Milk will drive methane emissions in India

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July 3, 2021

Abstract

Livestock is a significant contributor to global anthropogenic emissions of methane, a short-lived greenhouse gas that is responsible for about 20% of the warming induced by greenhouse gases since pre-industrial times. India is a major contributor to these emissions, and its demand for livestock products is continually increasing in response to both growth in incomes and in population. We estimate methane emissions from livestock in India by estimating the demand for milk and milk products using countrywide representative consumption data over the period 1983-2012. We find that the average annual growth rate of methane emissions from dairy cattle is about twice as large (2.4%) as current estimates that do not take into account the economic factors that influence livestock demand. The difference in growth rates translates to an almost 40% difference in forecasted emissions from dairy cattle by 2050. Our findings suggest that, in a rapidly changing economic environment, current forecasts of greenhouse gas emissions from livestock may inaccurately estimate emissions since they fail to consider the economics governing it. We also estimate emissions under different scenarios, in terms of milk price trajectories and livestock composition. The changes in price do not alter our results significantly but the transition to crossbred animals in livestock drastically reduces future methane emissions from milk production.

Key Words: milk — enteric fermentation — methane — global warming — demand system estimation — growth rate of emissions

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Acknowledgments

We thank E. Somanathan, Jeffrey Vincent, Parikshit Ghosh, Martino Pelli, as well as seminar participants at Indian Statistical Institute Delhi, UQAM, University of Gothenburg and participants at conferences at the 6th World Congress of Environmental and Resource Economics (WCERE) in Gothenburg, 2nd Annual Workshop of the Centre for Research on the Economics of Climate, Food, Energy and Environment in Ranthambore for useful comments on the manuscript.

1 Introduction

Globally, the livestock sector accounts for approximately 14.5% of all anthropogenic greenhouse gas emissions (7.1 of 49 Gt CO_2e yr^{-1}) (**?**). About 44% (3.1 Gt CO_2e yr^{-1}) of the livestock sector's emissions are in the form of methane, the second most important greenhouse gas after carbon dioxide (**??**). The Global Warming Potential (GWP) of methane is estimated to be 28 for a time horizon of 100 years (**?**). This means that over a 100 year period a tonne of methane warms the earth 28 times more than a tonne of carbon dioxide. From 2003-2012 about 60% of all methane emissions came from anthropogenic source with ruminant production being the largest contributor (**??**). This is because of enteric fermentation, a digestive process in ruminants that releases methane as a by-product (**???**). Currently, enteric fermentation contributes about 32-40% to global greenhouse gas emissions from agriculture and over 90% of the enteric emissions are from cattle and buffaloes (**?**).

Present estimates of methane emissions from livestock are obtained by multiplying animal populations with animal specific emission factors (**????**). Forecasts of emissions are simply based on trends in the number of animals that do not take into account economic factors such as income and population growth that determine the demand for livestock products. However, in major contributors to emissions, such as India, (contributes about 13% to global methane emissions from livestock) there is an explosive growth in demand for livestock products due to rising incomes and a higher population (**???**). Using India's National Sample Survey data we estimate that between 1983-2012 the total number of households that consume milk increased from about 79.5 million to 185 million, an increase of 133% (see *SI*, Figure S1). Monthly household expenditure, a proxy for household income, increased by 37% over the same period. If these trends continue in the future, we forecast that by 2050 the monthly consumption expenditure of an average household will go up by another 35%. The number of milk consuming households will increase to almost 349 million. This increase in milk consumption has the potential to significantly influence greenhouse gas emissions of India.

Our goal is to estimate methane emissions from livestock in India taking into account the changing economic environment that determines the consumption of livestock products. We approach this in two steps. First, we use countrywide representative household consumption survey data over the period 1983-2012 to estimate the demand of milk and milk products. Second, we use the estimated demand function to predict India's milk consumption and the resulting methane emissions in the near future. We focus on milk because income from the sale of milk is the primary determinant of the size of the livestock in India. Farmers own cattle largely due to earnings from milk (see *SI*, Table S1). There are no beef farms in India (**?**). Most of the beef produced is sourced from culled and spent cattle and buffalo in the dairy industry. The non-viability of male cattle is reflected in their numbers in the livestock population. The share of males in the total population of cattle and buffaloes was about 28% in 2012, the latest year in which the livestock census was conducted in India (see *SI*, Table S2).

