# Beef Consumption Reduction and Climate Change Mitigation

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***Selected paper prepared for presentation at the Southern Agricultural Economics Association's 2018 Annual Meeting, Jacksonville, Florida, February 2-6, 2018***

**Abstract**

Keeping global temperature rises below two degrees Celsius is a targeted international community goal. The literature suggests that it is important to explicitly consider the consumption side, as well as the production side to achieve this goal. However, the lack of awareness among the public related to the linkage of the livestock sector and climate change may hinder consumers to change their consumption behavior to reduce Green House Gas (GHG) emissions. This study has two purposes. First, we quantify the environmental loading of U.S. beef sector by calculating emission levels over the period of 1990-2017. Beef cattle is one of the most emission-intensive sectors, which is responsible for 54% of total GHGs from livestock. Following International Panel on Climate Change (IPCC) guideline, we identify three sources of emissions, including enteric fermentation, manure management, and manure left on pastures. Second, we provide an understanding of consumption-environmental connection related to the beef industry. This knowledge might help to avoid the catastrophic climate change consequences in the future.

Keywords: Climate Change, Mitigation Strategies, U.S. Beef Sector

## Introduction

Debates about climate change are one of the most political debates today (Rejesus, 2013). Climate change could lead to disasters such as more severe storms, rising average temperature, more intense rains or increased drought, and more forest fires (USDA, 2017). Researchers estimate that climate change has cost the United States more than $350 billion over the last decade (GAO, 2017).

The Agriculture sector accounts for about 22% of global total emission. This share is greater than that of the transportation sector. Within the agriculture sector, livestock production systems (including transport of livestock and feed) account for about 80% of total emissions (McMichael, *et al*., 2007).

Researchers believe that greenhouse gas emissions (GHG) from livestock are an emerging problem and can be discussed from several aspects. Beef and dairy are principal sources of GHG emissions amongst livestock products that account for 65% of total GHGs emitted by livestock (FAO, 2013). See Table 1.

In addition, livestock production contributes to deforestation and carbon dioxide ($CO_2$) emissions both directly and indirectly. Directly by animal grazing which results in degradation or cutting down the forests to provide more ranching space. Indirectly from increasing demand for animal feed which leads to the expansion of pasture through deforestation.

On the other hand, the increase in the world population will result in more food demand (Godber and Wall, 2014). It is predicted that consumption of meat and dairy products would increase by 76% and 65% respectively compared to a 2005-07 baseline (Bailey, Froggatt, and Wellesley, 2014), and livestock production is estimated to double by 2050 (Caro, *et al.*, 2017).

Table 1: Total Emissions from the Global Livestock Sector, by Main Animal Species

| Animal Species | Equivalent $CO_2$ (Million Tonnes) | Share in Livestock Sector Emissions (%) |
|---|---|---|
| Beef Cattle | 2495 | 35.30 |
| Dairy Cattle | 2128 | 30.11 |
| Pigs | 668 | 9.45 |
| Buffalo | 618 | 8.74 |
| Chickens | 612 | 8.65 |
| Small Ruminants | 474 | 6.70 |
| Other Poultry | 72 | 1.01 |
| Total Emissions | 7076 | 100 |

Sources: Research Calculation based on (Gerber, *et al.*, 2013) data.

Noticeably, the share of beef and dairy cattle is more than 65% of total livestock emissions. However, the results of Caro *et al.*, (2014) suggest that the beef cattle are responsible for 54% of total livestock emissions in 2010.

In general, Brazil, the United States, and China are the top emitters of livestock emissions in the world (Caro *et al.*, 2017). See Table 4-2. The United States is among the major meat-consuming and dairy-consuming countries. It is the third largest meat consumer after China and the European Union (EU), and the share of beef consumption among other red meats is considerable. The U.S. has the fourth rank in consuming milk and eggs, and is behind China, India, and the EU (Bailey, Froggatt, and Wellesley, 2014).

Table 2: Largest Emitter of Livestock Emissions in 2010
(Expressed as Equivalent $CO_2$)

| Region | Equivalent $CO_2$ (Mt $Co_2$eq/y) | Share |
|---|---|---|
| Brazil | 311 | 19% |
| United States of America | 140 | 8% |
| China | 129 | 8% |
| India | 109 | 7% |
| Argentina | 77 | 5% |
| Ethiopia | 52 | 4% |

Data Source: Adopted from Caro *et al.*, (2017)
Note: The numbers in the above tables refer to the total emission of livestock.

These six countries in the above table produced 50% of the global emission related to beef cattle in 2010.

To estimate emissions from beef cattle, following (Caro *et al.,* 2017) we take into account three emission sources, including enteric fermentation, manure management and manure left on pasture. Each of these sources is described blow.

