Ann Wolverton*

Retrospective evaluation of costs associated with methyl bromide critical use exemptions for open field strawberries in California

Abstract: Methyl bromide (MBr) has been widely used as a fumigant to control pests in the agricultural sector, but it is also an ozone depleting substance. After 2005, methyl bromide could only be produced when a critical use exemption was agreed to by the signatories to the Montreal Protocol. This paper examines how the EPA's *ex ante* cost analyses for open field fresh strawberries in California for the 2006–2010 seasons compare to an *ex post* assessment of costs. A key input into the *ex ante* cost analysis is the assumed yield loss associated with methyl bromide alternatives. The EPA used conservative assumptions given the wide range of estimates in the literature at the time, but it appears that a number of viable MBr alternatives – either new fumigants or new ways of applying existing fumigants – may have become available more quickly and resulted in lower yield loss than initially anticipated. Likewise, it appears that farmers who substituted away from methyl bromide did so without imposing large negative impacts on production in prime California strawberry growing areas. *Ex post* evaluation also confirms the effect of California regulatory restrictions in limiting the use of various economically competitive alternatives. It is worth noting that unanticipated complications after switching away from methyl bromide, such as new diseases, slowed the transition to MBr alternatives.

Keywords: cost analysis; methyl bromide; open-field strawberries; retrospective study.

DOI 10.1515/jbca-2014-0025

1 Introduction

Methyl bromide (MBr) has been widely used as a fumigant to control pests in a variety of agricultural sectors (e.g., tomatoes, walnuts, strawberries, and

***Corresponding author: Ann Wolverton,** U.S. EPA, National Center for Environmental Economics, 1200 Pennsylvania Ave., NW, MC 1809T, Washington, D.C. 20460, USA, e-mail: wolverton.ann@epa.gov

nursery crops). It is used to fumigate the soil before planting and in some post-harvest applications as well as to meet export requirements. However, MBr is also a significant ozone-depleting substance. In 1992 it was brought under the auspices of the Clean Air Act and the Montreal Protocol, an international treaty to protect the stratospheric ozone layer in the atmosphere. Developed countries agreed to phase out the production and importation of MBr between 1993 and 2005,[1] while developing countries began phasing out methyl bromide use in 2002 with a complete phase-out by 2015. Carter, Chalfant, Goodhue, Han, and DeSantis (2005a) note that a major objective of the long phase-outs was to allow time for users to develop competitive substitutes for MBr.

After 2005, MBr for non-quarantine use could only be produced in developed countries when a critical use exemption (CUE) had been agreed to by the signatories to the Montreal Protocol.[2] This provision was included "in recognition of the uncertainty of the innovation process" (Carter et al., 2005a). A critical use exemption can be granted to a developed country on behalf of farmers of a particular crop if:

– "The specific use is critical because the lack of availability of methyl bromide for that use would result in a significant market disruption; and
– There are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environment and public health and are suitable to the crops and circumstances of the nomination" (UNEP, 2006).

In 2010, the Methyl Bromide Technical Options Committee (MBTOC), an advisory group set up by the Montreal Protocol, indicated that economic feasibility should assess the effects of using MBr alternatives on "the 'bottom line' of individual firms"; alternatives that "lead to decreases in gross margins of more than around 15 to 20% or more are not financially feasible."[3] However, MBTOC recognizes that, because "it is not always possible to provide proprietary information

1 Methyl bromide used for quarantine and pre-shipment purposes is exempt from this phase out schedule.

2 Title VI of the 1990 Clean Air Act Amendments allows for critical use exemptions for the production, import, or consumption of methyl bromide that are consistent with the Montreal Protocol.

3 DuPois and Gareau (2008) criticize the MBTOC for emphasizing impacts on industry through an analysis of market disruptions instead of using economic welfare analysis, such as benefit-cost analysis, to also consider the health and environmental implications of continued methyl bromide use.

on individual firms, data should be provided for either a 'typical' or an average enterprise" (UNEP, 2010).[4]

The EPA solicits applications for MBr critical use exemptions from agricultural users on an annual basis several years prior to the relevant growing season. As part of the determination of whether and how much methyl bromide is nominated for critical use exemption, the EPA conducts a technical assessment, including a cost analysis to evaluate the economic feasibility of MBr alternatives. Once the evaluation is complete, the US Government submits its critical use exemption nominations by commodity to the Ozone Secretariat for the Montreal Protocol. This occurs 2 years in advance of the season to which it will apply. The packages are forwarded to MBTOC, which reviews the packages and makes a recommendation to the Parties for the amount of methyl bromide needed for each critical use.