The data we use to estimate milk consumption is from a sample of about eight hundred thousand Indian households over the period 1983-2012. The households are respondents in a survey conducted by the National Sample Survey (NSS). This is a repeated cross-section of nationally representative household survey data. The demand estimation is done using the Quadratic Almost Ideal Demand System (QUAIDS) developed by (**?**). The estimated milk consumption is converted to corresponding methane emissions by using estimates of emissions per unit milk from **?**. We combine the estimates of the parameters of the milk demand function with trends in all the variables in the milk demand function to predict India's milk consumption till 2050.

Finally, we examine the potential of reducing methane emissions from livestock by changing its composition. We develop two scenarios for which we estimate future methane emissions due to milk consumption. The first assumes that all milch animals have been replaced by buffaloes and the second assumes that all animals have been replaced by crossbred cattle.

The following section describes the data sources. Results of milk demand estimation are presented in Section 3. Section 4 discusses estimates of methane emissions from future milk consumption. The effect of livestock composition on emissions is explored in Section 5. Section 6 shows how emissions respond to changes in the price of milk and Section 7 concludes with implications and limitations of our findings.

2 Data

The data on household consumption is taken from surveys conducted by the National Sample Survey Organisation (NSSO). This is a quinquennial survey of rural and urban households from all regions of India. We use data from all the seven large rounds conducted between 1983-84 (38th Round) and 2011-2012 (68th Round). Households are asked to recall expenditure incurred and quantities purchased on most items of domestic consumption.

Total expenditure on any item includes money spent on purchase and value of consumption out of home production. The latter is valued at the average retail prices prevailing in the household's district of residence. In order to make expenditure and prices comparable across rounds we use industrial and agricultural consumer price indices reported by the Labour Bureau of India to deflate or inflate to 2004 equivalent values.

The survey also collects information on several household-level demographic and economic characteristics. Data on household income is not collected. Therefore, we use total monthly consumption expenditure as a proxy for total income. Summary statistics for all the variables used in our demand estimation are presented in *SI* Figure S1, Figure S2, Figure S3 and *SI* Table S3.

District-level data from 19 states on livestock population was obtained from the ICRISAT VDSA (Village Dynamics in South Asia) unapportioned Meso database (**?**) for the years 2003, 2007 and 2012. These 19 states account for about 90% of the geographical area of India.This dataset provides the number of cattle by cattle type, gender and also the numbers by age and milk producing status.

3 QUAIDS Model

The demand of milk was modeled using the Quadratic Almost Ideal Demand System (QUAIDS) developed by **?** (see *SI*). We estimate the consumption of liquid milk as well as the consumption of milk products i.e. curd and ghee (Indian processed butter). All other consumption items (food and non-food) are combined into a single composite commodity representing other consumption.

We chose the QUAIDS model because it belongs to the class of demand systems that can generate income elasticities that vary with income while allowing for price effects that are consistent with utility maximization. Hence, it is capable of generating the quadratic Engel curves (the relationship between expenditure on a commodity and income) that we observe in the data (see *SI*, Figure S4). We estimate the parameters of the demand system by iterated feasible generalized nonlinear least-squares method. The estimation was done in the software Stata using the program developed by **?**.

3.1 Results of the QUAIDS Model

Figure 1 shows the non-parametric plot of price elasticity of demand of milk against total monthly consumption expenditure of the household. The price elasticity of demand of milk is relatively high for the poor. The magnitude of elasticity falls from around 0.5 to 0.35 over the distribution of consumption expenditure. The estimates of expenditure elasticity of demand are to be interpreted as the percentage change in share of expenditure on an item by the household in response to a 1% change in household monthly consumption expenditure. We find that the expenditure elasticity of demand of milk is very high at low levels of consumption expenditure but it falls quite rapidly with an increase in consumption expenditure (see *SI*, Table S4) and Figure 2). The expenditure elasticity of demand of curd also falls with an increase in consumption expenditure but the decrease is much smaller than the decline in the expenditure elasticity of milk (see *SI*, Figure S5). On the other hand, the expenditure elasticity of demand of ghee increases with an increase in consumption expenditure (see *SI*, Figure S6). This is expected as unlike milk ghee is a normal good.

