type	Growth model	Mixed complementary programming model (MCP)
Overall Objective	Projects herd dynamics.	Projects equilibrium values for supply, demand, and prices of livestock products.
Geographic Scope	Country-level analysis (Tanzania).	Tanzania is divided into seven regions, plus the Rest of the World (RoW).
Sectoral Scope	Four cattle production systems, each comprising specific sub-systems, are identified: Grass-based (3 sub-systems) Mixed rainfed (3 sub-systems) Mixed irrigated (3 sub-systems) Peri-urban dairy (2 sub-systems)	Three cattle production systems are identified: Smallholder systems Fattening (medium) systems Peri-urban (large) systems
Time Dimension	Recursive-dynamic	Recursive-dynamic
Time Horizon (Years)	2016-2028	2016-2028
Price of Commodities	Exogenously determined (fixed) over time.	Endogenously determined through the interaction of demand and supply, varying dynamically over time.
Herd Dynamics	Accounts for detailed animal attributes, including age, sex, size, reproduction rate, mortality rate, offtake rate, and other demographic factors.	Herd dynamics are not incorporated.

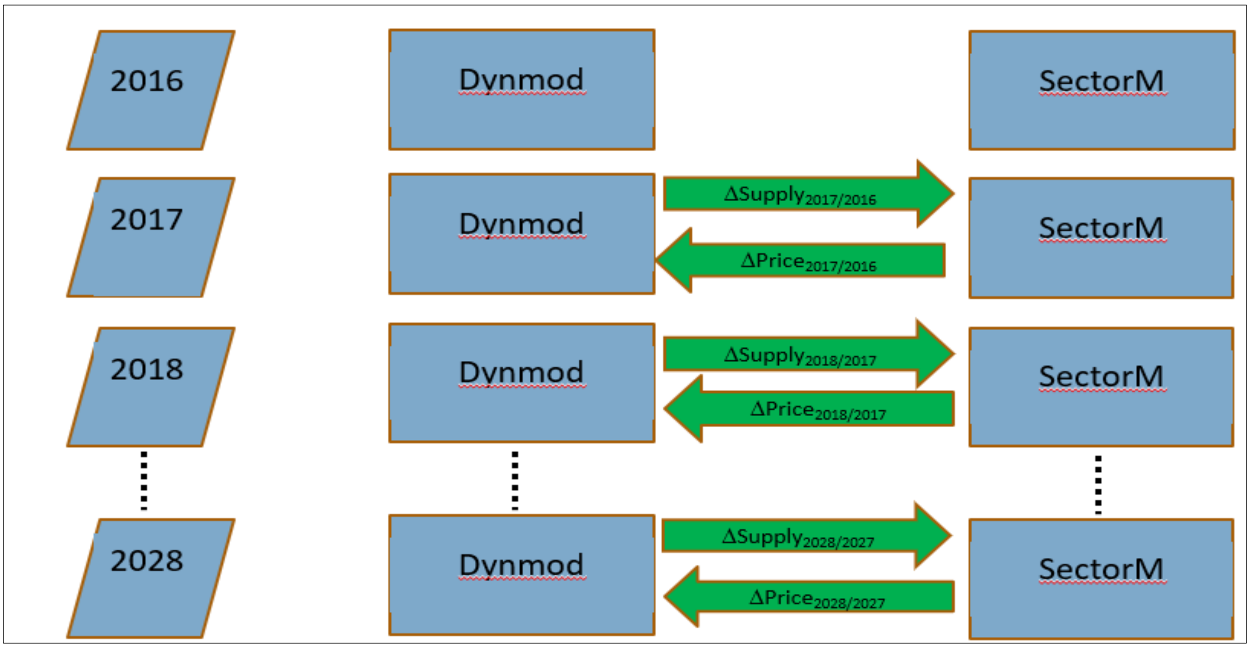
IV. Implementation of the Model Linkage

Following the terminology of Delzeit et al. (2020), a two-way model linkage between Dynmod and SectorM is implemented, as depicted in Figure 1. Due to the recursive-dynamic nature of both models, the linkage follows a stepwise process rather than requiring iterative solutions, with information systematically exchanged for each simulated time period. The information exchange begins in 2017, as percentage changes for 2016 relative to 2015 are unavailable.