**Enteric Fermentation**

The highest emission level of methane ($CH_4$) and nitrous oxide ($N_2O$) relates to livestock production. Enteric fermentation[1] is the largest source of $CH_4$. Manure and fertilizers applied in feed production are the biggest sources of $N_2O$ (Bailey, *et al*., 2014).

$CH_4$ and $N_2O$ emissions have a smaller share of global of global GHG emissions compared to $CO_2$ emission. However, their Global Warming Potential (GWP) is 21 and 310 times higher than $CO_2$. In other words, $CH_4$ and $N_2O$ contribution to climate variations is 21 and 310 times more than $CO_2$ (Caro, *et al.*, 2017). For example, emissions of one tone of $CH_4$ have the same effect on climate change as the emission of 21 tons of $CO_2$ over a one-hundred year period. This serves to demonstrate how quantities of gases, such as $CH_4$ and $N_2O$, which seem negligible at first glance, actually contribute significantly to climate change.

**Manure Management**

Animal manure is consisted of water and organic material (Bouwman, 1996). Manure management is responsible for emission of both $CH_4$ and $N_2O$. The $CH_4$ production potential of manure is associated with the temperature and the way that manure is treated.  (E.P.A., 2006). However, $N_2O$ emissions are not associated with air temperature, and they are directly released from the nitrogen in animal waste as the result of nitrification and denitrification process (IPCC, 2006).

On the other hand, indirect $N_2O$ are emitted from volatile nitrogen losses in the forms of ammonia ($NH_3$) and ($NO_x$)[2]. Nitrogen losses happen at animal production areas

[1]- Methane is emitted from the enteric fermentation, which is a digestive process in ruminant animals (Hook *et al.,* 2010).
[2]- $NO_x$ is a generic term for the nitrogen oxides

at the point of excretion, and continue through on-site management in storage and treatment systems (IPCC, 2006).

**Manure Left on Pasture**

The third source of GHGs emissions are the manure which are left on pasture, and in other words are under no management system. $N_2O$ is produced from this source directly and indirectly (Caro, *et al*., 2017). The direct $N_2O$ emissions were explained before. Indirect $N_2O$ emissions is related to nitrogen losses through runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures (IPCC, 2006). Therefore we take it into account this emission source in this study.

However, we exclude emissions from the production of animal feed and forage, including nitrous oxide emissions associated with fertilizer application; land use changes; the transportation of animal feed, livestock, and food animal products; and emissions associated with imported food animal products. Considering all of the above mentioned sources is beyond the scope of this study. Appendix A, describes some of the equations for livestock emissions.

**Literature Review**

The impact of climate change on agriculture sector has been well-studied in the climate change literature (e.g., Mendelsohn, Nordhaus, and Shaw, 1994; Roesenzweig and Hillel, 1998; Adams *et al*., 1998; among many others). However, the contribution of agriculture and in particular the livestock sector to the Green House Gas (GHG) emissions has been largely neglected. Bailey, Froggatt, and Wellesley (2014) call livestock the forgotten sector in climate change studies, and discuss that the lack of knowledge among consumers regarding the contribution of the livestock sector to climate change hinder them to reduce their consumption of livestock products. Recently, there are several attempts to investigate this important issue though (e.g., Boer, Schösler, and Boersema, 2013; Hedenus, Wirsenius, and Johansson, 2014; Bajželj *et al*., 2014).

Caro, *et al.*, (2014) estimate the GHG emission from cattle production for the period 1961–2010 using IPCC guidelines. They found global GHG emitted from beef cattle have risen by 59% over the last five decades. They argue that beef cattle are responsible for 54% of total GHGs from livestock, while share of pork and chickens are 5% and 1%, respectively. They believe livestock emissions are mainly due to the dietary choices. As a solution for mitigating livestock emission, they suggest consumer to shift toward diets that cause less emission. It is while the current global trend is toward consumption of more cattle products.

In summary, the majority of existing research investigates the possible impact of climate change on agricultural production. In other words, they look at this issue from the producers' perspective.

The contribution of our study is to use the latest available data and estimate the emission levels for the period 1970-2014. The present study suggests an empirical model to quantify the impact of each mitigation option suggested by previous studies. Our hypothesis is that some activities such as, beefless Monday has a positive impact on climate change mitigation. This study has some policy implications for both supply side and demand side.