In order to ensure that the results are robust to model specification, 4 types of QUAIDS model were estimated (see *SI* Table S4). The numbers in *SI* Table S4 imply that once we control for the fact that households choose whether to consume a food item or not (see *SI* Columns 2-4 Table S4), the results are stable.

3.2 Extrapolating Milk Demand

To forecast milk consumption, we use the trends observable in the data to estimate the values of all the variables in the demand function of a representative household for each year from 2012-2050. The future values of the price, consumption expenditure and household size variables are estimated by fitting a linear trend model. The linear trend model is a good approximation of the actual data (see *SI*, Figure S7 and Figure S8). Also, due to the limited number of time periods in the data there is a possibility of over-fitting with more flexible specifications. All the other variables in the demand system are modeled with either a linear trend or no trend. We check if the data supports a linear trend for each of these variables. If there is no significant trend we assume that the mean of the variable for all the years in the sample will be a good prediction of its future value.

The predicted values of these variables was then combined with the estimated parameters of milk demand to compute the future consumption of milk, curd and ghee of a representative household. Thus, we assume that the underlying parameters of the demand function are time invariant. Total milk demand was calculated by converting the quantities of curd and ghee to liquid milk.

The expenditure elasticity of milk demand is decreasing slowly in the future (see Figure 3). This is not surprising since the population is getting richer and milk is a necessary consumption good. However, the elasticity is still positive and it falls very slowly.

Assuming that herd composition and methane emission per kilogram of milk per animal in the area of the residence of the household do not vary with consumption expenditure of the household in a given year, the expenditure elasticity of methane emission for that year equals the expenditure elasticity of demand of milk. Since the methane emission conversion factor is invariant to household consumption expenditure, it does not affect the expenditure elasticity which is a ratio of proportionate changes. Of course, herd composition and hence methane emissions would change over time. We account for this by using trends in the emission factor.

4 Methane Emissions from Milk

Methane emission factors per kg of milk per animal were taken from the study by **?**. The authors' develop India specific emission factors for livestock that take into account the difference in rearing practices in India in comparison to the developed countries. Emission factors are available for three types of cattle i.e. indigenous, crossbred and buffalo. In the data we cannot observe the type of cattle that produces the milk consumed by a household. So we approximate it by using a weighted average of the three emission factors, the weights being the proportion of female cattle of the corresponding type in the district of residence of the household. These data are only available for three years (2003, 2007, 2012) and 19 states, so the methane emission conversion factor was computed for this sub-sample of the data.

4.1 Extrapolating Methane Emissions from Milk Consumption

We use a linear trend in the methane conversion factor to predict values of emission factors for the future representative agent. The predicted milk consumption is then multiplied by the predicted methane emission factor to estimate the predicted methane emissions of a household (see *SI*, Figure S9). The country-level future methane emissions due to milk consumption were calculated by multiplying the methane emissions of a future representative household with the predicted total number of households. The predicted number of households is estimated by fitting a linear trend model to the number of households in the whole country in each year of the NSS survey.

Figure 4 shows that even though the average milk consumption of a household increases slightly (see Figure S9 in *SI*), the total consumption of milk increases by a much larger magnitude as more and more households start consuming milk and more households start existing each year.

Results indicate that between 2012 and 2050 methane emissions from milk production in India will more than double from about 2.19 ± 0.01 (95% CI) million tonnes to 5.45 ± 0.08 million tonnes in 2050 (see Figure 4). This amounts to an annual growth rate of about 2.4% and it is much higher than other projections of emissions from enteric fermentation. The closest comparable figure to our estimate is FAO's (Food and Agriculture Organisation of the United Nations) widely used country-wise estimate of methane emissions from enteric fermentation from dairy cattle for each year till 2014 and projections for 2030 and 2050. FAO's data implies a growth rate of just about 1.1% in enteric emissions from dairy cattle in India over the period 2012-2050. Both the set of estimates are plotted in Figure 5. We find that FAO might underestimate future enteric emissions due to milk by almost 40% in 2050. And as is evident from Figure 5 this underestimation increases the further we go in time.