The sequence begins with the Dynmod model, which, after solving for 2017, transmits changes in meat supply data to the SectorM model. In SectorM, this data is incorporated as a supply shock, influencing variables such as livestock product prices. After accounting for this shock and solving for 2017, SectorM transmits updated price data back to Dynmod as a price shock. This iterative exchange of information continues annually until the end of the simulation horizon in 2028. This coordinated process ensures a dynamic and integrated simulation between Dynmod and SectorM, effectively capturing the complex interplay between meat production and market responses over the specified period.

The integration of the Dynmod and SectorM models facilitates the introduction of diverse shocks or scenarios at any point during the simulation period. For instance, in this study, an FSAI shock was implemented in 2022, increasing the female cattle population in the Dynmod model. This adjustment affected meat supply in the SectorM model, subsequently influencing meat prices. The resulting price changes in the SectorM model were then reintroduced into the Dynmod model as a shock, enabling a dynamic interplay that effectively captures the complex relationships between herd dynamics and economic factors over time[1].

Figure 1: A Two-way Model Linkage between Dynmod and Sector



Source: Created by the authors

[1] The comprehensive technical details regarding the implementation of the linkage between the Dynmod and SectorM models in GAMS can be found in Stepanyan et al. (2023).

V. Pre-linkage and Post-Linkage Trends of Price of Meat and Income

To evaluate how the models capture changes related to biological and market conditions, we employ a systematic methodology to compare trends in key economic variables within Dynmod and SectorM from 2016 to 2028. First, prior to linking the models, we introduce a market-related shock in 2022, focusing on an increase in the price of meat. Given the differences in how the models account for market conditions, distinct strategies are applied. In Dynmod, where prices are exogenously determined, we introduce a 21% increase in the price of meat in 2022[2]. Conversely, in SectorM, where prices are endogenously determined through the interaction of supply and demand, we decrease a supply-related variable by 1%, leading to an increase in meat prices as the meat supply decreases. This approach allows for a comparison of how the models respond to market-related shocks.

Second, we introduce a meat supply shock in 2022, recognizing that each model captures biological aspects of the livestock sector differently. In Dynmod, where meat supply is influenced by herd dynamics, the shock is implemented via the introduction of FSAI, which reduces the number of offtake animals and subsequently decreases meat supply. In contrast, in SectorM, where meat supply is not directly linked to herd dynamics, the shock is applied by increasing a variable representing meat supply by 1%. Finally, the models are linked to analyze the effects of these shocks, particularly the impact of FSAI in Dynmod, on meat prices and income over the simulation period. The following sections present the pre-linked and post-linked trends in meat prices and income as captured by Dynmod and SectorM.

Pre-linkage Trends of Price of Meat and Income with Price Shocks

Figures 2 and 3 illustrate distinct trends in meat prices across the two models, highlighting their differing approaches to incorporating changes in market parameters, particularly the 2022 price shock. In Figure 2, the price of meat remains constant at 53 Tanzanian Shillings (TZS) per kilogram throughout the simulation period under the business-as-usual (BAU) scenario. When a 21% price increase is introduced in 2022, the impact is limited to that year, with prices immediately reverting to their original levels. This trend diverges significantly from real-world scenarios, where price increases typically diminish gradually unless price-stabilization policies are enacted.

In contrast, Figure 3 reveals a dynamic trend where meat prices vary over the simulation period. A 1% reduction in meat supply in 2022 triggers a price increase, reflecting a supply shortage relative to demand. Unlike the static behavior in Figure 2, the elevated price in Figure 3 persists and continues to rise unless counteracted by price-reducing interventions, demonstrating alignment with real-world market dynamics. These findings highlight the SectorM model's ability to capture market fluctuations more accurately compared to the static pricing assumptions in Dynmod.

[2] Notably, the 21% price increase and the year 2022 were randomly chosen for the introduction of the shock.