## Model Specification and Estimation Techniques

This study has two objectives. First, we estimate the total GHG emissions from U.S. beef cattle. We are interested in examining the relationship between beef consumption and emission levels. To do that, we constructed a conceptual model based on the result of Hedenus, Wirsenius, and Johansson (2014) study. They discuss that there are three options for reducing GHG emissions from livestock sector, including productivity improvement, technical mitigation measurements, and human dietary changes. In order to quantify the effect of each suggested option over time we construct the below equation.

$$GHG_t = \beta_0 + \beta_1\ Cons_t + \beta_2 Prod_t + \beta_3 Tech_t + \varepsilon_t \tag{1}$$

The definition of each variable and the expected sign are presented in Table 3.

Table 03: Variables Applied in the Model

| Variable name | Definition | Expected sign |
|---|---|---|
| $GHG_t$ | Total GHG emission associated with U.S. beef production (in log form) | Dependent variable |
| $Cons_t$ | beef consumption | Psitive |
| $Prod_t$ | Productivity improvement of beef production that is measured by yield of product | Negative |
| $Tech_t$ | The mitigation strategy that is measured as the amount of animal manure that leaches and volatilizes after applying on soil | Positive |

All variables are measured over period 1970-2014

We should mention that there are several practical strategies to mitigate the GHG emission level. The purpose of all strategies is to reduce the emission level. Leaching and volatilization from manures contribute to the GHG emissions. Mitigation strategies, such as adjusted application timing of manure aim to avoid leaching, and volatilization losses (Van Es, Sogbedji, and Schindelbeck, 2006). However, since we are measuring the amount of manure which is leached and volatilized in our model, it has a direct (positive) effect on GHG emission associated with beef cattle.

To estimate the long-run relationship between the aforementioned variables, we need to check the existence of cointegration vector. Once the existence of cointegration is approved, in the next step we can estimate the associated error correction model as follow:

$$\Delta GHG_t = \alpha_0 + \sum_{j=1}^{p1} \alpha_1 \Delta GHG_{t-j} + \sum_{j=0}^{p2} \alpha_2 \Delta Cons_{t-j} + \sum_{j=0}^{p3} \alpha_3 \Delta Prod_{t-j} + \sum_{j=0}^{p4} \alpha_4 \Delta Tech_{t-j} + \phi ECT_{t-1} + \varepsilon_t \quad (2)$$

Where $ECT$ is the error correction term, and its coefficient ($\phi$) should have a negative sign. This coefficient indicates how quickly variables converge to longrun equilibrium (Ozturk and Acaravci, 2011).

**Data**

To collect data for emission levels of beef cattle we referred to the FAO database. FAO has released this data to the year 2014. This data has been available to the public and research community for the first time at June 2016. Also for productivity that is measured as the yield of beef cattle products, and the relevant data for technical mitigation we referred to FAO.

Data retrieved from USDA-ERS show that per capita consumption of beef (solid line) is decreasing while that of poultry (dashed line) is increasing over time (See Figure 1). It might suggest that beef consumption is substituted by poultry consumption over time (we did not use the consumption of poultry in our model, but for comparison purpose, we provide the data here). Table 4-4 presents the summary statistic of data..

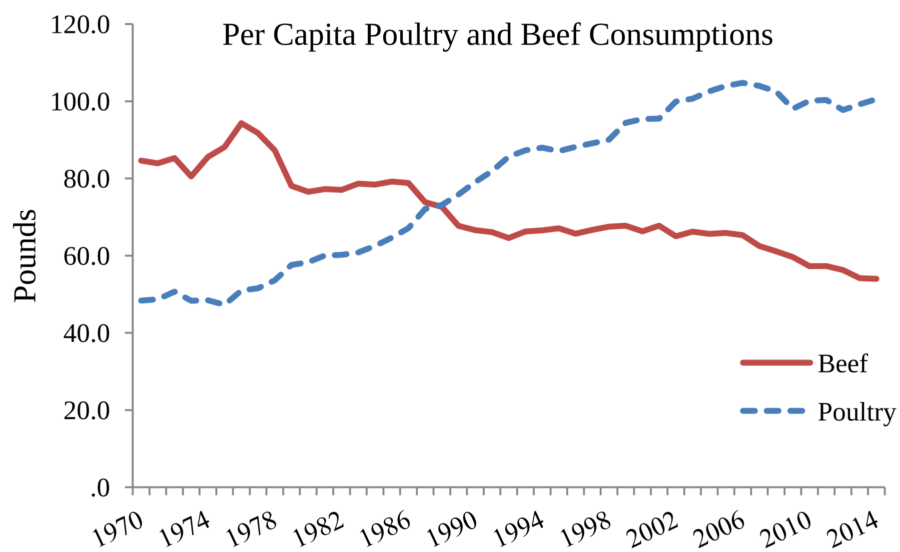



Figure 01: Per Capita Poultry and Beef Consumption in the U.S. from 1970 to 2014

Data Sources: USDA- ERS dataset

Table 0: Descriptive Statistics of Data (1970-2014)