Figure 5 also shows that in the initial years of the forecast our estimate of emissions is lower than that of the FAO. This gap widens as we go further in time because of the higher growth rate in emissions due to milk consumption estimated by our model. The difference in the magnitude of emissions during the initial years may be because of the fact that FAO uses higher emission factors compared to the India specific emission factors given by **?** that we use in the analysis. Further, we calculate emissions from liquid milk, curd and ghee consumption in India. Data limitations did not allow us to account for the demand for milk through the consumption of milk products such as ice-creams and cheese. Ideally, we would have liked to include the demand for these milk products in the analysis. However, we cannot estimate this demand because there are a variety of ice-creams sold in India and the data does not let us identify the type of ice-cream bought by a consumer. The NSS also does not have data on the consumption of cheese.

The difference between our forecast of enteric emissions due to milk production and that of the FAO is primarily due to the difference in approach. Our forecast is based on a model of milk demand that takes into account its determinants such as income. FAO on the other hand predicts the quantity of livestock and the resulting methane emissions by simply estimating a trend in the size of the livestock. FAO's supply side approach therefore does not account for the growth in milk demand that is likely to spur growth in livestock in India.

5 The impact of changing the composition of livestock on methane emissions

Crossbred cattle emit the lowest amount of methane per unit of milk (**?**). In India there has been a gradual increase in the number of crossbred female cattle (see *SI*, Table S2). The effect of this increase may get nullified by an increase in the total volume of livestock needed to meet the increased milk demand. To see which of these effects dominate, we estimate future methane emissions in India under two scenarios. The first assumes that all animals have been replaced by buffaloes and the second assumes that they have been replaced by crossbred cattle. We find that the rise in emissions will be significantly lower if all the milch animals are replaced by crossbred cattle (see Figure 6). Methane emissions from milk would have increased to about 3.66 ± 0.06 million tonnes in 2050 under this scenario (see *SI* Figure S10). Therefore, emissions would be lower by 33% in 2050 compared to the scenario in which livestock grows according to the current trends in the data.

6 Testing Sensitivity to the Price of Milk

So far we have assumed that the quantity of milk in equilibrium will be determined by its demand. Supply is able to cater to whatever quantity is demanded. This may not be an unreasonable assumption because in India the supply of milk has been able to meet the increasing demand of milk and is expected to do so in the future (**???**). Any mismatch in the demand and supply of milk is reflected in the price of milk. We therefore estimate the historical retail price of milk in the data and find that over the period 1983-2012 the real retail price of milk increased marginally (see *SI*, Figure S1). Recent data from other sources on the inflation adjusted retail price of milk in major markets in India also implies that the price increase has been very small. The real retail price of milk increased annually by just 0.9% from 2009-2016 (**?**). However, the wholesale inflation adjusted price of milk in India has increased by about 40% from 2008-2016 (**?**). The reason for this divergence between the wholesale price of milk and the retail price of milk is not clear. Further, the authors' project milk production in India till 2025-26 under two scenarios using the year 2012-2013 as the base year of the projections (**?**). The findings from the scenario that reflects the longer-term trend in livestock over the period 1997-2012 suggest that India can sustain growth in milk production in the near future. Key to this outcome, is likely to be the continued expansion of crossbred cattle, projected to remain the fastest growing segment of the population. In another study that predicts milk consumption in India till 2026-27, the authors' conclude that given current trends in milk production India can meet the projected increase in milk demand (**?**). But the authors' mention that any decline in the rate of growth of milk production could lead to an increase in the price of milk and milk products.

In our analysis the price of milk is assumed to follow a linear trend. To see how milk consumption will change if the price of milk increases faster than that predicted by the trend, we estimate milk demand under 3 scenarios of price change (see *SI*, Figure S12 and Figure S13). The effect of the higher price trajectories on methane emissions is shown in *SI*, Figure S14. We find that methane emissions do not decrease significantly in response to higher prices. Even under the assumption that prices grow thrice as fast as the current trend, emissions reduce by just about 11% from 5.45 million tonnes to about 4.88 million tonnes in 2050.