Figure 2: Pre-Linkage Price of Meat in Dynmod

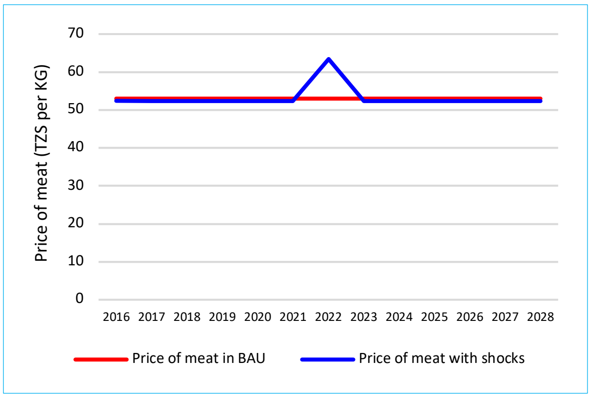
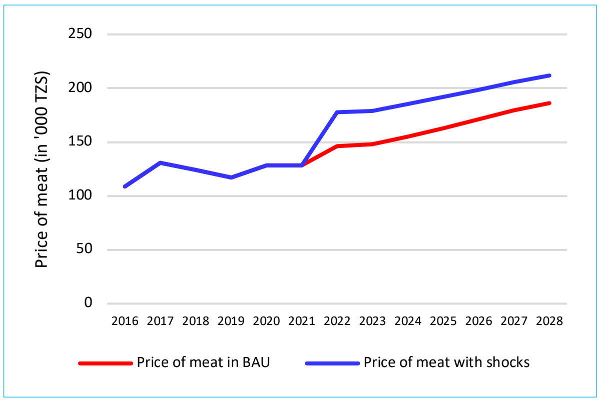


Figure 3: Pre-Linkage Price of Meat in SectorM



Source: Authors' calculations

Similarly, Figures 4 and 5 depict the trends in income from meat for Dynmod and SectorM, respectively. In Dynmod, income rises in 2022 due to the price shock but reverts to previous levels shortly thereafter. In contrast, SectorM exhibits a sustained increase in income beyond 2022, reflecting ongoing market adjustments. These contrasting trends underscore the limitations of Dynmod in capturing market dynamics and economic conditions, whereas SectorM demonstrates a more nuanced and realistic representation of market behavior.

Figure 4: Pre-linkage Income in Dynmod with Price Shock

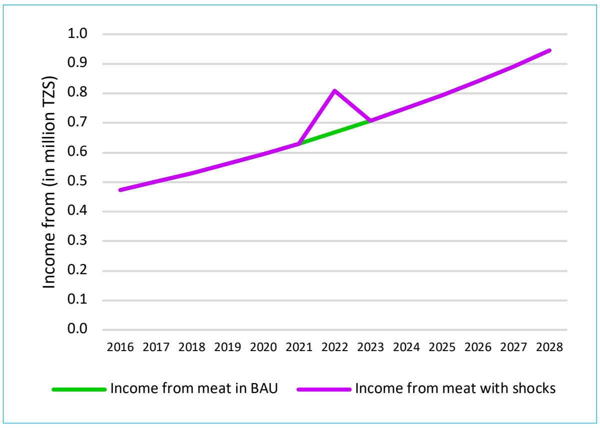
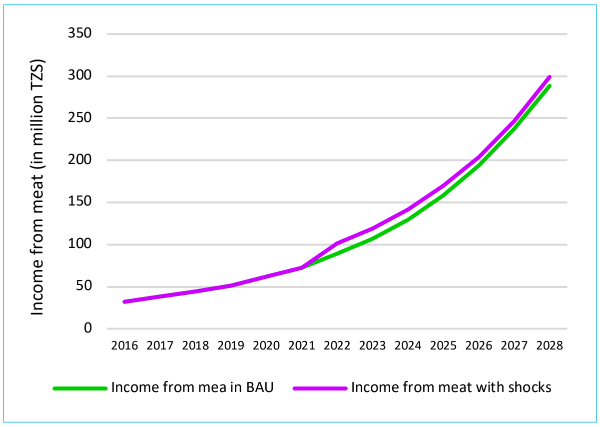


Figure 5: Pre-linkage Income in SectorM with Price Shock



Source: Authors' calculations

Pre-linkage Trends of Income with Meat Supply Shocks

Figures 6 and 7 illustrate the trends in meat supply as represented by the Dynmod and SectorM models, highlighting their differing capacities to capture the biological dynamics of the livestock sector. These differences are particularly evident in their responses to changes in meat supply in 2022, driven by the introduction of FSAI in the Dynmod model and a 1% increase in the variable representing meat supply in the SectorM model.