This paper examines how the EPA's *ex ante* cost analyses for open field fresh strawberries grown in California for the 2006–2010 seasons (conducted annually 2 years prior to the applicable season, 2004–2008) compare to an *ex post* assessment of costs.[5] The USDA (2000) notes that prior to phasing out methyl bromide, growers in Florida and California accounted for over 75% of its use in pre-plant fumigation of soils, with California alone accounting for almost 50% of total preplant methyl bromide use in the US. The best disaggregated data on fumigant use and unit costs for fruit and vegetable crops are available for California. No equivalent data are available for Florida. For these reasons, we focus on assessing the *ex post* costs of critical use exemptions in the state of California.

While the EPA uses the best available science to conduct its *ex ante* assessments, there are a variety of reasons why *ex ante* and *ex post* estimates may differ. For instance, market conditions, energy prices, or the cost and availability of technology may change in unanticipated ways. It is also possible that industry

4 MBTOC notes that "a financial analysis typically provides a snapshot of circumstances given existing prices of inputs and outputs. However, in some cases especially if the adoption of alternatives is expected to change the supply and/or demand for inputs and outputs, it will be necessary to supplement the financial analysis with a more comprehensive economic analysis. In this case, input and/or output prices will change, leading to different budget outcomes…. Furthermore, it may become necessary to extend the scope of the analysis to take account of the general equilibrium effects of such changes (i.e., the indirect effects of changes in these markets on other markets). General equilibrium analyses typically require considerable resources and will not be used often, but may become necessary in, for example, assessing the impact of the phase-out of QPS uses, which could impact on multiple markets…. it is MBTOC's considered opinion that a partial budget analysis will suffice in most economic assessments of CUNs."

5 Analyses continue to be conducted annually in support of the critical use exemption nomination process. We stop with the 2010 season due in large part to the availability of *ex-post* cost information.

under or overestimated the costs of compliance (the EPA often relies on industry to supply it with otherwise unavailable information on expected compliance costs). Finally, year-to-year variability of production in the agricultural sector and challenges of estimation in general introduce significant uncertainty into *ex ante* cost estimates. For this reason, we examine multiple years of EPA analyses conducted in support of the critical use exemption nomination process. The *ex post* data are also limited in several respects. Any insights offered herein should be viewed with these limitations in mind.

2 Overall trends in US critical use exemptions

US critical use exemptions nominations declined substantially from 2005 to 2010. For instance, the US submitted exemptions for 17 commodities for the 2006 growing season that represented 35% of US baseline use. US nominated critical use exemptions for the 2010 growing season also covered a myriad of commodities but constituted 13.4% of baseline use (Table 1).[6]

Several trends are worth noting (Figure 1). First, the aggregate amount of methyl bromide requested by industry for agricultural use was far higher than what the US nominated for exemption for the 2005–2010 growing seasons, though it also followed a downward trend. Second, the amount approved by the

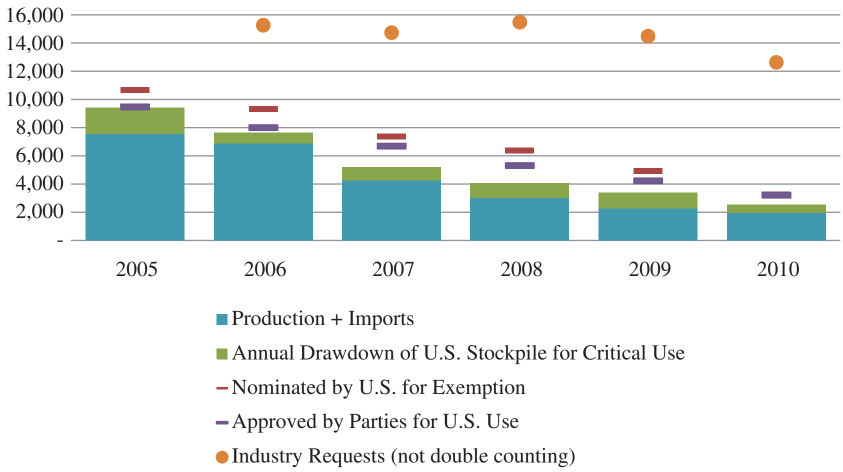
Table 1 Percent of baseline MBr consumption in US exempted for critical use by year.

