Greenhouse Gas Mitigation in Dairy Production Considering Incentives and Farm Heterogeneity

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Abstract

Reducing emissions from livestock production is at the forefront of the ongoing policy discourse aimed to reduce the environmental impact of agricultural emissions and achieving net zero goals. This study examines farmer incentive to adopt breeding practices with the potential to improve farm-level environmental outcomes in dairy cattle. The study employs two regionally representative bioeconomic simulation models in Canada to account for possible spatial heterogeneity. We find that whilst farmer uptake of breeding technologies can reduce the level of GHG emissions, producer incentives differ widely across agroecological zones. Further, we find that the combining breeding with complementary farm management practices may yield desirable environmental outcomes in specific regions.

Keywords: Net zero, farmer incentives, greenhouse gas emissions, dairy, genomics.

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1. Introduction

Reducing Greenhouse gas (GHG) emissions from livestock systems has been identified as critical to reducing overall agricultural GHG emissions and achieving net zero goals. Agriculture accounts for about one fifth of GHG emissions globally (OECD, 2022). A significant proportion of these emissions – an estimated 50% - is attributable to on-farm nitrous oxide and methane emissions from the livestock sector (Lassey, 2007). Farm adaptation strategies are crucial for increasing resilience and improving environmental outcomes (Castano-Sanchez, 2022). The relevant considerations for achieving the desired environmental outcomes at the farm-level includes the choice of pathway and the design of right incentives.

It is widely acknowledged that there is scope for considerable reduction in GHG emissions through practices such as breeding, manure management, feeding and other management practices (Food and Agriculture Organization, 2023). Additionally, new opportunities have emerged for the application of novel breeding technologies to identify and select for low emitting cows (Nickel, 2023). Along with this, are markets that offer additional revenue opportunities for livestock farmers in the new carbon economy (Solorio, 2024). Farmer uptake of these new breeding tools and the attainment of potential benefits dependents on proper incentive mechanisms (Pannell, 2017). There is also the question of complementarities in different management practices and possible heterogeneities across different agro-ecological zones. This paper evaluates farmers' incentive to improve environmental outcomes using breeding technologies. We argue that failure to account for important sources of heterogeneity between farms can lead an overestimation of the adoption potential and impacts. We develop a bio-economic stochastic farm level simulation models for two regional representative dairy farms in Canada. The modelling approach accounts for region-specific agroecological variables, milk yields, genomic improvement in resilience traits (i.e., feed efficiency, low methane cows) scenarios and different manure management practices. The model also accounts for differences in farm costs and input use.

Previous studies have evaluated strategies for reducing the environmental impacts of dairy production using farm-level simulation models (Castano-Sanchez, 2022; Rotz et al., 2020; Geough et al., 2012). Some attempts have been made to assess the impacts of different policy measures and incentives on dairy farmer decision-making pertaining to environmental outcomes (Adenuga et al., 2020; Yang et al., 2020; Lengers et al., 2013). Adenuga et al. (2020) used an optimization model to evaluate the outcomes of a nitrogen surplus tax and nutrient application standard across different clusters of farms in Ireland. The study found differential impacts of the different policy instruments based on scale of operation. Yang et al., (2020) in a study of New Zealand farmers found that price premiums higher than 15% could offset costs of transitioning to more environmentally sustainable practices.

Perhaps more relevant to the present study, Worden and Hailu (2020) preformed an ex-ante analysis of the dairy farmer adoption of genomics for improved feed efficiency. The study found that the impact of the innovation was conditional on its predictive accuracy. The authors modelled a typical Ontario dairy farm and did not account for differences in outcomes across agroecological zones. The effect of additional incentives such as carbon prices was not accounted for. Boaitey et al. (2019) accounts the effects of spatial heterogeneity and additional revenue opportunities from the offset market. The authors however, focussed on cow-calf producers in Canada and did not account for improvements in other traits such as methane reductions. Beef and dairy systems differ with respect to management and production practices. For example, dairy production in Canada is supply managed (McLachlan and van Kooten, 2022). This important implications for the environmental impacts of production practices and farmers incentive to adopt different mitigation measures (Adenuga et al., 2020).

This study addresses this research gap by developing a detailed bioeconomic model that accounts for different trait improvements, management practices, agroecological effects and economic incentives. The model also accounts for stochasticity in economic and biological variables. This whole farm approach allows for the systematic evaluation of the interaction between different components and outcomes (Crosson et al, 2011). Further, using a micro-level perspective allows us to account for variations in emissions and use efficiencies between farms (Tan et al., 2022). The paper focusses on two regions, i.e., Alberta and Ontario. These regions represent Western and Eastern Canada respectively. We generate the novel insights into the possible drivers of farm-level uptake of technological improvements in traits relevant to environmental performance and resilience. This is relevant given the role of livestock as a key source of GHG emissions and the opportunities to leverage new technologies as well as markets.

