Economywide Tradeoffs of Rwanda's Cattle Sector Development and Foot-and-Mouth Disease Challenges

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Abstract

Rwanda's cattle sector is an important component of its agricultural economy, contributing to employment, income generation, and food security. However, the sector's development faces challenges, particularly the recurrent outbreaks of foot-and-mouth disease (FMD), which disrupt production and market dynamics. This study assesses the tradeoffs associated with the cattle sector development and FMD management through a computable general equilibrium (CGE) model and multiplier analysis, projecting macroeconomic impacts, including GDP, employment, and wages, under four FMD outbreak and control scenarios: no control, targeted vaccination, quarantine, and a combined strategy.

The Rwanda CGE model integrates detailed economic interactions across sectors and factors of production, for a broader analysis of policy and external shocks. By incorporating data from the herd dynamics model (HDM) and the Rwanda FMD spread model (Rw-FMD), the CGE captures the interactions between livestock productivity, disease outbreaks, and economic outcomes. HDM projects herd sizes and productivity, using reproduction, offtake, and mortality rates, while Rw-FMD models the spread and impact of FMD under various control measures. These inputs are used to adjust productivity parameters in the CGE model, simulating how FMD-induced disruptions affect cattle output, sectoral linkages, and macroeconomic indicators such as GDP, employment, and wages.

The cattle sector accounted for approximately 2.4% of Rwanda's GDP in 2022, with projections indicating varied trajectories under different FMD management strategies. In the "no control" scenario, the sector's GDP share decreases from 2.43% in 2022 to 2.39% in 2030, reflecting the negative effects of unmanaged FMD outbreaks. In contrast, targeted vaccination and combined strategies result in more favorable outcomes, with the GDP share reaching 2.45%

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and 2.46% respectively by 2030. These strategies also support higher average annual growth rates for the cattle sector, ranging from 3.94% in the targeted vaccination scenario to 4.04% in the combined scenario.

Employment impacts capture the cattle sector's contribution to labor market dynamics, particularly among rural households. The employment multiplier for the sector stands at 2.08, indicating that every job created in the cattle sector generates an additional 1.08 jobs across the economy. Wage projections suggest similar trends, with significant gains under effective FMD management. For instance, the combined strategy results in a year-to-year increase in wages across all labor categories, with significant improvements for primary-educated labor (4.24% by 2030). In contrast, the no-control scenario yields minimal wage growth, which may cause economic vulnerabilities among the rural labor force.

The combined vaccination-quarantine approach is found to be the most effective strategy, delivering the highest gains in GDP, employment, and wages. By addressing both prevention and containment, this strategy mitigates the adverse effects of FMD while enhancing the sector's economic contributions. It is important for policymakers to consider the broader economic implications of FMD control measures and their role in inclusive growth and rural development. This study's findings may serve as a basis for informed decision-making, balancing short-term disease control costs with long-term economic benefits and leading to livestock sector development, employment generation, and food security.

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Keywords: Economywide, Rwanda, Computable General Equilibrium, herd dynamics, livestock

Introduction

Rwanda has recently experienced fast macroeconomic growth, as indicated by the production and employment data. The World Bank reported that Gross Domestic Product grew at about 8 percent yearly since the beginning of the century while poverty has reduced by about 14 percent between 2000 and 2010 only. Since households highly rely on labor to generate income, the significant reduction in poverty indicates substantial improvements in employment outcomes during this period.

According to the Fifth Integrated Household Living Conditions Survey 5 (EICV 5), employment in Rwanda is still characterized by agriculture, informality and low earnings, despite positive trends. The share of agricultural employment seems to decrease during the last decade, as households look for income diversification. The share of the labor force employed in non-agricultural sectors rose from 20 percent in 2011 to 27 percent in 2017. Meanwhile, the proportion of individuals working in wage employment grew from 13 to 16 percent, indicating a shift toward more formal and stable employment opportunities. These trends are particularly pronounced in urban areas, such as Kigali where individuals are mostly engaged in non-agricultural activities.

Government interventions in recent years have significantly contributed to Rwanda's economic growth, particularly through initiatives towards job creation and human capital enhancement. The Vision 2020 Umurenge Programme, designed to accelerate poverty eradication and promote rural development, has supported income generation and public infrastructure development. This has been achieved through targeted investments in education and vocational training. Additionally, specific programs have focused on the agricultural sector, not only to sustain farmer incomes in rural areas heavily reliant on agriculture but also to

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enhance high-value food consumption and affordability. For instance, the Girinka program, launched in 2006, has improved agricultural productivity and livelihoods by providing cows to impoverished households.