Calendar year growing season	US Nominated amount (percent of baseline)	Amount authorized by parties for use in US (percent of baseline)
2005	39	37
2006	35	32
2007	29	26
2008	23	21
2009	19.5	16.7
2010	13.4	12.7

Source: http://www.epa.gov/ozone/mbr/cueinfo.html.

6 For the 2014 season, the amounts nominated and authorized for US use decreased to 1.7 and 1.7%, respectively, and covered four commodity categories, one of which was California strawberries. Note that the EPA anticipates that California strawberry growers will completely transition out of methyl bromide by 2017 through the use of straight choloropicrin at rates up to 350 pounds per acre, steam and anaerobic soil disinfestation. See http://www.epa.gov/ozone/mbr/CUN2016/2016CUNStrawberries.pdf.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press



Source: US EPA[7] and UNEP (2010).

Figure 1 US MBr production, imports, and drawdown of stockpile for critical use (2005–2010).

Parties was lower than the US government nominated amount. Third, while the amount of methyl bromide nominated for exemption each year declined, the US sometimes increased the nominated amounts for specific crops or regions between years. Finally, the amount of methyl bromide allowed under the critical use exemption was met in part by drawing down the stockpile.[8]

At a national level, five open field crops were granted critical use exemptions at levels substantially below what was originally requested: cucurbits (i.e., squash and melons), eggplant, tomatoes, strawberries, and peppers. In California, cucurbit and eggplant farmers did not request an exemption for MBr use over this time frame. The three remaining crops were responsible for about 62% of US methyl bromide use in 1991, just prior to the beginning of the phase-out (Ferguson and Yee, 1997; USDA, 2000). They constituted 68% of the total amount of MBr nominated for critical use exemption in 2009.

Table 2 illustrates the amount of MBr the US nominated for exemption for use on strawberry fields in terms of the amount originally requested by growers

7 In lieu of information on actual stockpile drawdown for 2005, we use the authorized amount. Other years indicate that the actual drawdown was likely less than the authorized amount. Data are from http://www.epa.gov/ozone/mbr/otherreginfo.html, and http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0277-0044.

8 The stockpile consists of MBr produced prior to the 2005 phase-out. Use of stockpiled MBr for the replanting of turf was not allowed after April 2013, though the deadline was extended for golf courses through November 2014.

Table 2 MBr requested by industry and nominated for critical use exemption for US strawberries.[9]

	Year	2006	2007	2008	2009	2010
California	Amount (kg) nominated	1,086,777	1,267,880	1,244,656	1,064,556	952,543
	% of Amount requested by industry	67%	87%	98%	90%	100%
Florida	Amount (kg) nominated	295,853	297,909	220,302	176,333	163,440
	% of Amount requested by industry	51%	51%	38%	30%	28%
Eastern US	Amount (kg) nominated	230,332	165,735	137,334	93,488	75,832
	% of Amount requested by industry	66%	46%	36%	34%	28%

Source: EPA critical use exemption nominations for open field strawberries for the 2006–2010 seasons.

for the 2006–2010 seasons. California made up the vast majority of the requested amount each year (67% in 2006 and 80% in 2010). This is not surprising as more than 85% of strawberries grown in the US came from California in 2007. In each state/region that requested a critical use exemption, the amount requested by farmers was almost always higher than what EPA nominated for exemption. However, the rate of decrease in the amount nominated was markedly slower in California than in other parts of the country, mainly due to regulatory constraints (discussed later).

3 EPA *ex ante* cost estimates for open field strawberries in California

Three years prior to the year for which the MBr is approved for use, the EPA evaluates the per acre impacts of using methyl bromide alternatives on the net revenues (i.e., gross revenues minus operating costs) of a typical farmer on a per-crop basis. Net revenues for several alternatives are compared to those for methyl bromide to generate an estimated loss per acre. Because the EPA assesses the

9 The EPA tries to eliminate double counting from the requested amount – for instance, by identifying acreage counted in more than one application or rotated within a year of application to a crop that also uses methyl bromide – and subtracts out land that represents growth since 2005 – when the area for which methyl bromide is requested is greater than that historically treated – since it does not qualify for exemptions.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

burden associated with switching to MBr alternatives, the baseline against which they are assessed is the continued use of methyl bromide instead of zero MBr use. The EPA also assesses the rate at which MBr is applied and the total amount of land where economic, technical, and regulatory constraints inhibit the use of alternatives to determine the aggregate amount of methyl bromide to nominate for critical use exemption in a given year. The EPA does not provide aggregate estimates of costs as part of the CUE nomination package.

