Where is Risk in Fumigation Choice: Methyl Bromide versus Alternatives?

Serhat Asci[1]
Research Fellow
E-mail: sasci@csufresno.edu

John J. VanSickle[2]
Professor

Curtiss J. Fry[2]
Graduate Student

John Thomas[3]
Research Associate Professor

[1]Agricultural Business Center,
California State University, Fresno
[2]Food and Resource Economics Department,
[3]Soil and Water Science Department,
University of Florida

Selected Paper prepared for presentation at the Southern Agricultural Economics Association's 2015 Annual Meeting, Atlanta, Georgia, January 31-February 3, 2015

Where is Risk in Fumigation Choice: Methyl Bromide versus Alternatives?

Serhat Asci, John J. VanSickle, Curtiss J. Fry, John Thomas[1]

[1]The authors are (respectively): Research Fellow in Agricultural Business Center, California State University, Fresno, Professor and Graduate Student in the Food and Resource Economics Department, University of Florida and Research Associate Professor in Soil and Water Science Department, University of Florida

Abstract

The phaseout of Methyl Bromide (MBr) required by the Montreal Protocol on Substances that Deplete the Ozone Layer has decreased its use in soil fumigation in the United States (U.S.). Reduced supplies also increased the price of MBr and affected producers net revenues and its cost effectiveness as a soil fumigant. The phaseout encouraged some producers to switch to available alternatives. Previous studies using partial budget analysis show that some alternatives are more cost effective with higher yields. Nevertheless, the share of crop acreage treated with MBr remains high, especially for tomatoes and strawberries. This study analyzes producers' risk and risk aversion to construct a more comprehensive yield and economic analysis of the MBr use decision. The data are collected from fresh tomatoes production trials with MBr and alternatives conducted at the Plant Science Research and Education Unit, University of Florida in Citra, FL. The results show that alternative fumigants (especially carbonated Telone C35 with totally impermeable films) are often cost effective and provide higher yields. However, a risk analysis indicates that MBr has lower downside risk and is still preferred by risk averse producers.

Keywords: Methyl Bromide and alternatives, yield risk, stochastic dominance and efficiency.

Acknowledgement. The authors would like to acknowledge funding support for this study from United States Department of Agriculture, National Institute of Food and Agriculture award #2010-51102-21657. We would also like to thank Dr. Mike Aerts, the Director of Production and Supply Chain Management at the Florida Fruit & Vegetable Association for his help and useful suggestions for budget revision for field-grown tomato production.

1. Introduction

Methyl Bromide (MBr) is utilized in agricultural production as a soil and structural fumigant to control pests, pathogens, and weeds (EPA, 2014). Historically the largest consumers of MBr have been tomato and strawberry producers in Florida and California (Ristaino and Thomas, 1997). Widespread use of MBr began in the 1960's for California strawberries and late 1970's for Florida tomatoes (Carpenter, Gianessi and Lynch, 2000). At one point MBr was one of the top five most used pesticides in the United States (Ristaino and Thomas, 1997). Since its implementation yields have increased significantly. Florida tomato yields doubled from the 1960's to the 1990's (Carpenter, Gianessi and Lynch, 2000) and California strawberry yields increased from five tons per acre to over 20 tons per acre (Backstrom, 2002). MBr has proven to be a cost effective single instrument for producers to control soil borne diseases, fungus, insects, and weeds.

Although MBr has proven to be an essential tool in agricultural production it has been classified as an Ozone Depleting Substance. Ozone is a rare form of oxygen that plays a key function in moderating the Earth's climate by absorbing ultraviolet radiation (Ristaino and Thomas, 1997). Due to the United States' commitment to the Montreal Protocol on Substances that Deplete the Ozone Layer, the use of MBr in the U.S. has been phased out. The Montreal Protocol outlined a timeline of incremental reductions of the use of MBr. The phaseout began with a freeze at 1991 baseline levels of U.S. Consumption, 25,000 metric tons from 1993 to 1998. From 1999 to 2000 a 25% reduction from baseline levels was required. From 2001 to 2002 a 50% reduction from baseline levels was required. From 2003 to 2004 70% reduction and in 2005 a 100% reduction of MBr consumption was required. The protocol allowed for critical use exemptions that were agreed upon by the signing nations (EPA, 2014). According to the EPA's record of critical use exemption nominations, tomatoes were last nominated for a critical use exemption in 2013 and California strawberries have been nominated through 2016 (EPA, 2014). Florida tomato growers have started to feel the effects of the loss of MBr. Since the phaseout, pathogens have built up in the soil and contributed to a significant increase in disease incidence leading to crop loss (Vallad, 2014). In this study, we analyze MBr and its alternatives incorporating risk perception for understanding the decisions adopted by producers.