7 Discussion and conclusions

The principal finding from this paper is that if current trends in the determinants of milk demand and the composition of livestock continue methane emissions from milk production in India would more than double from about 2.19 ± 0.01 million tonnes in 2012 to 5.45 ± 0.08 million tonnes in 2050. This leads to an average annual growth rate of 2.4% and it is much higher than other projections of India's emissions from enteric fermentation. In its latest communication to the United Nations Framework Convention on Climate Change (UNFCC), India reported methane emissions in 2010 of about 10.8 million tonnes attributable to enteric fermentation. Using this estimate and assuming that emissions from livestock other than dairy cattle would also grow by 2.4% per year, enteric emissions in India would amount to about 27.5 million tonnes by 2050. This growth of methane emissions from enteric fermentation has huge implications for the environment. Not only is methane a far more potent greenhouse gas than carbon dioxide, it also has several other negative impacts on the environment. For example, it leads to increased formation of ozone in the troposphere that can reduce agricultural yields. Methane's reaction with hydroxyl reduces the amount of that chemical available to create cooling sulphate aerosols and more warming. It can also form water vapour another greenhouse gas (**?**).

We obtain higher estimates of methane emissions from livestock than previous forecasts because our estimation approach focuses on the demand of livestock products that in turn drives the demand of livestock. On the other hand previous approaches estimate enteric emissions by estimating the trend in the number of animals (**?**). They do not take into account the factors that impact herd size. Such approaches therefore, cannot predict how emissions will respond to changes in the market for livestock products.

Although India is the largest producer of milk in the world and it also has the largest population of cattle in the world, Indian milk yields are much lower than yields in the advanced dairy economies (**?**). So a natural way to reduce emissions from India's dairy sector is by improving the productivity of Indian livestock. We explore the impact of such changes by estimating methane emissions under scenarios where the entire livestock has been replaced by either crossbred cattle or buffaloes. We indeed find that the rise in future emissions would be significantly lower if all the milk is produced by high-yielding crossbred cattle.

The findings imply that the growth in enteric emissions in India would be much higher than what has been projected till now. Further, **?** find that climate change has adversely affected the productivity of Indian livestock. This implies that with rising temperatures more and more milch animals may be required to meet milk demand. This in turn would lead to a further increase in methane emissions than what we estimate and consequently more global warming.

8 References

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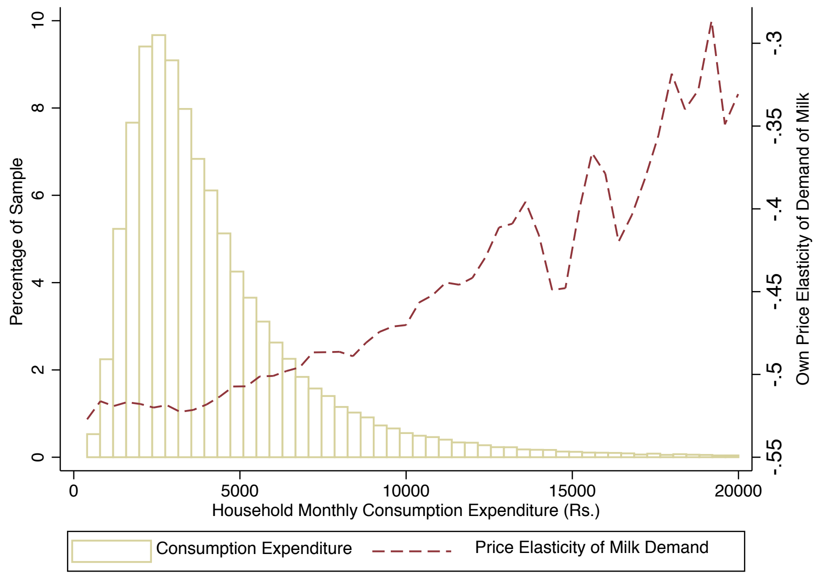
Figure 1: Own Price Elasticity of Demand of Milk