Figure 6 depicts meat supply trends in the Dynmod model under both the BAU scenario and with the application of FSAI between 2016 and 2028. The figure demonstrates that FSAI initially reduces meat supply in the short term by decreasing the number of offtake animals, as farmers prefer to retain female animals due to their reproductive potential. However, as FSAI increases the proportion of female animals in the herd, it leads to a long-term growth in herd size and, consequently, meat supply. This trend aligns with real-world biological dynamics, as meat supply initially decreases following the introduction of FSAI in 2022, but begins to rise after 2024, eventually surpassing BAU levels.

Figure 7, in contrast, presents meat supply trends in the SectorM model under both the BAU scenario and with a 1% increase in meat supply. Unlike Dynmod, the SectorM model does not incorporate herd biological dynamics. As a result, the figure shows a continuous and linear increase in meat supply under both BAU and shock scenarios, which does not reflect the complexities and real-world characteristics of the livestock sector. This comparison highlights the critical importance of integrating biological dynamics, as demonstrated in Dynmod, to achieve a more accurate and realistic simulation of meat supply trends.

Figure 6: Pre-Linkage Meat Supply in Dynmod

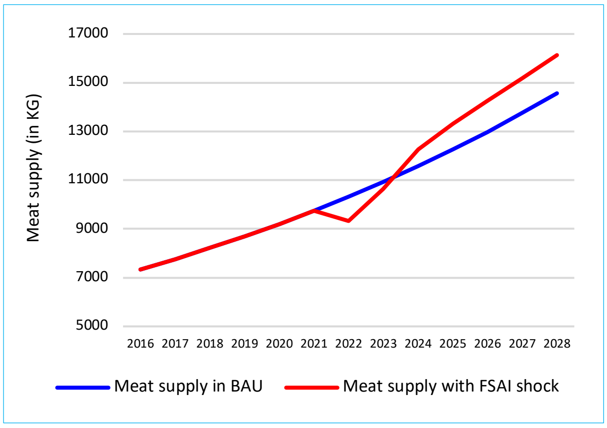
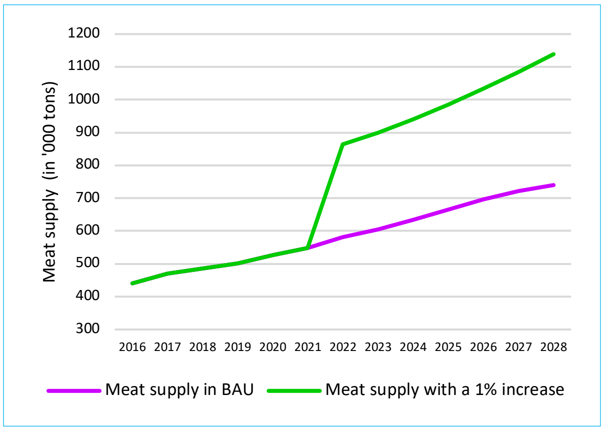


Figure 7: Pre-Linkage Meat Supply in SectorM



Source: Authors' calculations

Figures 8 and 9 illustrate the trends in income from meat under the BAU scenario and with a meat supply shock, highlighting how income from meat responds to changes in meat supply and how these responses are captured by the Dynmod and SectorM models. Figure 8 depicts income trends in the Dynmod model, showing that income from meat follows a similar pattern to meat supply. Specifically, income decreases immediately after the introduction of FSAI and begins to increase after 2024 as meat supply rises. This occurs because the Dynmod model assumes constant meat prices (as shown in Figure 2); thus, a decline in meat supply directly reduces income, while an increase in supply leads to higher income. However, this approach overlooks a critical market dynamic—the role of demand in determining meat prices. Since Dynmod does not account for demand, any increase in meat supply results in a proportional increase in income under the assumption of constant prices. This simplification diverges from real-world conditions, where an increase in meat supply, given constant demand, would typically lower prices and thereby reduce income from meat—an important dynamic absent in Dynmod.