2. Methyl Bromide Use and Alternatives for Tomato Production in Florida

Cash receipts for fresh market tomatoes account for around 8% of total cash receipts from farm marketing in Florida according to U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS 2014a). Florida still ranks first in terms of total value of production for fresh market tomatoes. The production area for tomatoes dropped significantly from 45,000 acres in 2005 to 35,000 acres in 2013 with a sharp decrease in cash receipts from $805 million to $456 million. We also witnessed a declining trend in market value of Florida fresh tomatoes and saw their yields in the last decade drop from 370 lbs/acre in 2005 to 265 lbs/acre in 2013 (USDA-NASS 2014a; Figure 1). Since Florida soil is generally sandy, the organic matter content and the fertility of the soil are low (Rosskopf et al. 2005). The development of plastic mulch in the early 1950s played a significant role in the commercial production and economic success of some vegetable production including tomatoes in Florida (Lament 1993). Plastic mulch used as a "raised bed-plastic mulch" system dependent on fumigation with a mixture of MBr and chloropicrin (Rosskopf et al. 2005). In the last decades, the estimates of MBr use for Florida fresh tomatoes were 5.6 million pounds in 1992 and no estimate for MBr use was reported after 2006 (USDA-NASS 2014b; Figure 2).

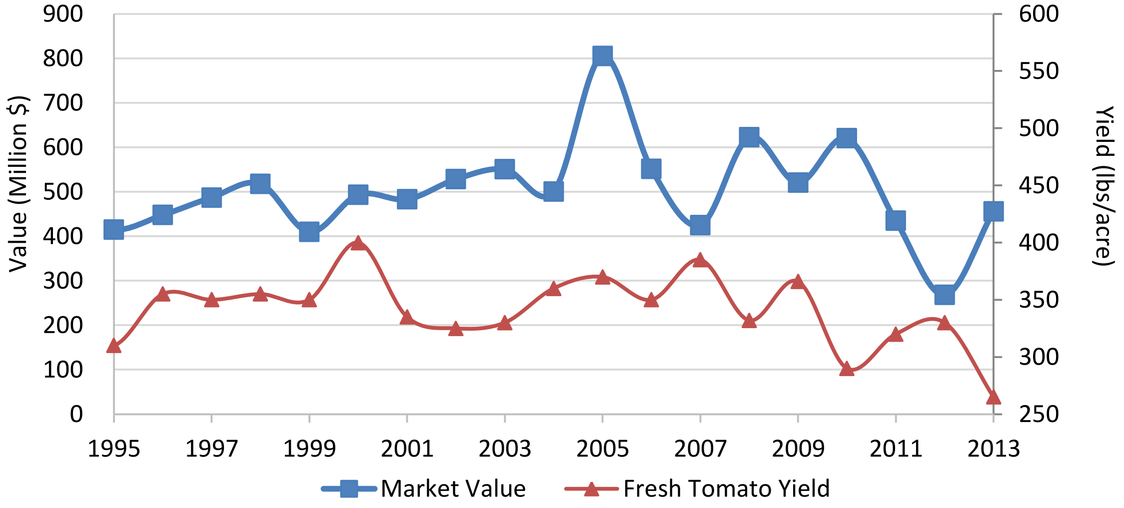

Figure 1. Fresh tomato market value and yield for Florida's fresh tomatoes, 1995-2013 (USDA-NASS 2014a).

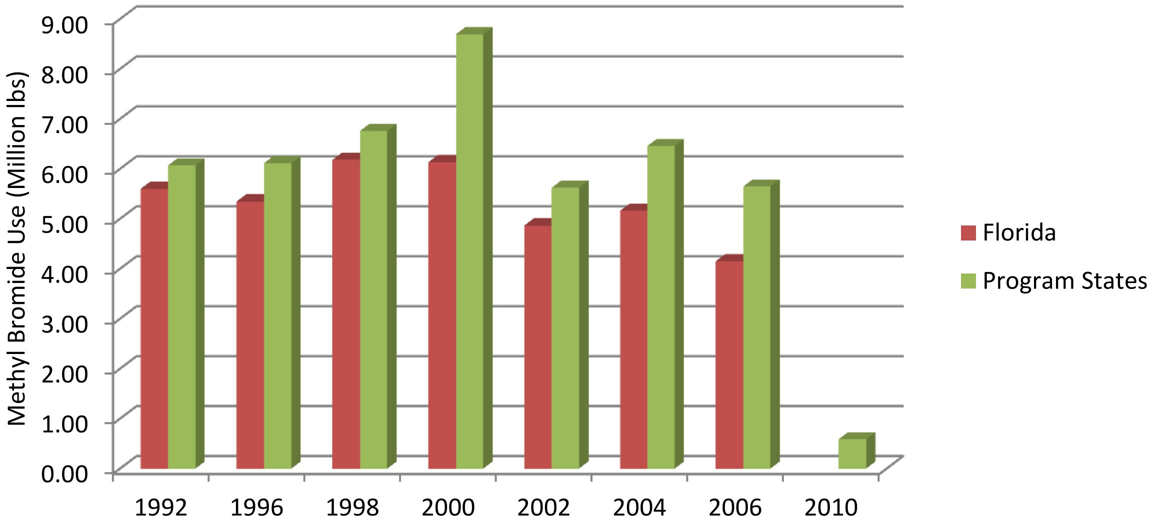

Figure 2. Methyl Bromide use estimates for fresh tomatoes in Florida and program states, 1992-2010 (USDA NASS, 2014b)