In the CUE nomination packages for the 2006–2008 seasons, the EPA evaluated net revenues for methyl bromide combined with chloropicrin (PIC) in a 67:33 formulation and three alternative fumigants, 1,3-dichloropropene + chloropicrin (1,3-D+PIC), chloropicrin + metam sodium (PIC+MS), and metam sodium alone (MS).[10] For the 2009–2010 seasons, the EPA dropped PIC+MS as an evaluated alternative.[11] While the EPA recognized several other potential MBr alternatives, it did not analyze them for the 2006–2010 seasons because they were not yet registered for use in the US.

3.1 Main drivers of *ex ante* cost estimates

Ex ante gross revenues per acre depend on three components: potential yield loss due to use of an alternative, the expected producer price of strawberries, and the potential loss of revenue due to a planting delay that results in a missed market window. Changes in product quality that could result in lower revenues, while discussed, were not quantified by the EPA. The EPA retained the same yield loss estimates for the 2006–2010 seasons due to a desire to rely on multi-year studies, as many factors can influence realized yield losses (e.g., weather, pest pressure) in a given year. However, while the EPA included an estimate of the effect of a planting delay on revenues in its assessment for the 2006–2008 seasons, it dropped it in later year analyses due to lack of evidence.

Based on information from industry, the EPA estimated the labor and material costs associated with land preparation (e.g., seed, fertilizer, pesticide, and fumigant), weeding, irrigation, and harvest when using MBr versus its main

10 In California, the entire surface of the field is typically fumigated, covered by a tarp, and left to sit for a period of time. After the tarp is removed, farmers form planting beds and cover them with plastic. Planting begins 2–6 weeks after fumigation. After harvest, new crops are planted that benefit from the initial fumigation (EPA, 2008).

11 MS+PIC was dropped because it does not distribute evenly or deeply enough in the soil to be effective against nematodes or pathogens and thus is used mostly for weed management after 1,3-D+PIC is applied.

alternatives.[12] The same approach to estimating operating costs was used for the 2006–2010 season CUEs, with only slight changes (e.g., updating fumigant prices) for later seasons. The EPA estimated that the application of MBr alternatives required a bit less manual (5% less) and harvest labor (between 7 and 15% less) than MBr. The cost of the fumigant also varied.

Table 3 summarizes estimated gross revenue and operating costs for California strawberries for the 2006 planting season. The losses per acre from switching to an MBr alternative were mainly driven by yield differences. The cost analyses for the 2006–2010 seasons concluded that switching to 1,3-D+PIC, the most viable alternative, would result in about a 16% loss per acre as a percent of gross revenues.

3.2 Main sources of uncertainty in *ex ante* cost estimates

Ex ante analyses are subject to many challenges and uncertainties. It is difficult to precisely estimate how much methyl bromide will actually be needed in a given growing season, what MBr alternatives will be available for use, and the yield loss and operating costs associated with each option. At the time the phase-out began, the USDA (2000) reported that the most promising alternatives to methyl bromide for agricultural use were a combination of the fumigants

Table 3 Yields, revenues, and operating costs for open field CA strawberries (2006–2008 growing seasons).

Fumigant	Methyl bromide	Alternatives		
		PIC+MS	1,3-D+PIC	MS
Yield loss	0%	27%	14%	30%
Yield (pounds per acre)	43,215	31,547	37,165	30,251
Strawberries price per pound	$0.69	$0.66	$0.66	$0.66
Gross revenue per acre	$29,818	$20,679	$24,362	$19,829
Operating costs per acre	$24,334	$22,395	$23,659	$22,226
Net revenue per acre	$5484	($1716)	$702	($2396)
Loss per acre	$0	$7200	$4782	$7881
Loss as percent of MBr gross revenue	–	24%	16%	26%

Source: EPA CUE nominations, converted to pounds and acres from kilograms and hectares.