| Variables | Mean | Minimum | Maximum | Std.Dev. |
|---|---|---|---|---|
| GHG emissions (Million metric tonnes) | 155.7 | 131.0 | 199.3 | 17.04 |
| Productivity of beef production (Hg/An) | 3009.5 | 2405 | 3712 | 357.22 |
| Animal manure that leaches and volatilizes (Million metric tonnes) | 0.234 | 0.197 | 0.299 | 0.02 |
| Beef consumption (Per capita- Pounds) | 71.3 | 54.0 | 94.3 | 10.29 |
| Poultry consumption (Per capita- Pounds) | 78.6 | 47.3 | 104.8 | 20.29 |

Source: Research calculations

Noticeably, the minimum value for both GHG emissions and the amount of manure that leaches or volatilizes occurred in 2014, and the maximum value for both variables was at 1975. In opposite, the minimum value for beef productivity was at 1975, and the maximum was at 2014.It would lead to the perception that any increase in production productivity has a positive impact on reducing GHG emissions. Also, any new technique to minimize the leaching of manure has a direct relationship with GHG emissions.

**Results**

Results of methane emissions from enteric fermentation process and manure management and total $N_2O$ emissions from manure management are depicted in Figure 2. The trend in this graph is mainly associated with trend in beef cattle inventory. Results are expressed in terms of $CO_2$ equivalent, using the 100-year GWP measures.

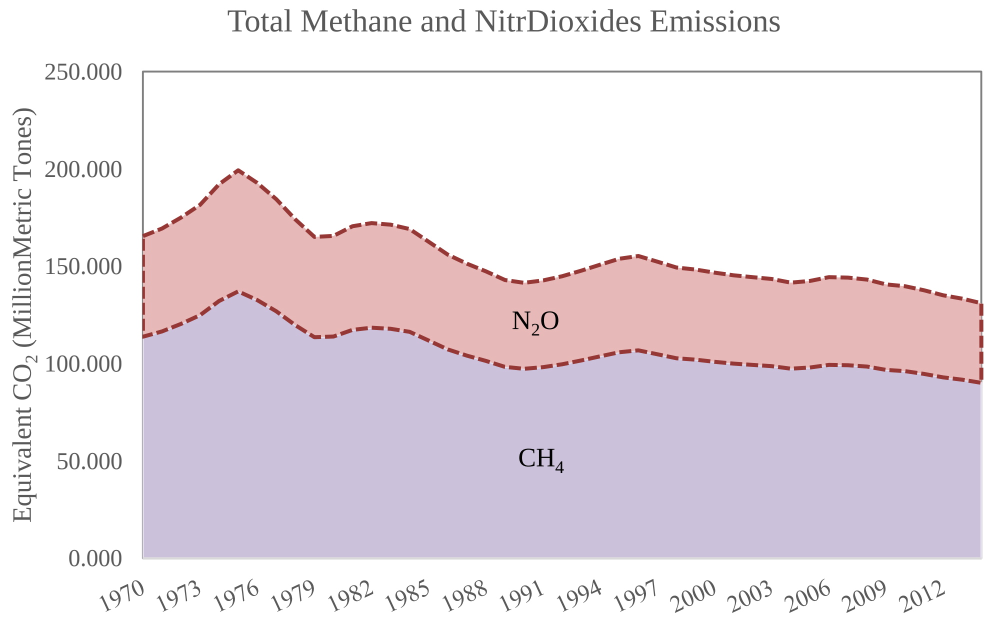



Figure 2: GHGs Emissions from U.S. Beef Cattle

Notes: Emissions are expressed in terms of CO2 equivalent and subdivided into methane ($CH_4$) and nitrous oxide ($N_2O$).

Nitrous oxide includes both direct and indirect emissions.

Sources: Research findings based on FAO data

As we can see in the above graph, $CH_4$ has the largest share in total emissions. $CH_4$ and N2O have both a stable trend over time except for an increase around 1975. This increase and reduction after that are relevant to the total number of beef cattle.

The next graph, display the share of each source of emission in total GHG emissions (Sum of $CH_4$ and $N_2O$).