In order to identify the best MBr alternatives for tomatoes, strawberry and floriculture production, extensive studies have been conducted by examining and/or re-examining new and existing soil fumigants such as 1,3-Dichloropropene, methyl isothiocyanate (MITC) generators and chloropicrin (Rosskopf et al. 2005). Based on the research results, Environmental Protection Agency (EPA) published a list of chemical and non-chemical alternatives and relevant studies for each crop. In this list, the registered chemicals for tomatoes include 1,3-Dichloropropene, Chloropicrin, Dazomet (only for California), Dimethyl Disulfide, Fosthiazate, Glyphosate, Metam Sodium, Paraquat, Halosulfuron-methyl, s-Metolachlor, Trifloxysulfuron-methyl, Rimsulfuron, Metam Sodium + Chloropicrin, 1,3-Dichloropropene + Metam Sodium, and 1,3-Dichloropropene + Chloropicrin (EPA, 2014). Most of the research on these products has been presented at the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions since 1994 and these conferences have been sponsored by Methyl Bromide Alternatives Outreach, EPA and U.S. Department of Agriculture. The research on alternatives shows that none of the alternatives perfectly substitute for MBr but some alternatives result in relatively similar pesticidal activity compared to MBr (Table 1).

Table 1.The relative effectiveness of various soil fumigant alternatives to methyl bromide for nematode, soilborne disease, and weed control in Florida

	Relative Pesticidal Activity		
Fumigant	**Nematode**	**Disease**	**Weed**
1) Methyl Bromide 50/50	Good to Excellent	Excellent	Fair to Excellent
2) Chloropicrin2	None to Poor	Excellent	Poor
3) Methyl Iodide	Good to Excellent	Good to Excellent	Good to Excellent
4) Metam Sodium	Erratic	Erratic	Erratic
5) Telone® II	Good to Excellent	None to Poor	Poor
6) Telone® C17	Good to Excellent	Good	Poor
7) Telone® C35	Good to Excellent	Good to Excellent	Poor to Fair
8) Pic-Clor 60	Good to Excellent	Good to Excellent	Poor to Fair
9) Metam Potassium (Kpam)	Erratic	Erratic	Erratic
10) Dimethyl Disulfide	Good to Excellent	Good to Excellent	Poor to Excellent

Notes: The table is adjusted from the University of Florida extension study on MBr alternatives (Noling et al. 2012).

Table 1 shows that the alternatives having relatively similar pesticidal activity compared to MBr are Methyl Iodide, Telone C35, and Dimethyl Disulfide. In this study, we analyze the yield risk of the later two chemicals and compare those with MBr.

3. Literature Review

Producers have been forced to seek alternatives to adapt to the phaseout of MBr. Finding and implementing cost effective alternatives that offer MBr's efficacy, ease of use and worker safety has proven difficult. As of now there is no known single substitute for MBr and research has been tasked with finding a feasible cocktail of chemicals as an alternative (Sydorovych et al., 2006). There are several studies that have evaluated the economics and the risk associated with MBr and its alternatives using various methods.

Phillips et al (2009) utilized a meta-analysis technique to compare MBr and its alternatives by comparing data from over 400 studies. The analysis comprised of studies that measured yield information for tomatoes and strawberries by comparing an untreated control, a MBr treatment, and alternatives. Meta-analysis is traditionally used for medical and social science research, its application to agriculture is a novel approach. The study first sought to determine if the application rate of MBr caused statistically different results in yield when compared to the untreated control using a 95 percent confidence interval. The meta-analysis found that for strawberries in California, the low rate of MBr was not statistically different. For Florida strawberries, the medium rate was not statistically different. For strawberries in Spain, the low, medium, and high rates were all statistically different. The low and medium rates were not statistically different for Florida tomatoes. The meta-analysis concludes that MBr works differently across sites and rates and that there are no available alternatives for U.S. producers that work as well as MBr.

In another study, Sydorovych et al (2006) employed partial budget analysis to evaluate MBr alternatives based on their cost effectiveness for the production of strawberries in the southeastern United States. The objectives of their study were twofold: first, to estimate the cost and returns associated with growing, harvesting, and marketing strawberries when using MBr and plasticulture and; second, to evaluate chemical alternatives to MBr currently available to strawberry growers based on the impact on net returns. A cost model was developed using MBr combined with chloropicrin as the standard production practice. This became the base budget to compare MBr and alternatives. In order to compare the yield data between different years and sites the researchers normalized yield data to the average strawberry yield for the MBr plots obtained in the same experiment in the same year. By doing this the researchers were able to sidestep yield variations due to years and site differences. After normalizing all the yield data to the MBr treatment a partial budget analysis was conducted. The partial budget analysis followed a seven point format outlined by Dalsted and Gutierrez (1992). The analysis looked at the negative effects which include the added costs attributable to the new fumigant, reduced returns attributable to the new fumigant, and the total negative effects attributable to the new fumigant. Next the analysis examines the positive effects which include the reduced costs attributable to the new fumigant, added returns attributable to the new fumigant, and the total positive effects attributable to the new fumigant. Lastly the analysis studies the total effects. Sydorovych et al (2006) concluded based on their analysis there are economically feasible fumigation alternatives to MBr for the production of strawberries in the southeast, but the performance of alternatives is not uniform across the region.