In contrast, Figure 9 illustrates income trends in the SectorM model, showing that income from meat decreases as meat supply increases by 1%. This outcome reflects the interplay of supply and demand: as supply increases, the resulting surplus leads to a decrease in meat prices (as shown in Figure 3), which, in turn, reduces income. This trend aligns closely with real-world conditions, where commodity surpluses drive down prices and subsequently lower income from those commodities. The SectorM model's ability to capture these market dynamics underscores its advantage over Dynmod in representing economic realities and the interactions between supply, demand, and price.

Figure 8: Pre-Linkage Income in Dynmod with Supply Shock

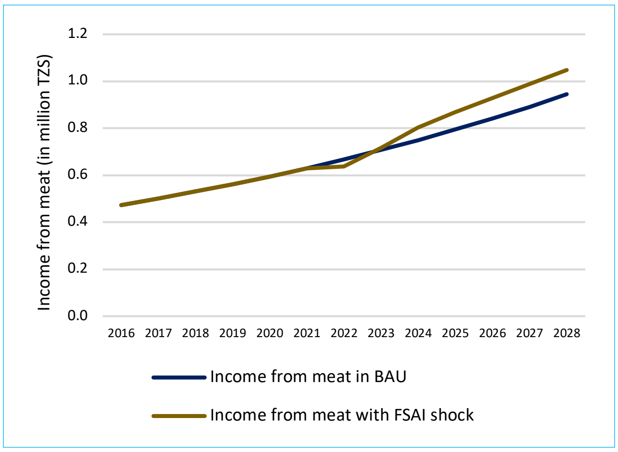
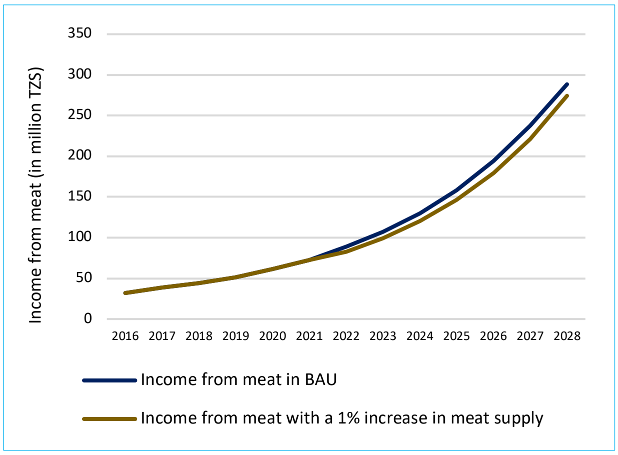


Figure 9: Pre-Linkage Income in SectorM with Supply Shock



Source: Authors' calculations

Consistent with the observations in Figures 2 to 5, Figures 6 to 9 reveal that the Dynmod model excels in capturing the biological dynamics of the livestock sector, while the SectorM model effectively addresses market-related conditions for livestock products. These patterns underscore the strengths and limitations of each model, highlighting Dynmod's inability to fully represent market dynamics and SectorM's limitations in capturing biological processes. This distinction reinforces the argument that while each model has its merits, neither can independently provide a comprehensive simulation of the livestock sector.

The complementary nature of the two models presents an opportunity to address their respective weaknesses by leveraging their strengths through linkage. This study aims to demonstrate the effectiveness of integrating Dynmod and SectorM using a two-way framework in GAMS software. The following section examines the trends in meat prices and income under this linked approach, specifically focusing on the introduction of a meat supply shock through the application of the FSAI shock scenario.