The rest of the paper is organized as follows. The next section provides an overview of dairy production in the two regions. The model is described in section 3. The results of the simulation model are presented in section 4. Section 5 concludes the paper.

2. Overview

The dairy production is a key sector of agriculture in Canada. The total net farm cash receipts in 2022 totalled $8.23 billion (Canadian Dairy Information Center,2023). The largest concentration of dairy farms (81%) is located in Ontario and Quebec. There are approximately 3298 farms in Ontario with a total population of 475200 cows and heifers. The average farm size in Ontario is approximately 144 cows (Holstein Canada, 2023). Overall milk production in the province amounted to about 31 million Hectolitres. This is equivalent to about 31% of total milk production nationally. In comparison, there are 488 farms in Alberta with a total population of 128,500 cows and heifers. This implies the average herd size in Alberta is approximately 263 cows per farm. In 2021, 8.4 million Hectolitres of milk was produced representing in Alberta. This represents 9% of overall milk production in Canada (Agriculture and Agri-Food Canada, 2024). Mixed dairy and crop production are a common feature of milk production in Canada. Dairy farmers combine home-grown feed such as hay and feed grain from crop production and purchased feed to meet herd feed requirements.

3. Methodology

This study applies a 25-year stochastic farm simulation model to estimate the impact of different mitigation measures attainable through breeding. The representative farm is modelled as a typical mixed dairy and crop operation. The model contains detailed information on milk yield, quota, on-farm cattle inventory, feed requirements, crop production, GHG emissions and net cashflow. A detailed description of key aspects of the model is described below. Figure 1 is a representation of the model.

Cow inventory: milk production is determined by the farm's quota allocation. This in turn drives the farm inventory. The cattle herd comprises lactating and non-lactating cows (dry cows and heifers). Milk yields per cow are estimated using a milk yield function. Milk is fat and protein corrected.

Feed: Feed demand is based on cattle feed requirements for lactating and non-lactating cows. Feed supply includes purchased and homegrown feed. Annual yields are determined based on agroecological factors such as precipitation and temperature. This framework allows us to account for spatial differences in these variables across different locations i.e., Alberta versus Ontario.

Economics: The module includes an economics component tracks the discounted net cashflow of the representative farm. Revenue sources include the sale of milk, surplus grains and cattle. The aggregated production costs include livestock and crop production costs, and other production costs such as labour.

Greenhouse gases: The model includes a detailed accounting of on-farm GHG emissions from methane and nitrous oxide sources in the addition the effect of different manure management practices (solid system, liquid system, manure directly excreted on pasture). The sources of

GHGs include methane emissions from enteric fermentation and manure management. Direct nitrous oxide emissions from manure management are also accounted for. Greenhouse emissions are aggregated for the whole farm and converted to carbon equivalence basis using the Intergovernmental Panel on Climate Change (IPCC) factors (IPCC, 2006).

The representative farm in each region is initiated with a herd of 91 cows plus 44 heifers. The initial quota limit was set at 720000 litres/year with an annual increase of 0.02% per year. Milk is corrected to 3.4% protein and 3.86% fat. We assume a crop acreage of 150 acres comprising 75% of owned and 25% rented land. Feed requirements for cows in the herd is based on the animal nutritional requirements. Grain production is primarily used to meet cows feed requirement. Surplus grains are sold. Annualized yield realizations are obtained with a yield function based stochastic precipitation and temperature. Climate data realization are based on historical data.

We focus on two strategies. Firstly, an improvement in feed efficiency and low-methane cattle breeding. With respect to the latter, we assume high and low levels of reduction of 0.75% and 1.5% respectively. We estimate scenarios with and without additional revenue from carbon the carbon offset market. Manure management practices are combined with the mitigation strategies to evaluate the effect of different combinations of measures. For any given mitigation approach in a specific region, abatement costs are estimated as (Huber et al., 2023):

$$Abatement\ cost = \frac{net\ returns\ (k) - net\ returns(b)}{GHG(k) - GHG(b)} \quad (1)$$

where net returns are a measure of profits, k and b represents new mitigation measures and baseline respectively.