Byrd et al (2007) addressed the financial feasibility of utilization of combination fumigation-herbicide MBr alternatives for Georgia bell pepper producers. The study examines alternatives from both risky and risk-free operating situations by utilizing two analytical tools, stochastic dominance and simulation-optimization techniques. First, the study applied second-degree stochastic analysis to consider the riskiness of the MBr alternatives to identify the most risk-efficient model. Data limitations with regards to the new alternatives required the study to formulate a multi-period linear programing framework to analyze the comparable yield efficiency and financial feasibility of three alternatives under a risk free operating environment. The three alternatives were based on field trials relative to a base treatment of MBr. To deal with the existence of crossing of distribution plots, Byrd et al (2007) applied two scenarios of high and low risk aversion to capture any variations in the ranking of alternatives. Four variables were considered separately in the stochastic dominance analysis. First, an aggregate yield measure that disregarded the pepper grade components of total yield. Second, a jumbo (fancy pepper grade) yield measure which commanded a higher price than the regular US 1&2 pepper grade. Third, a gross revenue measure where the grade components of total yield were weighted by the grades' respective prices. Fourth and lastly, a net return per acre measure derived from the extrapolated experimental yields and the corresponding variable and fixed costs for each acre of pepper farm operations. The stochastic dominance analysis was conducted using yield and cost data from two production cycles of six experimental plots. An enterprise budget model was developed and used to calculate values for gross and net returns. Next the study went on to analyze financial and production decisions of a representative Georgia pepper farmer using simulation optimization techniques. The study utilized a risk-neutral liner programing model to account for the net changes in final wealth regardless of the producer's risk considerations. The goal of optimizing a producer's net worth begins with the analysis of a base model. The base model accounts for a typical producer operation based on activity and financial considerations. The analysis involved adjustments in the production systems to the base model based on the fumigants and herbicides used. The MBr model serves as the base case. The study concluded that feasible alternatives to MBr do exist for Georgia pepper producers but their successful implementation has yet to be determined. Only actual commercial use will determine if the alternatives will prove to be a lasting replacement of MBr.

4. Data and Model

In this study, we used the data collected from field studies conducted at the Plant Science Research and Education Unit, University of Florida. The original field studies aimed to analyze the efficacy of Telone C35 (C35) for the 2011-2012 season and Dimethyl Disulfide (DMDS) combined with chloropicrin (Pic) for the 2012-2013 season with carbonation and low permeable films. The films used in these studies were virtually impermeable film (VIF) and totally impermeable film (TIF) in the 2011-2012 season and only totally impermeable film (TIF) in the 2012-2013 season. The study field site was located at the Plant Science Research and Education Unit of the University of Florida in Citra about 35 km south of Gainesville, Florida. The soil at the site was classified as Arredondo fine sand, a good representative of Florida soil (Thomas et al. 2012).

These studies aim to compare the marketable yields of tomatoes from various chemical applications. In 2011-2012 season, the samples were collected for carbonation of Telone C35 and Telone C35 dispersed by N_2 in different rates (full, 0.5, 0.3) and two different films (VIF and TIF). These samples were later compared with marketable yield from a MBr (50:50) plot and an untreated production plot produced under similar conditions. In the 2012-2013 season, a similar procedure was repeated for DMDS: Pic with carbonation and N_2 dispersion. However, in this case only TIF is used as a permeable film. The marketable yields obtained from various application rates of DMDS:Pic (15 GPA, 25 GPA, and 40 GPA) were compared with MBr and untreated production again. The study results are summarized in Table 2. The results show that MBr consistently gave high yield performance in both seasons while yield from C35 and DMDS:Pic vary based on the application rates and plastics.

Table 2. Summary Yield Results of Field Studies for 2011-2012 and 2012-2013 seasons

Treatment	Plastic	Season	Marketable Yield (Mean) (lbs/Plant)	Standard Deviation	Marketable Yield (Median) (lbs/Plant)
Methyl Bromide trials					
350 lb 50:50 MBr:Pic*	VIF	2011-12	8.23	1.18	8.41
400 lb 50:50 MBr:Pic	TIF	2012-13	8.37	2.38	8.61
Telone C35 trials					
Full C35 + N2	VIF	2011-12	6.42	1.36	6.33
0.5 C35 + N2	VIF	2011-12	4.94	1.71	4.84
0.3 C35 + N2	VIF	2011-12	3.38	1.84	3.35
0.3 C35 + N2*	TIF	2011-12	8.00	2.27	7.44
0.5 C35 + CO2	VIF	2011-12	5.39	1.85	5.37
0.3 C35 + CO2	VIF	2011-12	4.15	1.65	3.63
0.3 C35 + CO2*	TIF	2011-12	8.74	2.18	8.91
Dimethyl Disulfide trials					
15 GPA 79:21 DMDS:Pic + CO2	TIF	2012-13	7.77	1.73	8.09
25 GPA 79:21 DMDS:Pic + CO2	TIF	2012-13	7.17	1.61	7.12
40 GPA 79:21 DMDS:Pic + CO2*	TIF	2012-13	7.83	1.28	7.69
15 GPA 79:21 DMDS:Pic + N2	TIF	2012-13	6.98	2.18	7.22
25 GPA 79:21 DMDS:Pic + N2	TIF	2012-13	7.46	1.85	7.69
40 GPA 79:21 DMDS:Pic + N2*	TIF	2012-13	8.82	2.24	9.32
Control trials					
Untreated	VIF	2011-12	1.24	0.57	1.16
Untreated	TIF	2011-12	3.66	1.23	3.50
Untreated	TIF	2012-13	5.24	2.78	6.14

Notes: * represents the top yield performances from trials used in risk analysis.