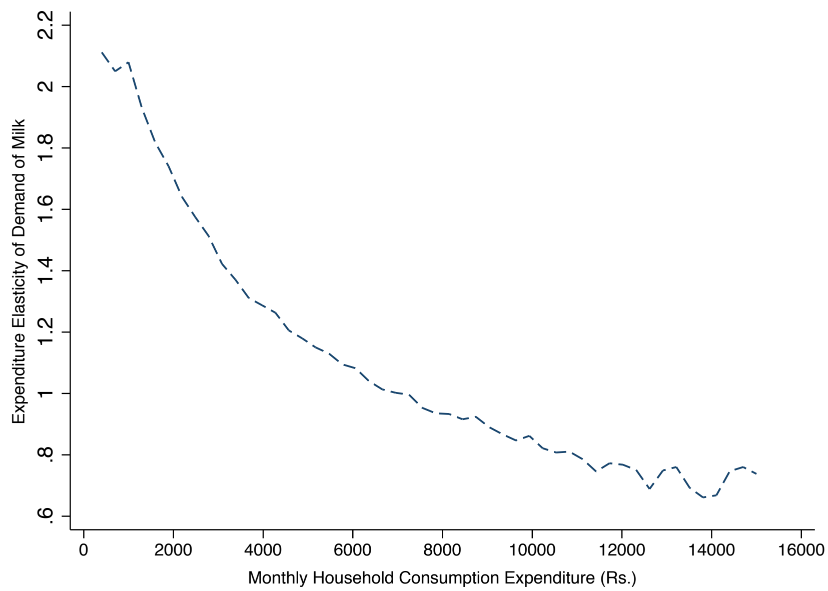


Notes: Non-parametric plot of own price elasticity of demand of milk and monthly household consumption expenditure.

Wholesale Price Index of Milk Compared to Other Commodities

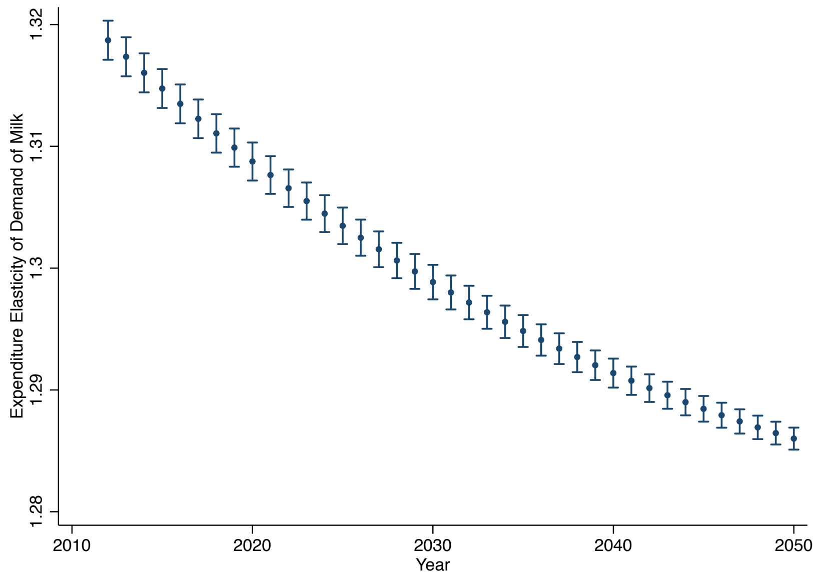
result2.png

Figure 2: Expenditure Elasticity of Demand of Milk



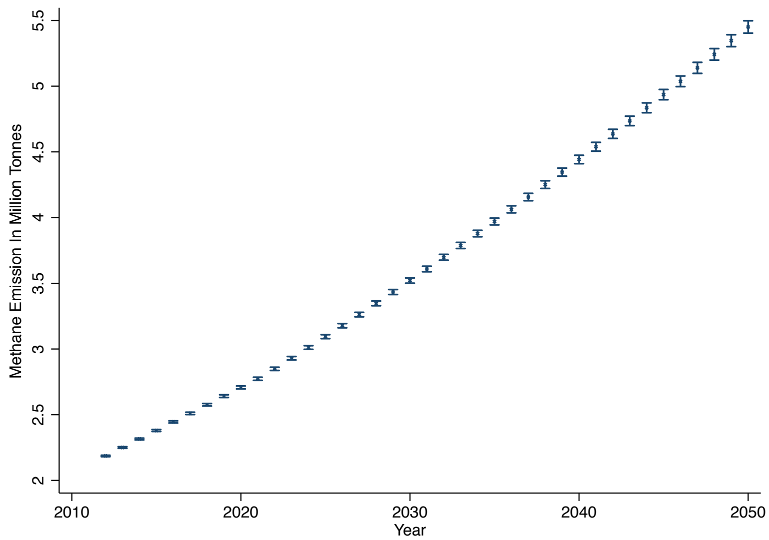
Notes: Non-parametric plot of expenditure elasticity of demand of milk and monthly household consumption expenditure.