Post-linkage Trends of Price of Meat and Income with FSAI Shock

As discussed earlier, we employed a two-way linkage between the Dynmod and SectorM models, as illustrated in Figure 1, leveraging the strengths of each model to address their respective limitations. The linked models facilitate the exchange of information: the Dynmod model transmits biological data, such as meat supply dynamics, to the SectorM model. The SectorM model processes this input to compute equilibrium values for quantities demanded, quantities supplied, prices, and other economic variables, such as income from meat. It then transmits updated price information back to the Dynmod model, which incorporates this data to calculate economic outcomes, such as income from meat. This iterative process continues annually until the end of the simulation period. While the linked models run without errors, error-free execution alone does not guarantee that the results are scientifically robust or intuitive. To validate the robustness of the results, we introduced a meat supply shock in 2022 through the implementation of FSAI in the Dynmod model.

Under this setup, the Dynmod model transmits the FSAI-induced meat supply shock to the SectorM model. The SectorM model integrates this shock, calculates equilibrium prices and other economic variables through demand and supply interactions, and sends the updated price information back to the Dynmod model. This iterative exchange enables the models to account for both biological dynamics and market conditions. Comparing the post-linkage trends of meat prices and income with the pre-linkage trends (Figures 2 to 9) provides a critical framework to evaluate the effectiveness of the linkage. Scientifically robust and intuitive results would reflect that the FSAI shock in the Dynmod model reduces meat supply immediately after the shock in 2022, as fewer animals are offtaken due to farmers retaining productive female animals. Over the long term, however, the increased proportion of female animals would lead to herd expansion, increased offtake, and higher meat supply, as shown in Figure 6. This increased supply, considered a shock in the SectorM model, is expected to lower meat prices given constant demand, thereby reducing income from meat.

The results from the linked models align with these expectations. Figure 10 illustrates that the post-linkage price of meat in the Dynmod model decreases after 2022 due to the increase in meat supply, in contrast to the constant price assumption in the BAU scenario. Similarly, Figure 11 shows that the post-linkage price of meat in the SectorM model declines after 2022 as the meat supply increases, consistent with the FSAI-induced supply shock from the Dynmod model. These findings confirm the robustness of the linked models in capturing both biological and market dynamics effectively.

Figure 10: Post-Linkage Price of Meat in Dynmod

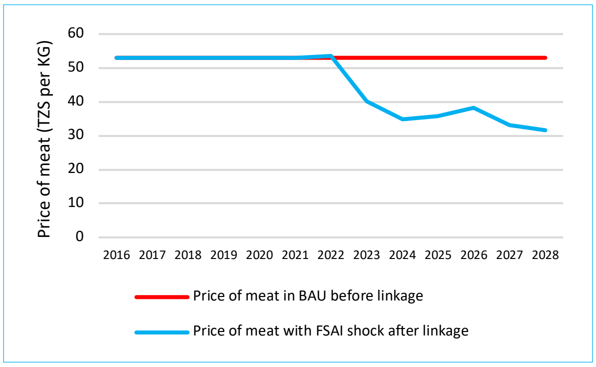
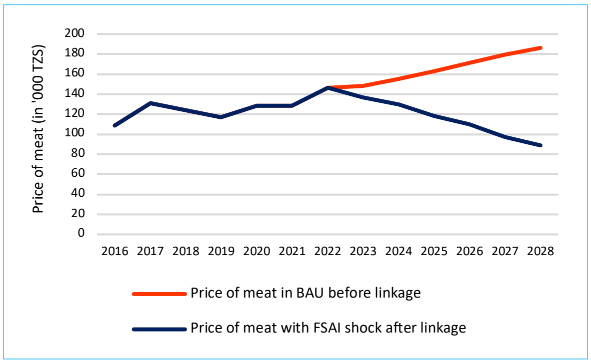


Figure 11: Post-Linkage Price of Meat in SectorM



Source: Authors' calculations

Moreover, Figures 12 and 13 illustrate the trends in income from meat after the linkage of the models. Both the Dynmod model (Figure 12) and the SectorM model (Figure 13) show a similar pattern, with income declining over time. This decrease is driven by a reduction in meat prices following the introduction of FSAI in 2022, which results in a surplus in meat supply due to increased production, subsequently exerting downward pressure on prices.