For comparison, we selected the top two yield performances for each alternatives trials and the top yield performance for methyl bromide trial. Then we simulated the yields and net present values (NPVs) using Monte Carlo simulation in Simetar© software (Richardson 2008; Richardson et al. 2000). Risk parameters are the yield from trial data and the sales prices correlated with the tomato yield for the financial statement analysis. Historical price and yield data were collected from U.S. Department of Agriculture, Economic Research Service (USDA-ERS) annual field-grown price and yield from 1990 to 2013 for Florida (USDA-ERS, 2014). Time series tomato price data are used to assess price/yield correlation and volatility. The correlation is used in price simulations, which is then applied to financial analysis which is constructed on the field tomato production budget in Manatee/Ruskin Area for 2008-2009 season, updated for 2013-2014 season (Smith and VanSickle, 2009). All simulated stochastic components are iterated simultaneously in the model and the key components of the financial model are simulated 500 times for each fumigant to estimate the probability density functions (PDF) and cumulative distribution functions (CDF). The distributions are ranked using Simetar© software tools such as mean variance method, first and second degree stochastic dominance, stochastic dominance with respect to a function (SDRF) and stochastic efficiency with respect to a function (SERF) to incorporate risk aversion (Hardaker et al. 2004).

Mean variance method, first and second degree stochastic dominance, SDRF and SERF were used to rank the risky production technology alternatives. Mean variance method simply looks for less variance and higher mean for ranking the risky alternatives. First degree stochastic dominance compares CDFs of the NPVs for the risky alternatives. If CDFs of two alternatives are represented as F(x) and G(x), and F(x) dominates G(x), then $\sum F(x) \leq \sum G(x)$ for all x. CDFs of the two alternatives compared should not cross each other (Richardson and Outlaw 2008). If they cross, one could use second degree stochastic dominance for ranking the risky alternatives. Using this criterion, if F(x) dominates G(x) when we obtain $\sum F(x) - \sum G(x) \leq 0$ for all x. Finally, SDRF was applied to incorporate known risk aversion coefficients (RAC) into ranking of risky alternatives. SDRF can be described as follows:

$$\sum U(x, r_i(x))F(x) \leq \sum U(x, r_i(x))G(x) \tag{1}$$

where F(x) is preferred to G(x) under given risk aversion coefficient ($r_i(x)$) of the decision maker where *i* refers to the upper and lower limits of risk aversion coefficients (Richardson and Outlaw 2008). At last, SERF examines the range of producers' risk aversion for which the certainty equivalent (CE) is calculated to determine the ranking of risky alternatives (Hardaker et al. 2004).

$$CE(x_{ij}, r_i(x))_{ij} = U^{-1}(x_{ij}, r_i(x)) \tag{2}$$

where $U^{-1}(\ldots)$ is the inverse utility function and CE values are calculated for *j* risky alternatives between upper and lower limits of risk aversion coefficients, respectively, represented as ($r_U(x)$) and ($r_L(x)$).

5. Results

5.1. Comparison of MBr with TeloneC35

The stochastic NPVs are computed when all budget information is substituted into the financial model at the mean values. NPVs for each fumigants are calculated separately for ten-year period. The probability distribution function (PDF) of NPV values for alternative fumigants are illustrated in Figure 3. NPV distributions suggest that production technology using Telone C35 alternatives have larger NPV mean than the tomato production with MBr use. Therefore, the production with MBr would not be preferable. However, tomato yield trails using MBr shows lower standard deviations which indicates that the shift away from MBr may be driven by cost and the late adopters may be driven by risk. Thus, we compare the yield distribution of these production scenarios.

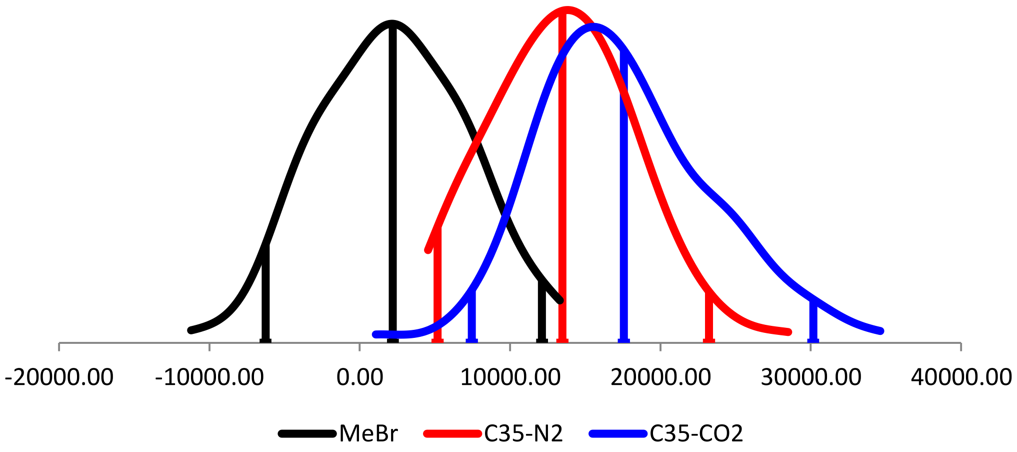

Figure 3. Probability Distribution Function Approximations of Net Present Values for a 1-Acre tomato farm with MBr and Telone C35.