These initiatives, combined with increased farmer awareness of stress management practices for challenges such drought and diseases, have led to greater production efficiency. The cattle sector, in particular, has seen significant improvements, with meat and milk production more than doubling since the start of the century (FAOStats). However, the sector continues to face obstacles that hinder its full potential, especially in terms of productivity and market access. The endemic foot-and-mouth disease (FMD) in the Eastern province has imposed high on-farm biosecurity costs and complicated livestock movement between provinces. Efforts to eradicate FMD in East Africa are primarily limited by interactions between domestic and wild animals susceptible to the disease, uncontrolled transboundary animal movements, and the high genetic diversity of the FMD virus in the region (Udahemuka et al., 2020). Over the past seven years, three major outbreaks have been recorded in Rwanda's Eastern province, including one in 2024, while no outbreaks have been reported in other provinces. On all occasions, the government has imposed strict cattle movement control and invested in widespread vaccination campaigns to restrict disease spread to other regions.

The persistence of FMD in Rwanda have not only limited cattle productivity, but also affected prices and availability of other substitutes or complements. Research by Surathkal and Chung, (2017) have explored the changes in cattle product prices and responses of wholesale beef prices as well as other products. Increases in beef price may lead to higher demand for alternative protein sources such as poultry, pork, or plant-based proteins. The magnitude of these

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effects often depends on factors such as income elasticity, cultural food preferences, and the availability of substitutes.

Agriculture is a primary source of income for many households in Rwanda, contributing about 26% to the country's GDP (NISR, 2021). Within this sector, livestock accounts for around 11% of agricultural GDP. According to the National Institute of Statistics of Rwanda, agriculture, forestry, and fishing collectively provide employment for about 45% of the labor force, while contributing to 31 percent of household income and 52 percent of export earnings (Aragie et al., 2022; Labour Force Survey, 2023). Consequently, targeted development initiatives in agriculture, such as effective control of FMD, have significant potential to improve production, food security, as well as employment and income levels.

Efforts to control FMD, however, often meet challenges caused by various geographical, logistical, and structural factors. Smallholder farmers, who constitute a substantial proportion of the cattle sector, often face barriers such as limited infrastructure, lack of biosecurity training, and financial constraints. The potential scenarios for FMD control include targeted vaccination, quarantine measures, and a combined vaccination-quarantine approach. Targeted vaccination can significantly reduce disease spread, but its effectiveness depends on coverage and adherence. Quarantine can contain outbreaks within affected regions but may disrupt market access. The combined vaccination-quarantine strategy has proven most effective, minimizing losses across all sectors by addressing both prevention and containment . However, this approach would require substantial government involvement, consistent farmer education, and resources for widespread implementation and enforcement.

This study's objective is to assess the effects of the cattle sector and FMD control measures on Rwanda's economywide outcomes, including overall outputs, employment, and

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income. A multiplier analysis is performed to quantify the direct, indirect, and induced effects of changes in cattle production on the broader economy in the base year (2022). This approach helps estimate how variations in cattle output, driven by different FMD scenarios, impact economic variables such as income, employment, and output across interconnected sectors. Additionally, a computable general equilibrium (CGE) model is employed to project agricultural GDP, wage, and employment until 2030 under four FMD outbreak and control scenarios. The FMD scenarios are derived from the integration of the Herd Dynamics Model (HDM) and the Rwanda FMD Spread Model (Rw-FMD), which project cattle-derived products and the potential impacts of FMD shocks on cattle production systems from 2017 to 2035. Outputs from these models inform the development of four scenarios: a "no control" scenario, a "targeted vaccination" scenario, a "quarantine" scenario, and a "combined" vaccination and quarantine scenario. These scenarios are then incorporated into the CGE model to analyze the macroeconomic impacts of the cattle sector under various FMD control measures.

CGE models are widely used to understand the implications of policy changes, economic shocks, and structural adjustments on various sectors in an economy (Piermartini and Teh, 2005; Burfisher, 2011). This approach is well-suited for capturing the ripple effects of interventions throughout the economy, as it integrates the behavior of producers, consumers, and markets into a system. CGE models have been used to analyze livestock policies in many developing countries, including Kenya, Tanzania, Indonesia, and Ethiopia (Trewin et al., 1995; Engeda, 2013; Shikur, 2023). These studies often explore the economic benefits of investing in livestock productivity, including increased economic growth, export earnings, and poverty reduction, as compared to focusing solely on cereal crop production (Engida, 2013; Engida et al., 2015).

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Others analyses have integrated herd dynamics modules into CGE models for a more accurate representation of the livestock sector's stock-flow relationships (Aragie et al., 2021).

HDM provides a detailed lifecycle model for tracking changes in herd sizes, reproduction, births, deaths, and offtake rates. This level of detail aims to capture the biological realities of livestock systems, and the challenges (for example, FMD outbreaks) that can affect their development. In the CGE model, shifts in livestock production directly affect economic outcomes such as meat and milk supply, sectoral prices, and household incomes (Aragie et al., 2021). Through this integration, policymakers can assess the direct and indirect impacts of livestock sector interventions, such as vaccination programs, on GDP, employment, and household welfare. This may also involve a broader economic analysis of livestock management contribution to poverty reduction and food security.