12 The EPA does not quantify fixed costs due to wide variability in factors that influence them (e.g., farm size, type of technology adopted), the effect of switching on a rotation crop, or other costs of switching (EPA, 2005).

1,3-dichloropropene and chloropicrin (1,3-D+PIC), or chloropicrin combined with metam sodium, napropamide (an herbicide registered for use on eggplant), or pebulate (also an herbicide, now de-registered for use on tomatoes). Metam sodium was viewed as a potentially viable alternative in areas where the use of 1,3-D was restricted.[13]

Other factors that could affect the adoption rates of MBr alternatives include use restrictions to protect workers and bystanders from health effects associated with their toxicity, and US EPA and state registration requirements. The USDA (2000) notes that several possible alternatives were not registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) when the phase-out began.

In addition, the EPA faced the challenge of generating *ex ante* estimates based on limited data and poor documentation in source reports on yield loss associated with MBr alternatives. For instance, the EPA reportedly used conservative assumptions of yield loss because the literature contained a wide range of estimates and gave little detail on what types of impacts were included.

Finally, while the EPA did not evaluate how lack of a critical use exemption would affect the ability of California farmers to compete in the global marketplace it is a relevant consideration and a source of uncertainty with regard to the ultimate financial welfare of farmers. In particular, it is important to understand how switching to a MBr alternative impacted the ability of conventional production in California to compete with organic production in California and imports from Mexico.

3.3 Exogenous factors that may affect estimated *ex ante* costs

The EPA noted that the rate of adoption of MBr alternatives was limited by a combination of transitional and regulatory issues. In general, the amount of land assumed to face technical constraints stayed about the same across growing seasons – approximately 10–15% of land used to grow strawberries in California was assumed to be on hilly terrain that does not support the drip systems required to apply many MBr alternatives. However, the EPA accounted for the use of strip fumigation (i.e., about 10% of land used this form of fumigation, which has a lower application rate) and the change in the ratio of MBr to PIC from 67:33 to 50:50 in its analysis of the 2009 and 2010 seasons.

13 A key challenge to transitioning out of MBr has been effectiveness against nematodes, disease, and weeds (Noling et al., 2010). Many registered alternatives are only effective against a subset: chloropicrin is effective against disease but less effective against nematodes or weeds; 1,3-D is effective against nematodes but does less well against disease or weeds; metam sodium is good for weed control but does little against disease or nematodes.

The impact of regulatory constraints on use of alternatives is not easy to determine and may differ by strawberry growing region. The main regulatory constraint accounted for by the EPA is California's restrictions on the use of 1,3-D. In the CUE nomination package for 2006, the EPA assumed these restrictions applied to a smaller subset of total acreage (47–67%) than in subsequent seasons (82–94%). This was based on the initial assumption that some townships would be allowed to exceed the cap by up to 2 times.[14] However, uncertainty regarding the process resulted in the EPA interpreting the caps strictly. The EPA noted that fewer townships would find the cap on 1,3-D binding if farmers switched to drip irrigation, as less chemical would be required (also, Carpenter, Lynch, & Trout, 2001). However, this could result in a 3–4 week planting delay. According to EPA experts, there were also county-level restrictions on the use of chloropicrin and metam sodium, though these effects were not quantified.

4 Data and literature available to conduct *ex post* evaluation

There are several key components of costs that can be potentially examined *ex post* [see Kopits et al. (2014) for a discussion of the conceptual framework for costs]: what types and how many entities comply with the regulation; what technologies or strategies are used to comply; the initial and ongoing costs of compliance; any indirect costs such as quality tradeoffs or missed market windows; and other opportunity costs in related markets. For this study we largely rely on publically available data. Specifically, we review the existing literature to identify *ex post* studies on MBr critical use exemptions and data sources on key inputs to the *ex ante* cost analysis.