Figure 4 shows the PDFs of yield for alternative fumigants. The mean values suggest that the production with carbonated Telone C35 (C35-CO2) gives the highest yield followed by the production with Telone C35 with nitrogen (C35-N2) and MBr. The graphs also indicates that the production with MBr is less risky than the alternative production technologies. Thus, risk aversion of the decision maker is taken into consideration when we rank the production alternatives with stochastic dominance with respect to a function (SDRF) analysis and then using stochastic efficiency with respect to a function (SERF) analysis.

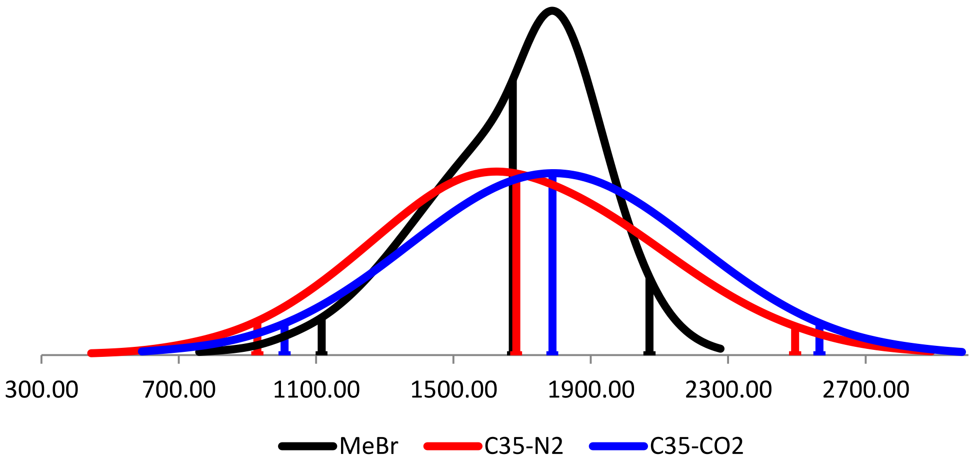

Figure 4. Probability Distribution Function Approximations of tomato yield with MBr and Telone C35.

The first preferred set based on SDRF at the lower risk aversion coefficient (RAC=0) shows the ranking for a risk neutral producer (Table 3). The ranking for risk neutral producer suggest that C35-CO2 is the first preferred alternative and it is followed by C35-N2 and MBr technologies, which is consistent with the PDF results. However, the preference among the alternative options changes for the extremely risk-averse producer. The absolute risk aversion coefficient is calculated by a (y) = (r (y) / y) = (4 / 8,000) = 0.005 where y represents mean yield from all trials and the relative risk aversion coefficients are classified from zero to four representing, respectively, from the risk neutral to the extremely risk-averse person (Richardson and Outlaw 2008). Thus, extremely risk-averse decision makers prefer the field-grown tomato production with MBr over both Telone C35 alternatives.

Table 3. Analysis of tomato yield with MBr and Telone C35 using Stochastic Dominance with Respect to a Function (SDRF).

	Efficient Set Based on SDRF at Lower RAC	**0**		Efficient Set Based on SDRF at Upper RAC	**0.005**
	Name	Level of Preference		Name	Level of Preference
1	C35-CO2	Most Preferred	1	MBr	Most Preferred
2	C35-N2	2nd Most Preferred	2	C35-CO2	2nd Most Preferred
3	MBr	3rd Most Preferred	3	C35-N2	3rd Most Preferred

SERF provides us a broad overview of the risky alternatives over a range of absolute risk aversion coefficients (ARAC). Figure 5 illustrates the certainty equivalent of the alternative technologies for a range of producers' risk-aversion levels (i.e., from risk neutral to extremely risk-averse). The figure indicates that C35-CO2 dominates for the ARAC values from 0 to 0.0025, and MBr dominates at the rest. This result implies that C35-CO2 is the preferred technology for the risk a neutral and a normally risk-averse producer. In turn, MBr is the preferred risky alternative for a moderately and an extremely risk-averse producer.