Data

The CGE model is built using the 2022 Rwanda Social Accounting Matrix (SAM) as its primary source of data (IFPRI, 2024). The Rwanda SAM follows IFPRI's Standard Nexus SAM framework, which categorizes domestic production into 42 activities, including manufacturing, mining, services, and agriculture. Within the agricultural sector, production is further detailed into the crops and livestock subsectors, with specific emphasis on the cattle sector in this study. The SAM also disaggregates production factors into labor, agricultural land, and capital. Labor is further disaggregated into three categories based on educational attainment: non-educated, primary school education, and secondary school education. Households are represented by 10 groups, capturing rural and urban populations across quintiles of per capita consumption.

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Additionally, the SAM consists of accounts for government, enterprises, and the rest of the world for a broader representation of Rwanda's economic structure (IFPRI, 2024).

Agricultural production (land area and yield) data for each crop activity are gathered from National Institute of Rwanda Seasonal Agricultural Survey (SAS) (NISR, 2022). Household-level data for representative groups are compiled from population surveys and incorporated into the IFPRI NEXUS SAM Dataverse for Rwanda (IFPRI, 2024). The CGE model projects production outcomes and household living conditions from 2022 to 2030, using growth rates and elasticities derived from the Global Trade Analysis Project (GTAP) database. Cattle production details and the impacts of FMD shocks are initially modeled using data from the 2017 Livestock Sector Investment and Policy Toolkit (LSIPT) and reports provided by the Rwanda Agricultural Board (ILRI, 2017, NISR, 2020). These HDM and Rw-FMD data sources are largely discussed in the first chapter of Jean-Pierre et al. (2025).

Multiplier Analysis

For the multipliers' estimation, the original Rwanda SAM was aggregated to assess changes in output, income, and employment across various industries (Appendix 1). In the updated SAM, all agricultural activities, except for cattle, are consolidated into a single account. Similarly, mining, manufacturing, and service activities are each combined into their respective single accounts. Additional accounts, such as government and the rest of the world, are also included in the revised structure.

The multiplier analysis is conducted in several stages. First, the SAM's new structure is used to develop the direct effects matrix, which outlines the inter-industry relationships within

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the Rwandan economy (Table 1). Each entry in this matrix represents the proportion of a sector's total output directly used by another sector or institution. For instance, 49 percent of the cattle sector's total output is consumed internally, primarily for herd maintenance or breeding. Similarly, 7 percent of the output from the "Other Agriculture" sector (for example, crops) is used as input by the cattle sector, likely as feed. Additionally, 39 percent of the cattle sector's output is allocated to factor payments, such as wages for labor and returns to capital (Table 1).

The table indicates that both the cattle sector and "Other Agriculture" sector are highly dependent on internal consumption to sustain production. Export activity is minimal, with only 5% of cattle sector output and less than 1% of "Other Agriculture" output destined for foreign markets. Moreover, the sectors show significant reliance on factors of production, indicating labor or capital-intensive operations.

Table 1. Direct Effect Table by Sector in Rwanda's Economy (2022)*

	Other Agriculture	Mining	Cattle	Manufacture	Service
Other Agriculture	0.45	0.00	0.07	0.01	0.01
Mining	0.00	0.40	0.00	0.01	0.00
Cattle	0.02	0.00	0.49	0.00	0.00
Manufacture	0.04	0.11	0.01	0.45	0.08
Service	0.01	0.01	0.00	0.02	0.58
Transaction Costs	0.04	0.19	0.01	0.08	0.00
Factors	0.35	0.26	0.39	0.11	0.26
Households	0.03	0.03	0.04	0.01	0.03
Taxes	0.01	0.00	0.00	0.05	0.01
Savings-Investment	0.00	0.00	0.00	0.00	0.00
Rest-of-the-World	0.05	0.00	0.00	0.26	0.03

*This matrix is generally denoted as the "A Matrix" where the sum of the column is equal to 1.

The direct effects table is combined with an identity matrix to calculate the direct and indirect effects across sectors in the economy. Table 2 presents the Leontief Inverse Matrix or $(I-A)^{-1}$, which quantifies the total direct and indirect effects of a one-unit increase in final demand

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for each sector. Each cell in the matrix represents the total output required from the supplying sector (row) to satisfy a one-unit increase in final demand for the consuming sector (column), accounting for both direct inputs and indirect inputs from upstream sectors. For example, the cattle sector requires 1.962 units of output to meet a one-unit increase in its demand, illustrating its significant internal reliance. Regarding inter-industry dependencies, a one-unit increase in the cattle sector demand necessitates 0.252 units of output from the "Other Agriculture" sector, such as feed or related inputs (Table 2).

The output multipliers in the last row of the table are calculated as the sum of all direct and indirect effects for each sector. These multipliers capture the total economic ripple effect of a one-unit increase in demand. Notably, demand for services and cattle generates the largest spillover effects, with output multipliers of 2.793 and 2.284, respectively. This indicates that a one-unit increase in service demand has the most substantial total economic impact, as this sector is highly interconnected with others in the economy (Table 2).