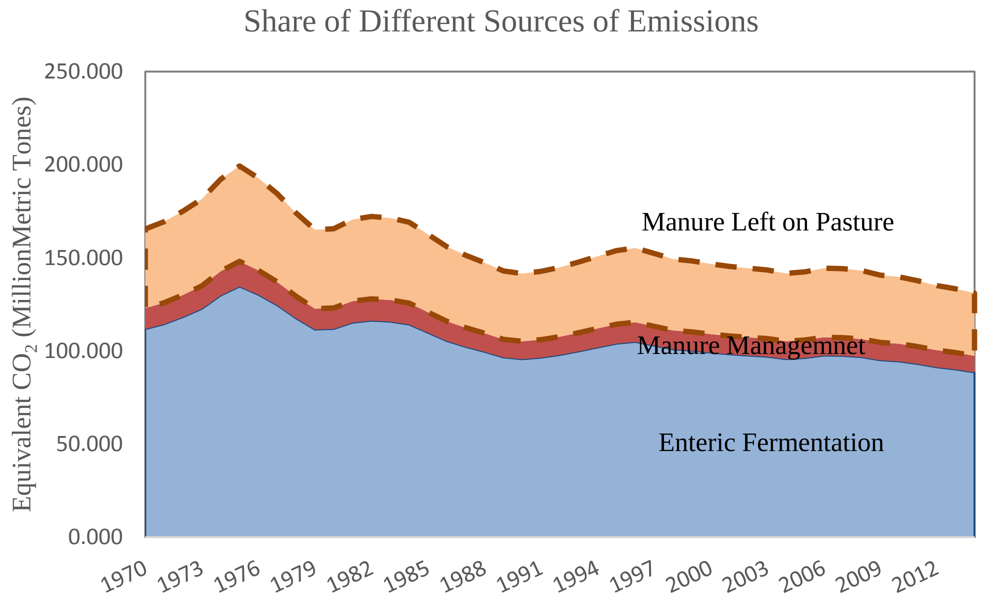



Figure 3: GHGs Emissions from U.S. Beef Cattle

Note: Emissions are expressed in terms of $CO_2$ equivalent and subdivided into enteric fermentation, manure management, and manure left on pasture.

Sources: Research findings based on FAO data

As we can see in the above graph, the largest area is related to the enteric fermentation process. This source of emission is mainly responsible for the total emission, and as we discussed earlier this source led to the emission of both CH4 and N2O. Afte that, manure left on pasture has the biggest share in emission. Finally, the smallest area is related to the share of manure management on total emission.

The result of the stationary test is reported in table 5. The results of the cointegration test and the error correction model are presented in Table 6 and 7.

Table 5: Stataionary Test Results (ADF)

Null Hypothesis: Variable has a unit root.

| Test in | Level | | First Difference | |
|---|---|---|---|---|
| Variable | T-statistics | Prob. | T-statistics | Prob. |
| *GHG* | -0.884 | 0.783 | -4.408*** | 0.001 |
| *Prod* | 0.124 | 0.964 | -6.087*** | 0.000 |
| *Tech* | -2.686* | 0.085 | 4.551*** | 0.000 |
| *Cons* | -0.463 | 0.888 | -5.460*** | 0.000 |

Source: Research findings

The results of ADF test indicate that the null hypothesis of a unit root for all series is rejected at the first difference. Therefore, we can estimate the VECM model if the existence of a cointegration vector is approved.

Table 6: Johansen Cointegration Test Results

Unrestricted Cointegration Test Rank Result (Trace)

| Null Hypothesis | Eigenvalue | Trace statistics | 0.05 critical value | Prob** |
|---|---|---|---|---|
| R=0 ** | 0.488 | 58.23 | 55.24 | 0.026 |
| R<=1 | 0.355 | 29.36 | 35.01 | 0.0177 |
| R<=2 | 0.127 | 10.49 | 18.39 | 0.0433 |

Note: R is the cointegration rank. ** indicates rejection of the hypothesis at the 5% leve.

Source: Research findings

The results reject the null hypothesis R=0 .This indicates that there is at least one vector of long-run relationships.

Table 7: Error Correction Representation

(Dependent variable is $\Delta GHG_t$)

| Regressors | Coefficients | Standard-Error | T-statistics |
|---|---|---|---|
| $\Delta Prod_t$ | 5.21E-07 | 1.1E-0.5 | 0.0048 |
| $\Delta Tech_t$ | $3.16^{***}$ | 0.211 | 14.93 |
| $\Delta Cons_t$ | $0.0023^{***}$ | 0.0006 | 3.814 |
| Error Correction Term | -0.346 | 0.252 | -1.36 |
| $\Delta Constant$ | -4.13 | | |
| R -Squared | 0.81 | | |
| F-stat. F( 5,38) | 25.36 | | |

Note: $^{***}$, $^{**}$, and $^{*}$ indicate significant at 1%, 5%, and 10%, respectively.