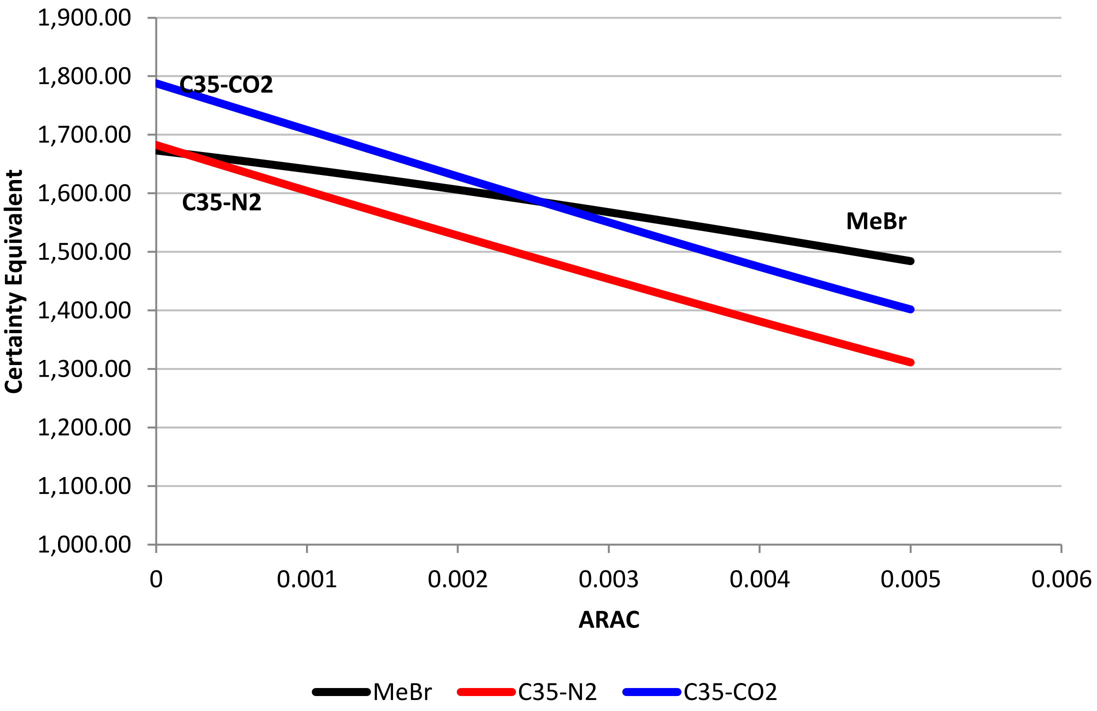

Figure 5. Analysis of tomato yield with MBr and Telone C35 using Stochastic Efficiency with Respect to a Function (SERF).

5.2. Comparison of MBr with DMDS

The comparison of field-grown tomato production using MBr with production using DMDS give us the similar results. Figure 6 shows the PDFs of yield for alternative fumigants including MBr and DMDS production technologies. The mean values suggest that the production with carbonated DMDS with nitrogen (DMDS-N2) gives the highest yield followed by the production with MBr and carbonated DMDS (DMDS-CO2). When we include risk aversion of the decision maker into consideration using stochastic dominance with respect to a function (SDRF) analysis, we witness the shift in preference of extremely risk-averse producer into production using MBr (Table 4).

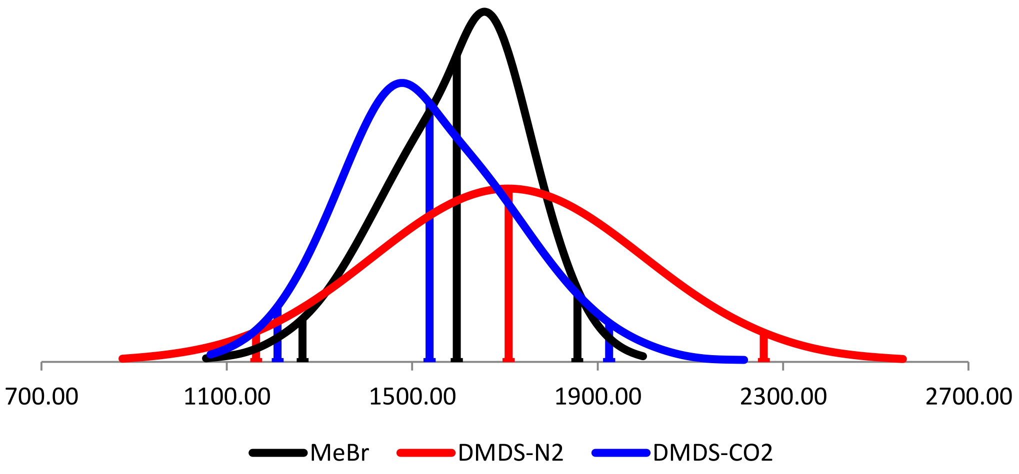

Figure 6. Probability Distribution Function Approximations of tomato yield with MBr and DMDS:Pic.

Table 4. Analysis of tomato yield with MBr and DMDS:Pic using Stochastic Dominance with Respect to a Function (SDRF).

	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**0**		Upper RAC	**0.005**
	Name	Level of Preference		Name	Level of Preference
1	DMDS-N2	Most Preferred	1	MBr	Most Preferred
2	MBr	2nd Most Preferred	2	DMDS-N2	2nd Most Preferred
3	DMDS-CO2	3rd Most Preferred	3	DMDS-CO2	3rd Most Preferred

6. Conclusion

- NPV distributions suggest that production technology using Telone C35 alternatives have larger NPV mean than the tomato production with MBr use.