Table 2. Direct and Indirect Effects by Sector in Rwanda's Economy (2022)

	Other Agriculture	Mining	Cattle	Manufacture	Service
Other Agriculture	1.820	0.007	0.252	0.019	0.051
Mining	0.004	1.684	0.001	0.038	0.008
Cattle	0.070	0.000	1.962	0.001	0.005
Manufacture	0.151	0.334	0.051	1.844	0.356
Service	0.036	0.063	0.017	0.073	2.373
Output Multiplier	2.080	2.088	2.284	1.976	2.793

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After computing the direct and indirect effects across sectors of the Rwandan economy, employment and income effects are estimated from applying sector-specific coefficients. For employment, the employment-output ratio (jobs per unit of output) is multiplied by the total output change in each sector to calculate the number of jobs created or lost. For income, the

labor income-output ratio (wages per unit of output) is used to determine the total additional labor income generated. The overall employment and income effects are obtained by summing up the results across sectors. Income multipliers, as shown in table 3, are the total increase in income across the economy resulting from a unit increase in initial income, while employment multipliers indicate the total employment generated by the addition of a single job in a given sector (Table 3).

A higher income multiplier reflects a sector's contribution to household earnings. In Rwanda, the agricultural sector plays an important role in generating income, particularly for rural households and laborers. “Other Agriculture” has an income multiplier of 1.92, which implies that every unit increase in demand for the sector’s output leads to 1.92 unit increase in household income. The cattle sector also has a strong income impact (2.23), contributing to rural livelihoods, where livestock ownership provides income for many households. In terms of employment multipliers, sectors with higher values create more jobs per unit of final demand. The high number (2.99) for “other agriculture” indicates that agriculture is labor-intensive and directly or indirectly employs a large portion of the population. In contrast, the cattle sector’s employment impacts are lower than “other agriculture”, as cattle production may rely more on family labor (Table 3).

Table 3. Income and Employment Multipliers for Rwanda (2022)

	Income Multipliers	Employment Multipliers
Other Agriculture	1.98	2.99
Mining	1.94	3.25
Cattle	2.23	2.08
Manufacture	2.14	1.90
Service	2.60	2.97

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Rwanda CGE Model

The multiplier analysis for Rwanda's economy uses an aggregated SAM to assess sectoral impacts and contributions in 2022. To project outcomes such as GDP, employment, and wages over the period from 2022 to 2030, a recursive-dynamic Computable General Equilibrium (CGE) model is applied. This model is adapted from the International Food Policy Research Institute's (IFPRI) standard CGE model initially developed by Lofgren et al. (2002). IFPRI's model provides a flexible framework for capturing complex interactions in an economy by integrating a detailed SAM with non-linear, simultaneous equations that define production, consumption, trade, and macroeconomic balances.

The Rwanda CGE consists of multiple equations blocks that captures the structure of the 2022 Rwanda economy. The main ones are the price block, which determines prices for imports, exports, and domestic products based on trade and cost factors. The relationships between activities and commodity outputs, including the aggregation and allocation of outputs, are captured through the constant elasticity of substitution and the constant elasticity of transformation within the production and trade block. The three other main blocks are the institutions, systems constraints, and the closure and calibration blocks that define income and expenditure for institutions, equilibrium conditions, and the model calibration with base year data. Key equations in the model include the composite commodity market equilibrium, expressed as

$$QQ_{C,A,H} = \sum_A QINT_{C,A} + \sum_H QH_{C,H} + QG_C + QINV_C + qdist_C + QT_C \quad (1)$$

where the total composite supply QQ per commodity C is made up of domestic production sold domestically and imports. $QINT_{C,A}$ denotes intermediate consumption of commodities or used as

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inputs in production. $QINV$, $qdist$, and QT are investment demand, inventory adjustments, and trade and transport services demand, respectively. The model includes other equilibrium conditions such as the savings-investment balance that ensures that total savings in the economy equals total investment and a government budget balance, constraining government revenue to equal government spending. Once those conditions are met, employment projections can be derived from the factor market equilibrium as the total demand for labor across all activities A in the economy at time t:

(2) $$\sum_A QF_A^{Labor} = L_T.$$

Household income Y_H can be derived from factor incomes Y_H^{Factor}, transfers, and net taxes as described in equation 3:

(3) $$Y_H = \sum_A Y_H^{Factor} - Transfers - taxes$$

Macroeconomic aggregates macroeconomic aggregates will result from total output from activities, sectoral shares and government budget balance. Cattle production and FMD scenarios are introduced to the CGE model by shocking α_{va}, the shift parameter affecting overall productivity in the CES value-added production function. The function is expressed as

(4) $$QVA_{F,A} = \alpha_{va} \cdot \left(\sum_F \delta_{va} \cdot (fprd_{F,A} \cdot QF_{F,A})^{-\rho}\right)^{-\frac{1}{\rho}}$$

where QVA denotes the aggregate value-added in activity, δ_{va} is the share parameter for factor $F, fprd$ is the factor-specific productivity, and QF is the quantity of factors, and ρ is the elasticity of substitution between factors. The FMD shocks update the shift parameter δ_{va}. This is defined in equation 5 as