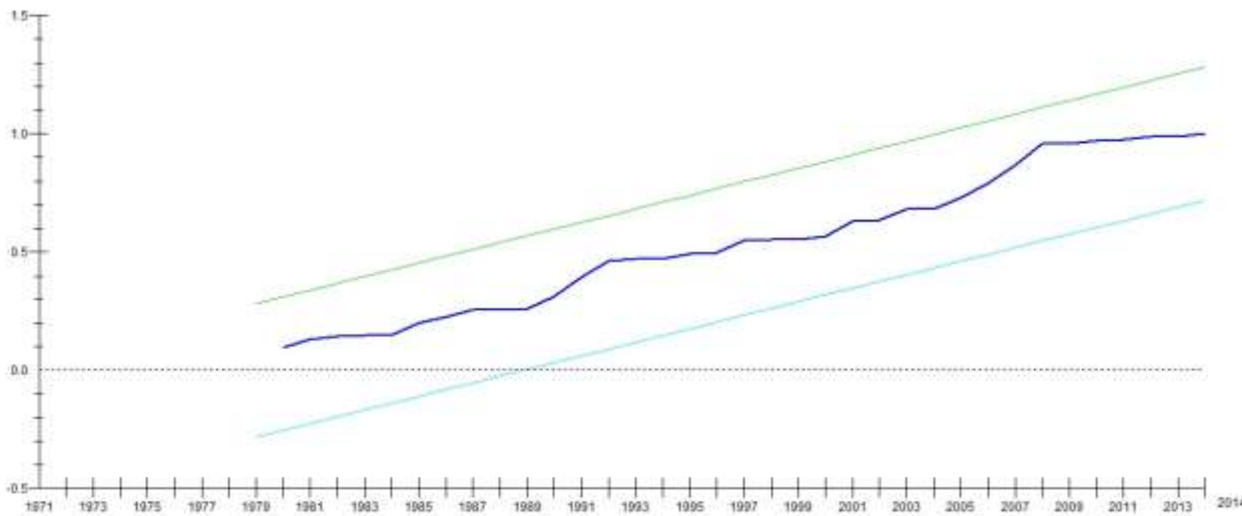
Source: Research findings

The results suggest that if all American consumers reduce their beef consumption, the associated GHG emissions from U.S. beef cattle would reduce by 0.0023 million metric tonnes annually. This suggests that changing consumption patterns do matter in mitigating GHG emission levels associate with beef cattle. However, this effect is small.

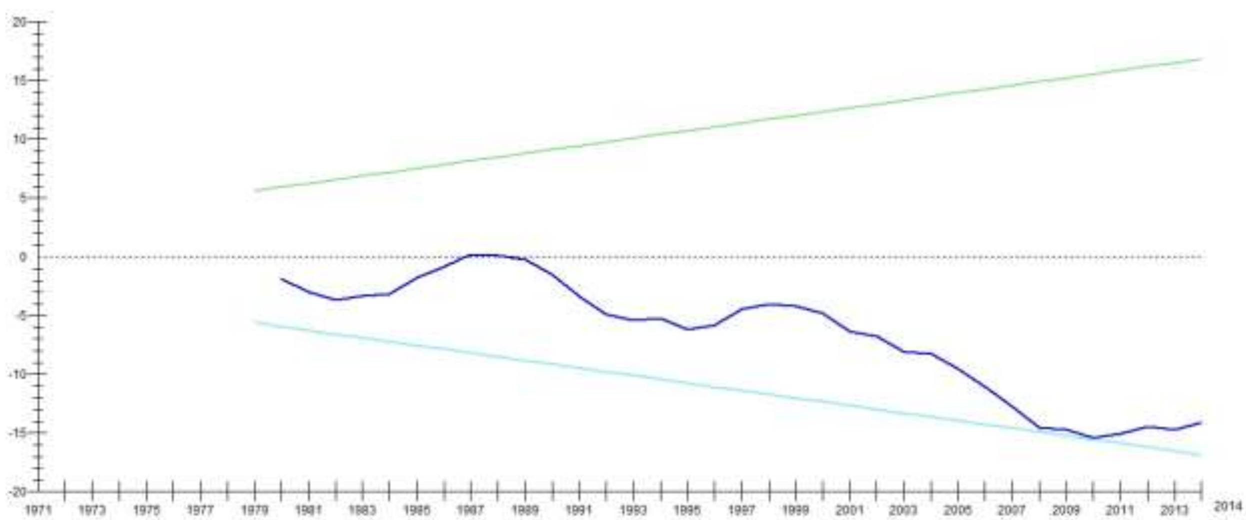
The coefficient for the productivity variable is not significant. One explanation for that is the fact that it is impossible to increase the productivity of beef production unlimitedly over time, and therefore we should focus on other mitigation solutions, such as technical strategies to reduce emissions. The variable for the technical mitigation has a positive and significant coefficient, meaning that if we could find some ways to reduce the leaching and vitalization of animal manure, then the GHG emissions would decrease. Otherwise, more leaching and volatilization from animal manure would result in more GHG emissions.