- The PDFs of yield for alternative fumigants show that the production with MBr is less risky than the alternative production technologies.

- When we include risk aversion of the decision maker into consideration using stochastic dominance with respect to a function (SDRF) analysis, we witness the shift in preference of extremely risk-averse producer into production using MBr.

- Lastly, to understand whether the shift away from MeBr is driven by cost, we repeated the financial NPV analysis using MBr unit price of $2.5 per pound which is the average chemical price before reduction began in 1999 (Osteen, 2003). Previously, the recent MBr price was taken as $7 per pound for NPV analysis. The results show that, in 1999 prices, MBr becomes the most attractive fumigant even to risk neutral producers compared to the Telone C35 alternatives which indicates that the shift away from MBr is driven by cost since the late adopters are riskier alternatives in terms of yield.

References

Backstrom, M.J., II. Methyl Bromide: The Problem, the Phase Out, and the Alternatives. *Drake Journal of Agricultural Law* 7 (2002): 213-39.

Byrd, M.M., Escalante, C.L., Fonsah, E.G., and M.E. Wetzstein. Feasible Fumigant-Herbicide System Alternatives to Methyl Bromide for Bell Pepper Producers. *Journal of Agribusiness* 25.1 (2007): 31-45.

Carpenter, J., Gianessi, L., and L. Lynch. *The Economic Impact of the Scheduled U.S. Phaseout of Methyl Bromide*. Rep. Washington DC: National Center for Food and Agricultural Policy, 2000. Print.

Environmental Protection Agency (EPA). 2014. The Phaseout of Methyl Bromide, 5 Aug. 2014. Available online at http://www.epa.gov/ozone/mbr/index.html.

Hardaker, J.B., J.W. Richardson, G. Lien, and K.D. Schumann. 2004. Stochastic Efficiency Analysis with Risk Aversion Bounds: A Simplified Approach. *The Australian Journal of Agricultural and Resource Economics* 48(2): 253-270.

Noling, J.W., Botts, D.A., and A.W. MacRae. 2012. Alternatives to Methyl Bromide Soil Fumigation for Florida Vegetable Production. UF/EDIS Publication #CV290. Available online at http://edis.ifas.ufl.edu/cv290.

Osteen, C. 2003. Methyl Bromide Phaseout Proceeds: Users Request Exemptions. *Amber Waves*, 1: 22–27. Available online at http://www.ers.usda.gov/amber-waves/2003-april/methyl-bromide-phaseout-proceeds.aspx#.VLcJ3yvF98E.

Phillips, B., Chism, B., Augustyniak, C. and T. Narayan. 2009. *Meta-Analysis of MBr and Alternatives for Pest Control in Strawberry and Tomato*. Proc. of 2009 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, The DoubleTree Hotel Mission Valley, San Diego.

Richardson, J.W. 2008. Simetar: Simulation and Econometrics to Analyze Risk. Simetar Inc. College Station, Texas.

Richardson, J.W., Klose, S.L and A.W. Gray. 2000. An applied procedure for estimating and simulating multivariate empirical (MVE) distribution in farm-level risk assessment and policy analysis. *Journal of Agricultural and Applied Economics*, 32(2): 299-315.

Richardson, J. W., and J. L. Outlaw. “Ranking Risky Alternatives: Innovations in Subjective Utility Analysis.” *WIT Transactions on Information and Communication* 39(2008):213-224.

Ristaino, J.B., and W. Thomas. 1997. Agriculture, Methyl Bromide, and the Ozone Hole: Can We Fill the Gaps? *Plant Disease* 81(9): 964-77.

Rosskopf, E.N., Chellemi, D.O., Kokalis-Burelle, N., and Church, G. 2005. Alternatives to methyl bromide: a Florida perspective. Plant Health Progress doi:10.1094/PHP-2005-1027-01-RV.

Smith S., and J.J. VanSickle. 2009. Interactive Budgets. June 2014. http://www.fred.ifas.ufl.edu/iatpc/ibudgets09.php.

Sydorovych, O., Safley, C.D., Ferguson, L.M., Poling, E.B., Fernandez, G.E., Brannen, P.M., Monks, D.M., and F.J. Louws. Economic Evaluation of Methyl Bromide Alternatives for the Production of Strawberries in the Southeastern United States. *HortTechnology* 16.January-March (2006): 118-28. Print.

USDA-ERS. 2014. Vegetables and Pulses Data. Access date: December 2014 http://www.ers.usda.gov/data-products/vegetables-and-pulses-data.aspx.

USDA-NASS. 2014a. U.S. Tomato Statistics. Access date: December 2014 http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1210.

USDA-NASS. 2014b. Agricultural Chemical Usage Reports. Access date: January 2015 http://www.nass.usda.gov/Statistics_by_Subject/Environmental/.

Vallad, G. 2014. Tomato Diseases on The Rise In Absence Of Methyl Bromide. *Growing Produce*. Meister Media Worldwide, Available online at http://www.growingproduce.com/vegetables/tomato-diseases-on-the-rise-in-absence-of-methyl-bromide/.