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(5) $$\alpha_{va} = \alpha_{va} \cdot (TFPGR_{A,T} - FMDSHK_{A,T}^{cattle})$$

where $TFPGR$ denotes the exogenous growth rate of total productivity, which is derived from the HDM for cattle. $TFPGR$ reflect improvements in productivity due to technological progress, better management, and increased efficiency. $FMDSHK$ introduces a negative shock to productivity caused by FMD, these shocks derive from scenarios initially built in the Rwanda FMD spread model. Four disease scenarios are considered: targeted vaccination, quarantine, and a combined approach, comparing them to a no-control scenario. The vaccination scenario assumes biannual immunization of one-third of the cattle population in the Eastern province, while the quarantine scenario focuses on enforcing animal movement restrictions, with both approaches evaluated individually and jointly for cost-effectiveness.

CGE Results

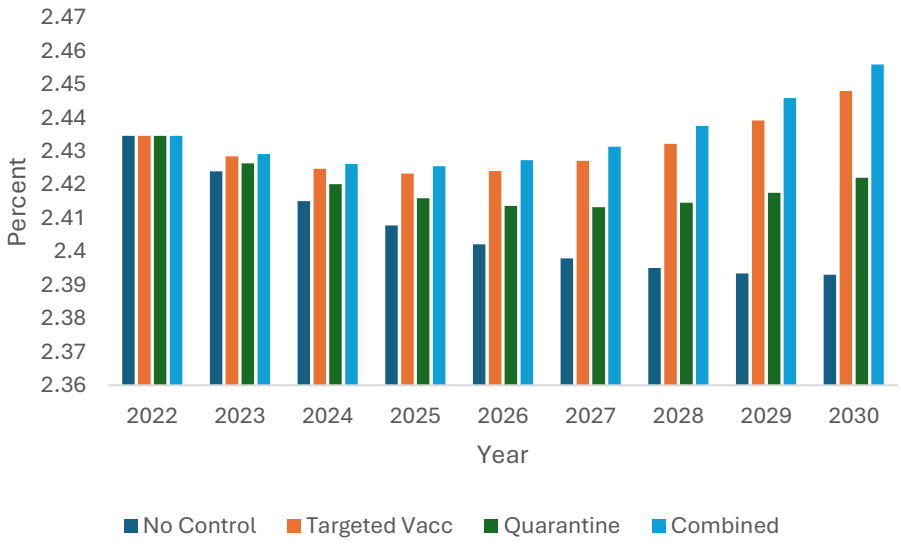
The CGE model projects trends in key macroeconomic variables, with a specific focus on the cattle sector and the impacts of FMD-related disruptions. The results will inform policymakers on the role of the cattle sector and the effectiveness of FMD management strategies in driving economic growth, employment, and income. The cattle sector's contribution to GDP was about 2.4 percent in 2022. Figure 1 projects change in the sector's GDP share under the four disease scenarios until 2030. Findings indicate that, under the "no control" scenario, the cattle sector's GDP share tend to decline from 2.43 in 2022 to 2.39 in 2030, a result of the adverse effects of unmanaged FMD outbreaks on productivity and economic contribution. In contrast, an effective use of FMD vaccines will contribute to stabilize the sector and mitigate FMD consequences. the

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"targeted vaccination" scenario shows a gradual increase in GDP share, from 2.43 in 2022 to 2.45 in 2030.

The "Quarantine" scenario suggests a limited but positive effect on FMD containment by 2030. Cattle sector's GDP share initially declines under this scenario until 2026, followed by a modest recovery to 2.42 in 2030. Quarantine measures often cause short-term disruptions, such as restricted movement of livestock and reduced market activity. However, as quarantine efforts help contain FMD outbreaks, the sector begins to recover in its GDP share by the end of the period. The "combined" strategy, which integrates vaccination and quarantine, suggests the most significant improvement, with the GDP share increasing from 2.43 in 2022 to 2.46 in 2030.

Figure 1. Projection of Cattle Sector's GDP Share in Rwanda (2022-2030)