Figure 12: Post-Linkage Income in Dynmod with FSAI

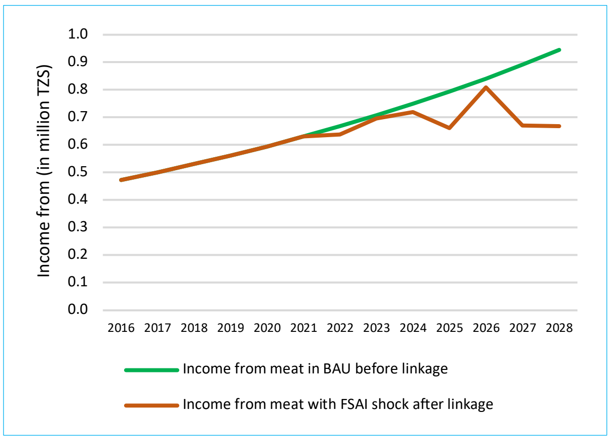
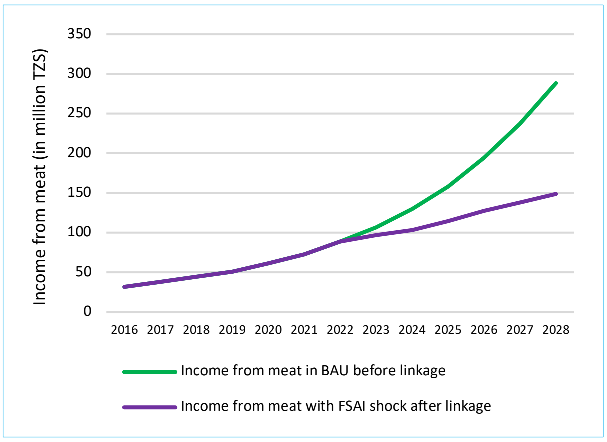


Figure 13: Post-Linkage Income in SectorM with FSAI

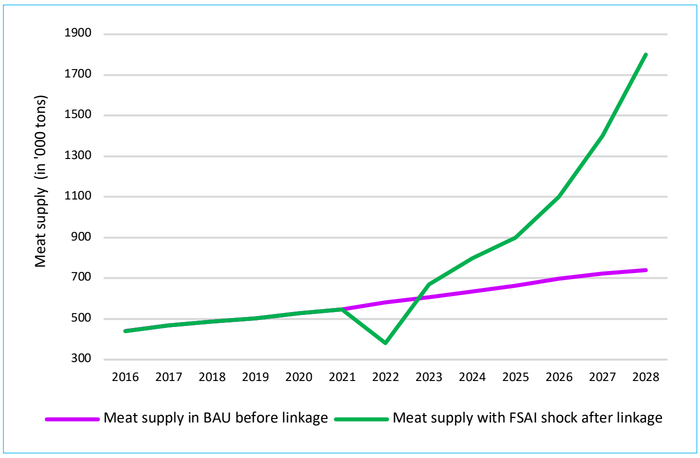


Source: Authors' calculations

Figures 10 and 12 demonstrate that the post-linked Dynmod model exhibits scientifically robust trends in meat prices, effectively incorporating market conditions through the interaction of meat supply and demand—an aspect absent in the standalone Dynmod model. This indicates that linking the Dynmod model with the SectorM model successfully addresses its limitations in capturing market dynamics within livestock sector simulations.

Furthermore, to evaluate whether the linkage effectively resolves the SectorM model's limitations in representing the biological dynamics of the livestock sector, we analyzed the trends of a variable representing meat supply in the linked SectorM model. As shown in Figure 14, the post-linkage trends of meat supply align with the expected biological dynamics. Specifically, the introduction of an FSAI shock in 2022 results in a short-term decrease in meat supply due to a reduction in the number of offtake animals. However, after 2023, the meat supply surpasses BAU levels as the FSAI shock leads to an overall increase in herd size, subsequently enhancing the total meat supply. This outcome highlights the effectiveness of the model linkage in capturing both market and biological dynamics.