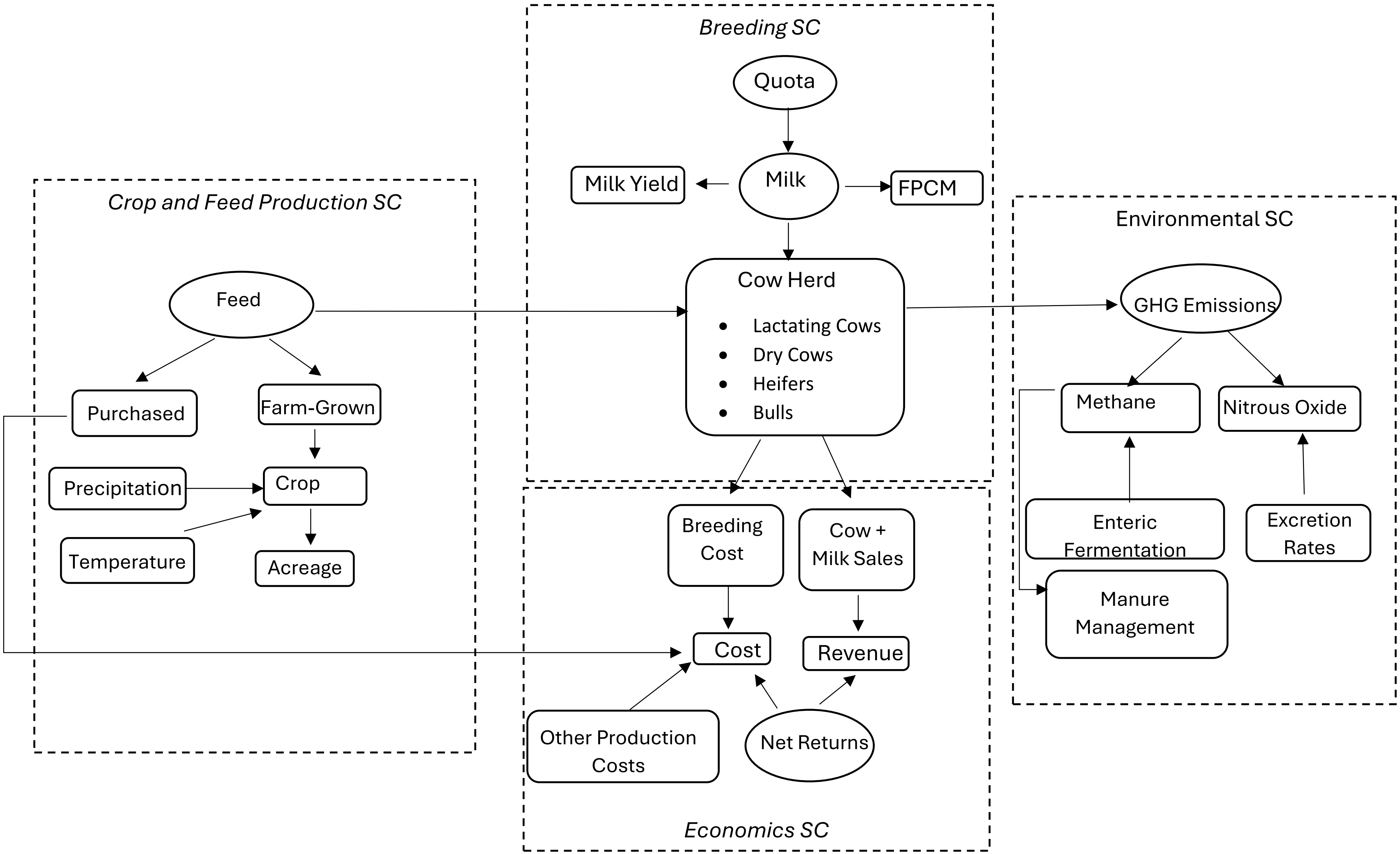

Figure 1: Diagrammatic representation of dairy farm simulation model
Note: SC denotes sub-component

4. Results

Table 1 is a summary results of the simulation model showing the environmental and economic impact of the different mitigation measures relative to the baseline. We assume the changes in the net returns from the two main approaches i.e., breeding for improved feed efficiency and selecting for low methane emitting cows are identical[†]. This simplifying assuming allows us to establish a common baseline for the assessment of the relative impacts of these measures on emission reductions. The main source of spatial heterogeneity evaluated is difference in growing season precipitation.

Table 1: Summary results from farm simulation model

Mitigation measures		Ontario			Alberta		
		mean	min	max	mean	min	max
Baseline							
	Net returns (mean$)	38904.51	-65835.17	101072.54	39049	-65681.1	101201.3
	GHG emissions (Co2eq/FPCM)	1.33	1.26	1.4	1.33	1.26	1.4
Breeding for Improved feed efficiency							
	Net returns (mean$)	47533.63	-54401.07	108396.63	47680	-54245.8	108563.6
	GHG emissions (Co2eq/FPCM)	1.29	1.22	1.36	1.107	1.05	1.16
Breeding low methane emitting cows (0.75%)							
	GHG emissions (Co2eq/FPCM)	1.24	1.17	1.3	1.24	1.17	1.3
Breeding Low methane emitting cows (1.5%)							
	GHG emissions (Co2eq/FPCM)	1.14	1.08	1.2	1.14	1.08	1.2
low methane cow (1.5%) + manure on							