It is important to note several data limitations that will affect the extent to which we can opine on some aspects of the *ex ante* cost analysis. First, *ex post* evaluations of MBr critical use exemptions are rare in the literature. Second,

14 California began to allow use of 1,3-D on a restricted basis after 1995. Most townships, defined as a 36 square mile area, were allowed to use up to 90,250 pounds annually if applied between February and November at a soil depth of 18 inches or more. Beginning in 2002, California allowed townships to exceed the cap by up to twice the allowable amount. The degree to which a township is allowed to exceed the cap is proportional to how far below the cap it has been in previous years (i.e., previous over-compliance with the cap is used as a bank), so that on average the original limit is met. If the chemical is applied in December or January or at shallower depths, then the cap is more restrictive. See www.cdpr.ca.gov/docs/emon/pubs/ehapreps/analysis_memos/4327_sanders.pdf and www.cdpr.ca.gov/docs/emon/methbrom/telone/mgmtplan.pdf.

market data on fruit and vegetable crops are not as widely available as for row crops, particularly at a geographically disaggregated scale. Third, publically available data to evaluate the operating costs associated with switching to an MBr alternative in California are also limited.

4.1 *Ex post* literature

Many papers have evaluated the potential impact of banning MBr use in the US and, in some cases, have analyzed to what extent critical use exemptions may alleviate this impact (e.g., Carpenter, Gianessi, & Lynch, 2000; Carter et al., 2005a; Carter, Chalfant, Goodhue, & McKee, 2005b; Goodhue, Fennimore, & Ajwa, 2005; Norman, 2005; VanSickle and NaLampang, 2002).[15] However, we found only one published *ex post* analysis of the impact of critical use exemptions for MBr use. While there is no formal counterfactual, the authors point to rising yields, acreage, exports, revenues, and market share as evidence that strawberry farmers have not faced substantial negative impacts of the phase out, in part due to exemptions (Mayfield and Norman, 2012).

Recent studies also estimate yield effects of various fumigants compared to MBr+PIC for strawberries based on field trials. We identify a meta-analysis covering studies from 1997 to 2006 sponsored and approved by the MBTOC (Porter, Trinder, & Partington, 2006). The MBTOC also discusses recent evidence in its 2010 assessment report (UNEP, 2010). Recent studies by Othman et al. (2009) and Fennimore and Ajwa (2011) are particularly relevant because of their focus on California. Since yield loss is one of the key uncertainties identified in the *ex ante* analysis, we discuss these studies in greater detail in Section 5.

4.2 Data for evaluating costs *ex post*

We rely on several data sources for conducting the *ex post* analysis. The critical use exemption nomination packages are a good starting point for information on

15 The *ex ante* literature disagrees regarding the likely impact of banning methyl bromide on US farmers. Initial studies tended to predict larger impacts than later studies in part because they often evaluated an immediate ban and assume no technological innovation over time. Another key difference across studies stems from assumptions regarding Mexico's ability to rapidly increase strawberry exports to the US. As a developing country, Mexico does not have to fully phase out methyl bromide until 2015. Some researchers argue that competition from Mexican imports will be limited due to little overlap in growing seasons, the perishable nature of strawberries, and seasonal differences in prices.

MBr used in prior years. For instance, the nominating package for the 2013 season reports observed application rates and overall usage for the 2006–2010 seasons. Post-2010 CUE nomination packages also indicate when new alternatives were registered and contain some limited information on fumigation practices in previous seasons.

The EPA relied on the 2002 USDA-administered Agricultural Chemical Usage Vegetables Survey for an estimate of California acreage likely to rely on methyl bromide. Since that time, USDA has published 2006 and 2010 survey data, which also include average application rates and pounds applied in California. Data collected separately through the California Pesticide Information Portal (PIP) indicate the amount of a specific chemical used and the acreage treated by month, year, and crop on a more spatially disaggregated scale.[16] To estimate gross revenues, we use yield information from the literature and the US Department of Agriculture (USDA). The market price of strawberries is based on national and state-level prices received by growers from the USDA.

We explore several sources of information on operating costs. Crop budgets for open field strawberries are available for Monterrey, Santa Barbara, Santa Cruz, and Ventura Counties in California (Bolda, Tourte, Klonsky, & De Moura, 2010; Dara, Klonsky, & De Moura, 2011; Daugovish, Klonsky, & De Moura, 2011; Takele, Klonsky, & De Moura, 2006). They generate sample operating (and to some extent, fixed) costs and revenues for a representative farm. The 2006 and 2010 reports used MB+PIC as the default fumigant, while the 2011 reports included alternative fumigants to methyl bromide in the crop budgets. We are cognizant of the limitations of using crop budget information. They are produced to help farmers assess the profitability of growing particular crops and may include cost categories that do not apply to many growers. That said, they are produced for strawberry-growing regions in California that overlap with areas seeking critical use exemptions and are described as representative of costs faced by a typical farmer, which is the focus of the EPA *ex ante* cost analyses.