Figure 7: Post-Linkage Meat Supply in SectorM



Source: Authors' calculations

Linking models such as Dynmod and SectorM provides a more comprehensive framework for designing and implementing policy interventions to enhance the long-term development of the livestock sector compared to using them independently. The integration leverages the strengths of both models: Dynmod excels in capturing the biological dynamics of the livestock sector, such as herd demographics and reproductive trends, while SectorM adeptly incorporates market conditions, including the interaction of supply, demand, and prices. This dual capability enables a more holistic understanding of the sector, allowing policymakers to assess the multifaceted impacts of interventions. For instance, linking the models ensures that biological shocks, such as those induced by Female-Sexed Artificial Insemination (FSAI), are reflected in market conditions, such as price and income trends, creating a feedback loop that captures real-world dynamics. This comprehensive approach not only enhances the accuracy and robustness of simulations but also provides valuable insights into the long-term trade-offs and synergies between biological and economic factors, ultimately informing more effective and sustainable policy decisions for the livestock sector.

VI. Conclusion

This study investigates the potential of linking two distinct models, Dynmod and SectorM, to address the complex interplay between biological and economic factors in the livestock sector. Utilizing GAMS software, the research integrates Dynmod's detailed representation of herd dynamics with SectorM's robust modeling of market conditions. By linking these models, the study provides a holistic framework to simulate the impacts of various interventions on livestock production and market outcomes, offering a valuable tool for policy analysis and decision-making.

The linkage of these models represents a significant advancement in economic modeling for the livestock sector. By combining the detailed herd dynamics captured by Dynmod with the economic flexibility and market insights provided by SectorM, this approach offers a more comprehensive and nuanced simulation framework. This linkage enables a dynamic representation of the complex interactions between biological and economic factors in the livestock sector, thereby enhancing the realism and applicability of the simulation results.

The introduction of a reproductive shock, specifically Female-Sexed Artificial Insemination (FSAI), served as a pivotal test of the robustness and effectiveness of the linked models. FSAI, a proven tool for advancing genetic progress and optimizing herd composition, was effectively modeled within this framework. The simulation demonstrated intuitive and scientifically consistent outcomes, such as a short-term reduction in meat supply due to fewer offtake animals and a subsequent long-term increase in herd size, meat production, and supply. This dynamic adjustment in herd and market parameters led to shifts in prices and income, showcasing the linked models' ability to reflect real-world conditions.

Moreover, the study highlights the potential of FSAI not only as a technical intervention but also as a strategic policy tool for improving productivity and addressing key challenges in the livestock sector, such as overgrazing and herd management inefficiencies. By linking the biological and economic dimensions of livestock systems, the research provides valuable insights for designing policies that support sustainable production, enhance farmers' incomes, and contribute to the long-term development of the livestock sector.

Future research could further refine this framework by exploring additional interventions, such as feed efficiency improvements or climate-smart technologies, to test the models' robustness in diverse scenarios. Additionally, expanding the linkage to include environmental and social dimensions, such as greenhouse gas emissions or gender equity in livestock management, would enrich the applicability of the models in addressing broader sustainability challenges. This study underscores the critical importance of integrated modeling approaches and highlights promising avenues for advancing livestock sector research and policy development.

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The CGIAR Research Initiative on Sustainable Animal Productivity for Livelihoods, Nutrition and Gender inclusion (SAPLING) is is working in seven countries focusing on livestock value chains to package and scale out tried-and-tested, as well as new, innovations in livestock health, genetics, feed and market systems. SAPLING aims to demonstrate that improvements in livestock productivity can offer a triple win: generating improved livelihoods and nutritional outcomes; contributing to women's empowerment; and, reducing impacts on climate and the environment. Its seven focus countries are Ethiopia, Kenya, Mali, Nepal, Tanzania, Uganda and Vietnam.

It forms part of CGIAR's new Research Portfolio, delivering science and innovation to transform food, land, and water systems in a climate crisis.