The $R^2$ is 0.81, supporting that the model fits the data well. The computed F-statistics rejects the null hypothesis that all coefficients are equal zero. The absolute value of the Error Correction Term (ETC) indicates that 34 percent of the disequilibrium is offset by short-run adjustment in each year.

Finally, to examine the stability of the long-run coefficients and the short-run dynamics we employ the CUSUM and CUSUMQ test. These tests are respectively based on the cumulative sum of recursive residuals, and the squared recursive residuals of the model (Bahmani-Oskooee and Ng, (2002)). Figure 4 displays a graphical representation of the above mentioned test. As can be seen, none of two plots cross the critical bounds that affirmed the stability of long-run coefficients. In other words, the null hypothesis that all coefficients in the error correction model are stable cannot be rejected.




**a- Plots of CUSUM Statistics for Coefficient Stability**



**b- Plots of CUSUMSQ Statistics for Coefficient Stability**

Figure 0-4: Plots of CUSUM statistics for coefficient stability (a), and Plots of CUSUMSQ statistics for coefficient stability (b)

Note: The straight lines represent crotical bounds at 5% significance level

Source: Research findings

**Conclusion**

This article contributes to the existing literature on climate change and quantifies the GHG emissions from beef cattle production. In particular, this study has confirmed that reducing beef consumption by American consumers would reduce the GHG emissions. In addition to the expected signs obtained from the model, the estimation results suggest that changing consumption patterns do matter in mitigating GHG emission levels associate with beef cattle. However this effect is small.

On the supply side, some actions have been recommended by researchers. For example, methane abatement strategies, timing manure application, or modifying dietary combination for cattle that led to less emission (Lupis, *et al.*, 2012). These strategies are discussed in previous studies (e.g., Hook, *et al*., 2010).

We used Tire 1 method calculations in this study. As (Caro, et al., 2014) argue, this method does not provide information about livestock production efficiency over time. However, it indicates how GHG emission associated with livestock production has occurred. This method will provide the basic information for establishing policies to mitigate climate change. We encourage to use Tire 2 method in future studies. It is also recommended to see the impact of changing geographical locations of cattle farm to the regions that have lower emission factors in future studies. Because air temperature is a factor that affects the emission from livestock manure.

In summary, apart from the need to practice appropriate mitigation techniques on the supply side, and to promote the productivity of livestock production, the authorities should also take steps to magnify the importance of consumption side actions. For example, by providing information to the public that encourages people to consume more environmentally friendly diets such as vegetarian, and flexitarian[3]. Media attention is needed to convey this message to the public that eating more meat is environmentally detrimental, and we need to change our diet to confine GHG emissions.

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3- Flexitarian consume meat only several days per week (Dagevos and Voordouw, 2013).

## Appendix A. GHG Emissions Equations Based on IPCC (2006) Guideline

To estimate emissions from U.S. beef cattle, we followed IPCC guideline. Equation (1) and (2) represent the released methane from enteric fermentation and manure management, respectively.

$$Methane_{fermentation(t)} = EF_{fermentation} \times N_t \times 10^{-6} \qquad \text{Equ (1)}$$

Where:

$Methane_{fermentation(t)}$= methane emissions from enteric fermentation at time t, (Gg $CH_4$ $yr^{-1}$)

$EF_{fermentation}$ = emission factor for beef cattle in North America region, constant over time, (Kg $CH_4$ $head^{-1}yr^{-1}$)

$N_{(t)}$ = the number of beef cattle at time t (head)

$$Methane_{manure(t)} = EF_{manure} \times N_t \times 10^{-6} \qquad \text{Equ (2)}$$

Where:

$Methane_{manure(t)}$= methane emissions from manure management, for a defined population, (Gg $CH_4$ $yr^{-1}$)

$EF_{manure\ (t)}$= emission factor for beef cattle at time t, (varying by annual temperature) (Kg $CH_4$ $head^{-1}yr^{-1}$)

$N_{(t)}$ = the number of beef cattle at time t (head)

After estimating equation (1) and (2), we multiply the results by global warming potential of $CH_4$ and $N_2O$ (GWP) to have carbon dioxide equivalent ($CO_2$ eq). As we discussed earlier, the dry lot and on-pasture manure management are two management systems relevant to beef cattle in North America (IPCC, 2006).