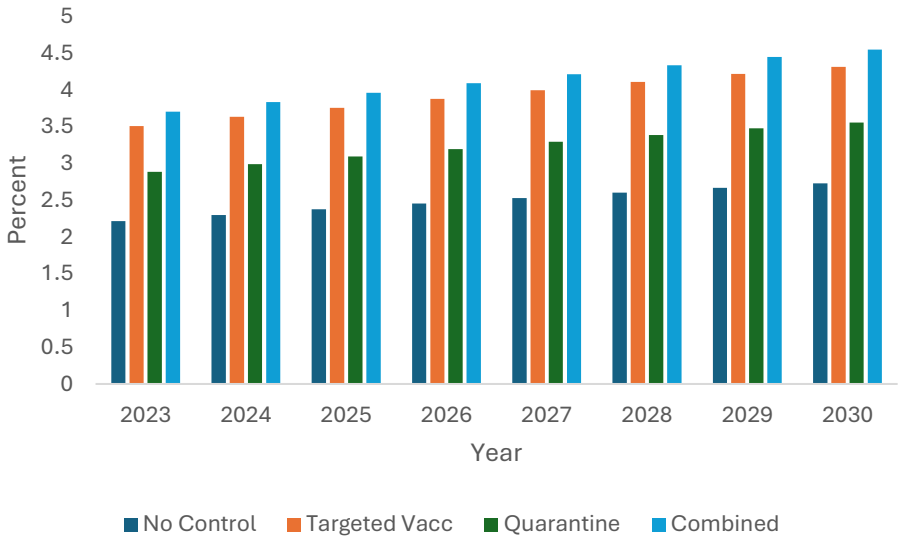


The cattle sector's GDP share is influenced not only by FMD outbreaks but also by interactions with other sectors in the economy. For instance, the availability and cost of inputs such as feed from the agriculture sector, as well as competition for resources, such as labor or capital, may limit the cattle sector's contribution to GDP if other industries expand rapidly. Figure 2 shows the changes in the sector's GDP from the previous year under FMD control

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strategies. While all scenarios indicate growth in the sector's GDP, the rates of growth differ significantly. The average year-to-year growth rate is to lowest (2.46%) under the "no control" scenario. In contrast, the "combined" strategy (4.04%), and "targeted Vaccination" (3.94%) indicate the highest average growth rate.

Figure 2. Projection of Year-on-Year Cattle Sector GDP Growth (2022-2030)



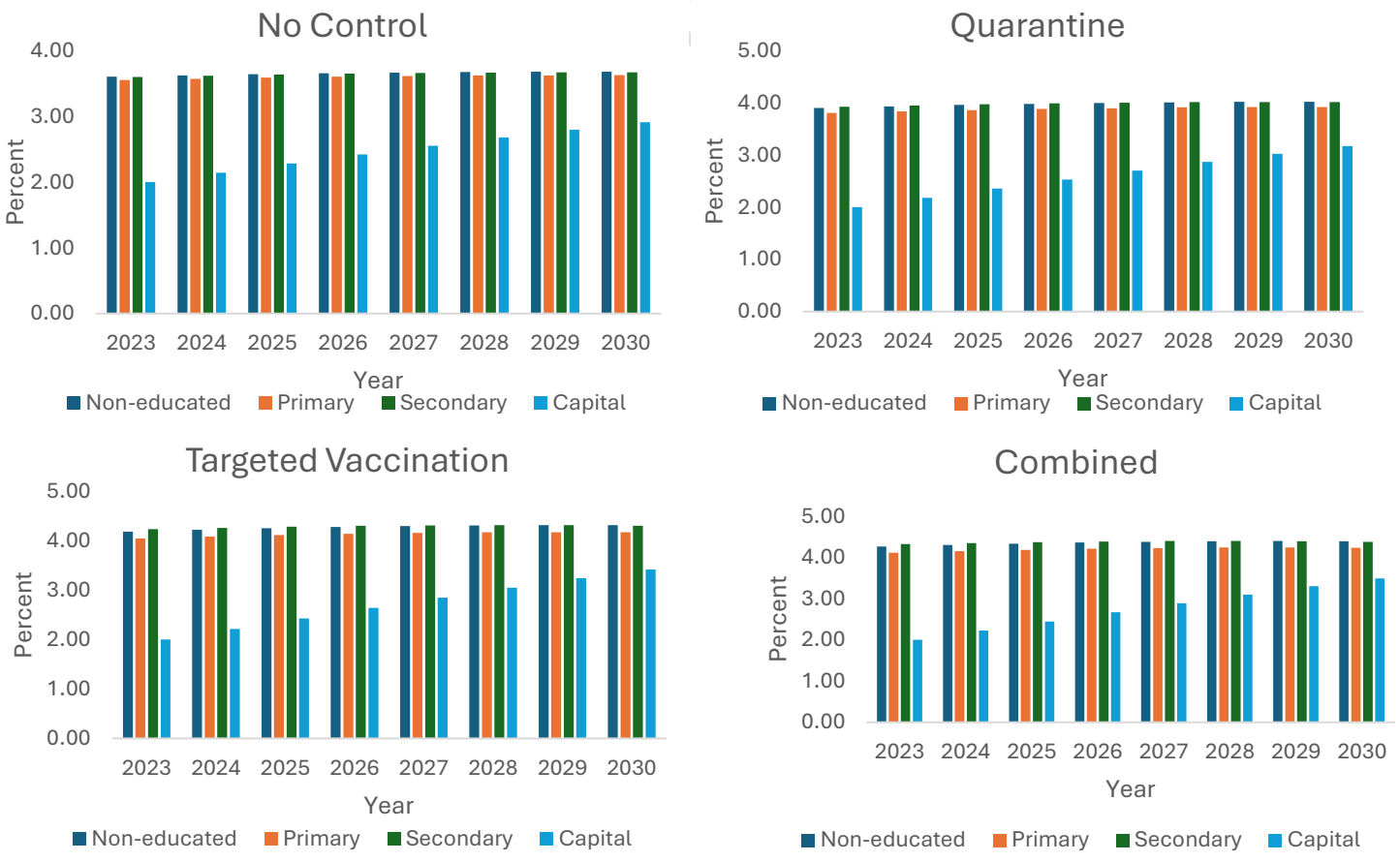
Employment is analyzed by type of labor, which is grouped by education level (noneducated, primary, secondary). Figure 3 shows the year-to-year changes in labor and capital employment from 2022 to 2030 by labor type for each disease scenario. In the "no control" scenario, changes in employment across all labor categories remain relatively stable. Labor employment from the non-educated and secondary education group tend to show a similar growth growth pattern, with about 3.61–3.60% in 2023 to 3.68–3.67% by 2030. Capital employment, however, grows significantly in the "no control" scenario, starting at 2% annually in 2023 and reaching 2.91% in 2030. This growth may be attributed to the sector's increasing reliance on fixed capital inputs as a substitute for labor.