Figure 3: Predicted Expenditure Elasticity of Demand of Milk



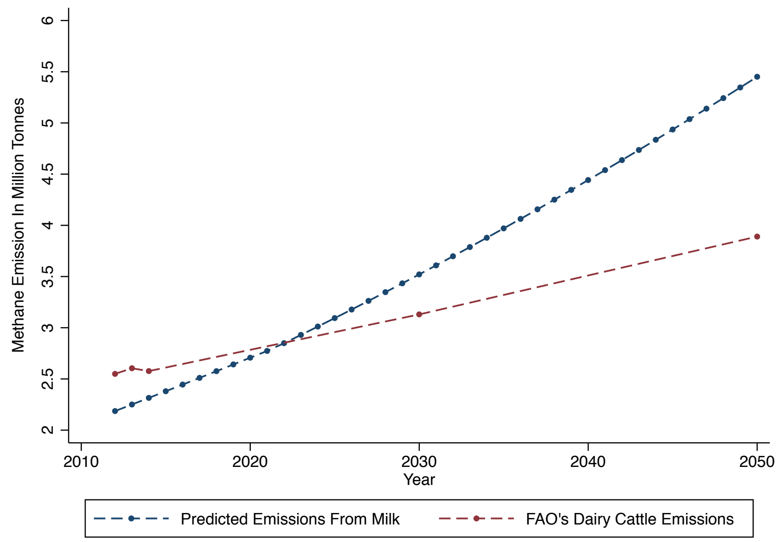
Notes: Figure plots the predicted expenditure elasticity of demand of milk of a representative household for the years 2012-2050. The bars indicate the 95% confidence interval.

Figure 4: Predicted Methane Emissions from Milk Consumption in India



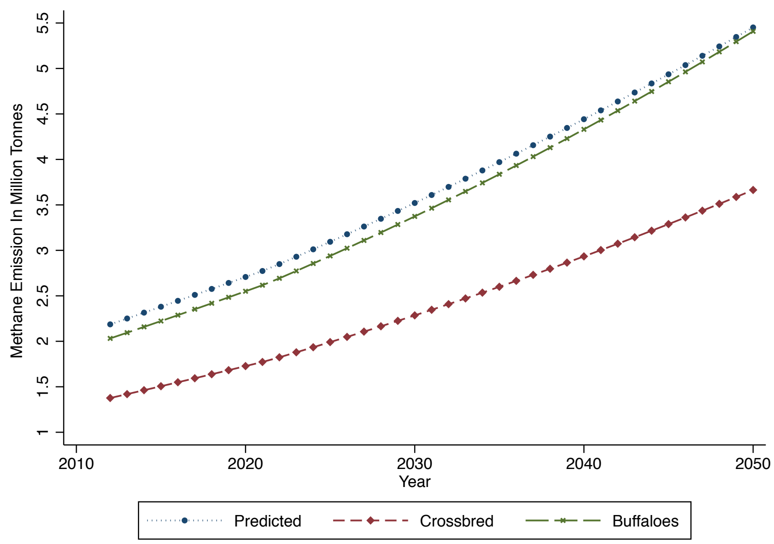
Notes: Figure plots the total emissions due to milk consumption in India from 2012-2050. The bars indicate the 95% confidence interval. Emissions are reported in million tonnes.

Figure 5: Comparison of Methane Emissions from Enteric Fermentation in India



Notes: Figure plots methane emissions due to milk consumption in India from 2012-2050 and by the FAO. Emissions are reported in million tonnes.

Figure 6: Predicted Methane Emissions: Alternative Scenarios



Notes: Figure plots the trajectory of emissions from 2012-2050 under three scenarios. The blue solid line represents the scenario in which the current trends in the composition of livestock are assumed to continue. The red dashed line represents the scenario in which all the milk producing livestock is made up of crossbred cattle. And the green long dashed line represents the scenario in which milk is produced only by buffaloes. Emissions are reported in million tonnes.