To estimate the direct and indirect nitrogen oxide associated with manure management, we use equation (3) and (4), respectively. These equations are based on IPCC guideline.

$$N_2O_{D(t)} = \sum_{s}\left[N_{(t)} \times Nex_{(t)} \times MS_{(s,t)} \times EF_{3(s)}\right] \times \frac{44}{28}$$

Equ (3)

Where:

$N_2O_{D(t)}$ = direct $N_2O$ emissions from Manure Management at time t, (Kg $N_2O$ $yr^{-1}$)

$N_{(t)}$ = the number of beef cattle at time t (head)

$Nex_{(t)}$= annual average N excretion per head at time t, (Kg $N$ $animal^{-1}yr^{-1}$)

$MS_{(t)}$ = fraction of total annual nitrogen excretion for beef cattle that is managed in manure management system *dry lot*, dimensionless

$EF_3$= emission factor for direct $N_2O$ emissions from manure management system *dry lot*, constant over time

And

$$N_2O_{ID(t)} = \sum_{S} \left[ NE_{(t)} \times Frac_{GasMS(s,t)} \times EF_4 \right] \times \frac{44}{28}$$

Equ (4)

Where:

$N_2O_{ID(t)}$ = indirect $N_2O$ emissions due to volatilization of N from Manure Management at time t, (Kg $N_2O$ $yr^{-1}$)

$NE_{(t)}$ = total nitrogen excretion from manure management

$Frac_{GasMS(s,t)}$= fraction of managed manure nitrogen that volatilizes as $NH_3O$ and $NO_x$ in the manure management system $S$, %

$EF_4$= emission factor for $N_2O$ emissions from atmospheric deposition of nitrogen on soils and water surfaces, constant over time

In the above equation the variable $NE_{(t)}$ is calculated by multiplying the variables $N_{(t)}$, $Nex_{(t)}$, and $MS_{(s,t)}$ that were explained in equation (3).

For complete coverage of the direct and indirect $N_2O$ emissions and accurate estimation we need to estimate emissions for all anthropogenic inputs and activities (IPCC, 2006). Figure (A-1) summarize the calculation steps schematically as follows:

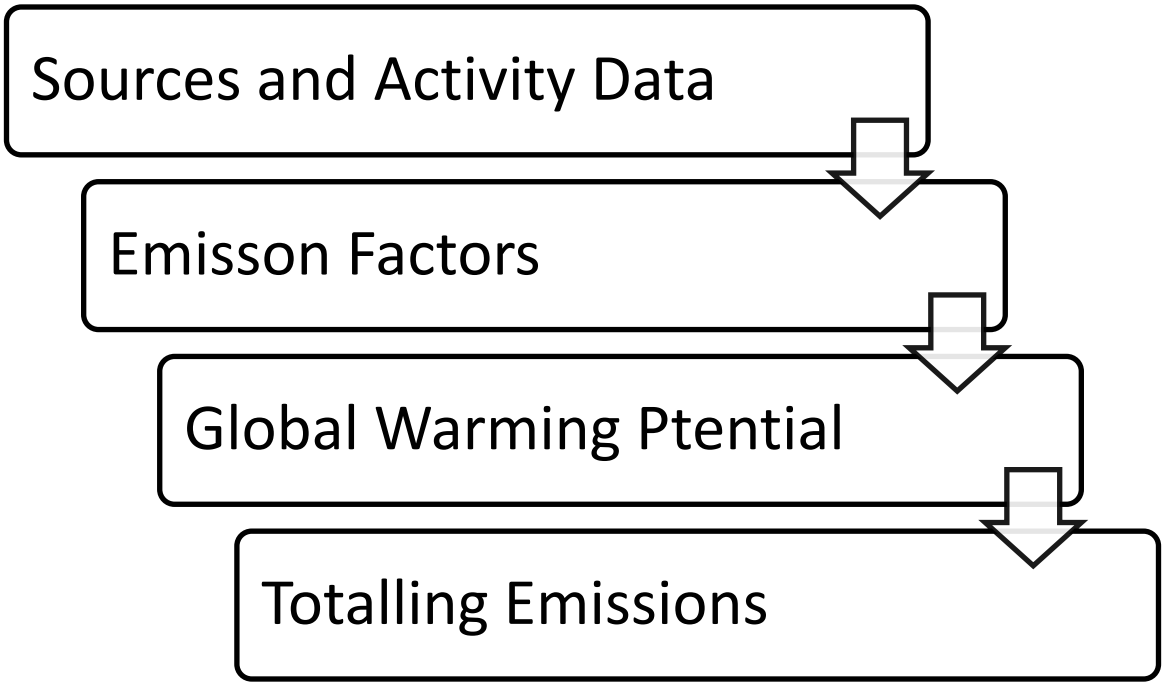


Figure A-1: Schematic View of Calculating GHG Emissions

Sources: Based on IPCC (2006) guideline

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