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Under the "targeted vaccination" scenario, changes in employment are consistently higher compared to the "no control" scenario. As shown in Chapter I of Jean-Pierre et al., 2025, targeted vaccination helps mitigate the impact of FMD outbreaks. A more stable production process encourages higher labor demand as producers can expand operations. Additionally, improved disease control will likely boost confidence in the sector, attracting more labor investment across all education levels. Non-educated labor increases from 4.18% in 2023 to 4.31% in 2030, while primary and secondary labor show similar growth trends, reaching about 4.17% and 4.30%, respectively, by 2030. Capital employment also experiences the most higher growth trends in the "targeted vaccination" scenario, rising from 3.42% by 2030 (Figure 3).

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Figure 3. Year-By-Year Change in Different Category of Labor and Capital Employment in The Cattle Sector (2022-2030)

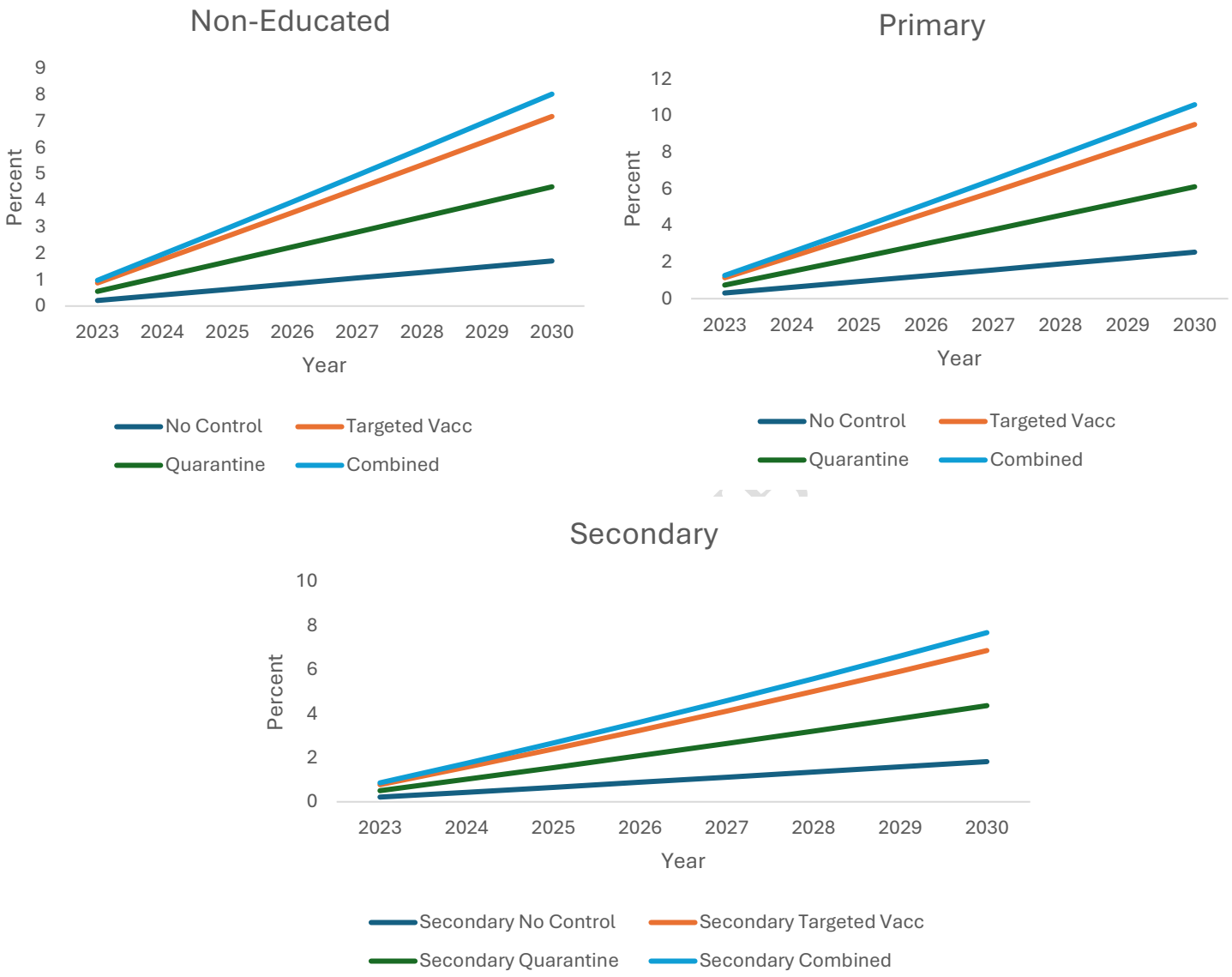


The "quarantine" scenario suggests a more moderate growth pattern, with non-educated labor rising from to 4.02% by 2030, while primary and secondary labor grow less rapidly. The "combined" strategy, however, shows the highest employment levels across all categories, with non-educated labor growing from 4.26% in 2023 to 4.39% by 2030. Primary and secondary labor follow a similar trend (Figure 3).

Wages in Rwanda indicate significant variation across sectors, with the agricultural sector relying on family labor and informal employment. Wage growth in Rwanda remains slow overall. Figure 4 illustrates the disparities in average yearly wage growth across education levels and FMD control strategies. Under the "no control" scenario, wage increases are minimal, with non-educated workers' wages rising by only 1.7% in 2030 and primary-educated workers' wages increasing by 2.5%. In contrast, the "targeted vaccination" and "combined" strategies lead to substantial wage growth. The "combined" strategy yields the most significant increases, with non-educated workers' wages growing by 8% and primary-educated workers' wages rising by 10% in 2030. Secondary-educated workers also experience gains under the "combined" strategy. These trends affirm the importance of targeted disease control measures in enhancing economic productivity and raising incomes, particularly for educated workers, within an agricultural economy recovering from FMD shocks (Figure 4).

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Figure 4. Yearly Wage Growth from 2022 across Labor Category and FMD Scenario



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Conclusion

Rwanda's cattle sector is an important component of its agricultural economy, contributing to employment, income generation, and food security. However, the sector's development faces challenges, particularly the recurrent outbreaks of FMD, which disrupt production and market dynamics. This study assesses the economywide tradeoffs associated with the cattle sector development and disease management through a computable general equilibrium (CGE) model and multiplier analysis. FMD outbreak and control scenarios are modeled by integrating a herd dynamics model and an FMD spread model within the CGE framework, providing a distinct perspective on the sector's interactions with the broader economy. The combined methodology enables estimation of direct and indirect impacts of cattle production changes and evaluates how FMD control measures influence macroeconomic indicators such as GDP, employment, and wages.