[†] This can be adjusted for by for example accounting for the differences in cost of low methane and feed efficient semen.

pasture (100%)							
	GHG emissions (Co2eq/FPCM)	1.25	1.18	1.31	1.25	1.18	1.31
Improved feed efficiency + manure on pasture (100%)							
	GHG emissions (Co2eq/FPCM)	1.39	1.31	1.46	1.39	1.31	1.46

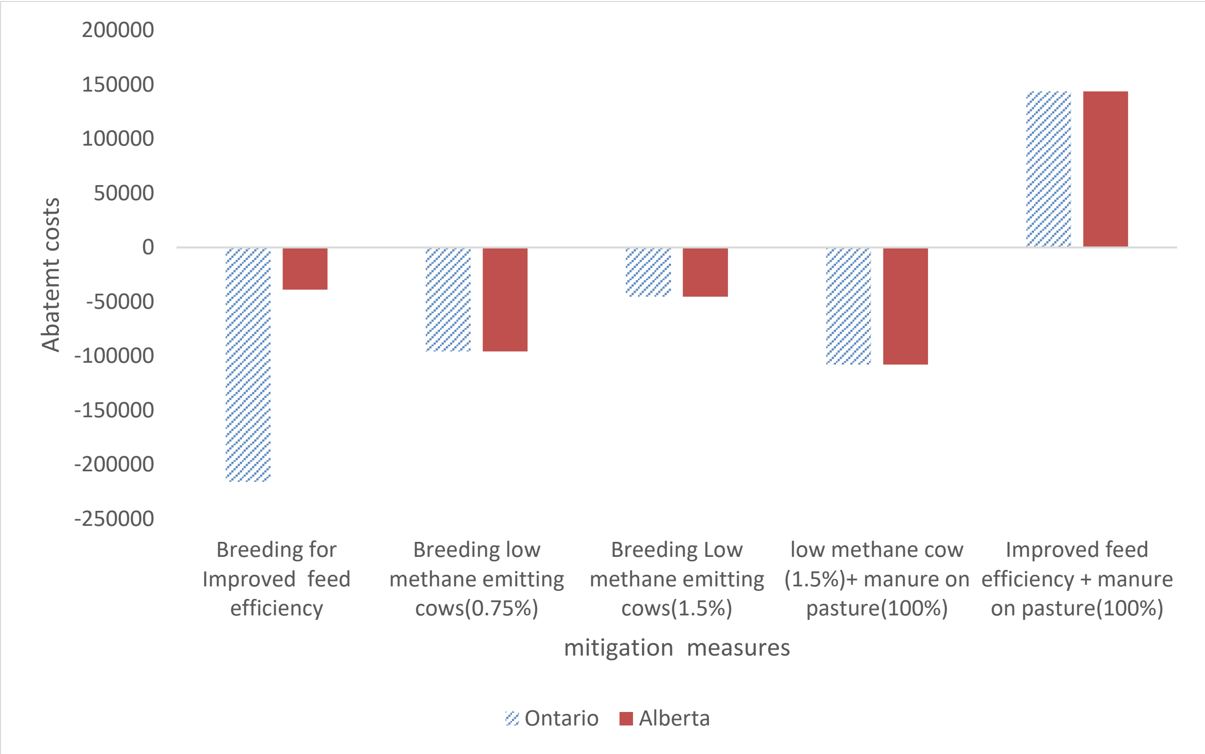

Figure 2: Estimates of abatement costs for different standalone and combinations of mitigation measures for Alberta. Difference in economic measure (net returns) relative to baseline assumed equal for all mitigation measures.

Given that emissions intensities are reduced whilst profits increase from the two breeding approaches analysed, high negative abatement costs are desirable. Breeding for efficiency appears to be the most desirable pathway as it yields the highest value. However, this only pertains to Ontario as the abatement cost estimate for Alberta is much lower. In the case of Alberta, complementary measures such as selecting for low methane cows at high intensity as well as spreading manure on pasture yields the most desirable scenario. This is comparable to selecting for low emitting cows at lower intensity in both provinces. Furthermore, selecting for feed efficient cows whilst spreading all manure on pasture leads to an increase in emission intensity although economic outcomes increase. From an environmental perspective, this is the most undesirable outcome as emission intensity increase relative to the baseline. The baseline manure management practice consist of solid (43%), liquid (40%) and manure excreted directly on pasture (17%).

Overall, the results show that breeding technologies may offer an economically feasible pathway to achieving net improved environmental outcomes by reducing emission intensities in livestock herds. However, these incentives differ spatially for farms. Farmers may face trade-offs between environmental and economic goals. Further, the full range of benefits may only be attainable in certain locations if breeding is combined with on-farm environmental management practices.

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