In Rwanda, the cattle sector serves multiple purposes, including generating revenue for producers, providing a protein source, and supplying traction for farming. The sector's significance extends beyond direct production to its interconnections with other industries, such as agriculture and services. For instance, the demand for feed from the agricultural sector highlights interdependencies, while higher wages and employment in cattle production can stimulate household consumption, amplifying indirect economic benefits. The multiplier analysis revealed that improvements in cattle productivity tend to stimulate broader economic growth by generating demand for inputs and services, as well as increasing household incomes.

The CGE framework has shown that effective FMD control strategies, particularly the combined vaccination and quarantine approach has the potential to improve GDP, employment, and wage growth until 2030. Increased employment and wages in the cattle sector will subsequently

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contribute to poverty alleviation by providing stable incomes for rural households. Higher GDP growth will likely benefit producers and support public revenues, which can be reinvested into development programs. These outcomes demonstrate the importance of targeted interventions in the cattle sector to achieve inclusive economic growth.

This paper builds on and complements other components of the dissertation (Jean-Pierre et al., 2025). The HDM focuses on the evolution of Rwanda's cattle herds and serves as the basis for understanding long-term productivity and disease control outcomes. The Rw-FMD model captures the epidemiological impacts of FMD, while the CGE model contextualizes these within the economywide framework. Together with the partial equilibrium (PE) analysis, which examines price and welfare dynamics, these components offer an integrated understanding of the interactions among biological, economic, and policy factors. This study, thus, contributes to a broad assessment of Rwanda's cattle sector, with actionable insights for policymakers aiming to balance short-term disease management costs with long-term economic development goals.

Despite the models' complementarity to assess the implications of FMD and cattle sector's dynamics for Rwanda's economy, the study acknowledges some limitations. The recursive-dynamic CGE methodology captures sectoral ripple effects over the simulation period, but the model is sensitive to key assumptions regarding productivity growth, market dynamics, and sectoral linkages. For instance, assumptions about labor and input mobility may not accurately represent the actual constraints faced by producers in reallocating resources between sectors. Additionally, interactions between the cattle sector and other industries, such as crop production for feed or competition for labor, introduce complexities that may not be fully reflected in the model. Rising input costs or labor shortages in the agricultural sector could constrain cattle production. Addressing these limitations in future research through greater disaggregation and

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dynamic feedback mechanisms could enhance the robustness of the findings and provide more precise guidance for policymakers.

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