We use a proprietary data set on fumigant prices based on a survey of farmers from a private pesticide marketing company. Because the database is proprietary, we report data only in highly aggregate form. The final source of cost information is studies that take a bottom-up approach to estimating costs associated with using methyl bromide or an alternative based on field experiment data.

16 The data can be downloaded from http://calpip.cdpr.ca.gov/main.cfm. Carpenter et al. (2001) note that acreage treated with MBr may be overstated in PIP due to duplicate entries as well as for perennial crops due to spot treatments on small areas that are reported as full-acre treatments.

Information on the role played by California regulatory constraints is limited to literature that pre-dates or coincides with the CUEs for the 2006–2010 seasons. While we discuss these studies, it is not possible to come to definitive conclusions regarding the role of regulatory restrictions on the pace and types of MBr alternatives utilized over this time period. To investigate whether strawberry growers faced unanticipated competitive disadvantages we use annual state and county level data on organic and conventional strawberry acreage and national level data on imports and exports by country.

5 Assessing costs of MBr critical use exemptions retrospectively

Comparing *ex ante* to *ex post* estimates of compliance costs is challenging for all the usual reasons – limited access to cost data in the post-regulatory period, few retrospective analyses, etc. However, a retrospective review of the cost analyses conducted by the EPA for MBr critical use exemptions faces additional challenges. Unlike regulations that seek to control a substance, MBr critical use exemptions allow for the use of a substance that is otherwise banned. The market does not reveal the cost of actions that would have been taken in the absence of the exemption; we do not have a measurable and quantifiable counterfactual based on real world revealed market behavior. However, since strawberry farmers requested far more methyl bromide than what the US nominates for exemption it may be possible to examine whether growers that had to switch to non-MBr substitutes faced larger than expected costs by comparing EPA estimates to what is observed in the marketplace.

In addition, it is challenging to isolate the cost implications of a CUE in a given year from those of future CUEs. In fact, some researchers have speculated that there may be a strategic element embedded in the requests made by industry, since it is repeated annually (Mayfield and Norman, 2012). We examine the cost analyses in the CUE nominations for the 2006–2010 growing seasons as a group, given the unique nature of the CUE process. This also makes sense because the EPA did not substantially alter the assumptions or inputs to its cost analyses over this timeframe.

The remainder of this section compares the EPA's *ex ante* cost estimates to available *ex post* estimates for each cost component, identifying possible reasons for substantial differences. Table 4 summarizes the main sources of information and our findings for each main cost category.

Table 4 Summary of findings.

Components of cost estimate			**Source of *ex post* information**	**Assessment (Compared to *ex ante*)**
Regulated universe	Farm types		–	–
	Strawberry acreage using MBr		USDA and CA PIP data	Reasonable
Baseline yields using MBr			USDA data	May be underestimate but based on data for typical farmer
Methods of compliance	MBr alternatives used (Types)		CA PIP data	Reasonable but adopt faster than assumed; no data on some practices
	Rate of application (Usage)		USDA and CA PIP data	MBr application – slight under estimate
Compliance costs	Direct, one-time	Fixed cost	–	–
		Variable cost		
	Direct, On-Going Net Cost	Gross Revenues	USDA + journal articles + UN meta-analysis	Strawberry prices – reasonable Yield loss for MBr alternatives – likely overestimate
		Operating Costs	Crop budgets + CUE requests + proprietary data	Reasonable
	Indirect – missed market window		USDA data	Inconclusive; also cannot evaluate quality trade-offs
Other opportunity costs	Conventional strawberry production loses to imports, organic production		CSC+USDA	Reasonable
Per acre net costs	Likely lower than anticipated – driven by yield loss assumptions			
Total costs	–			

5.1 Regulated universe

Since the EPA *ex ante* cost analyses only estimated per acre costs for a typical California strawberry farmer, not total costs, we have little information on the potentially regulated universe. For instance, we do not know what types of farms were expected to use MBr. However, the *ex ante* analysis presented some information on overall methyl bromide use, which allows for a limited comparison.

It appears that California farmers used slightly less MBr to grow strawberries than requested but that this was approximately in line with EPA expectations.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

Growers requested MBr for use on 75–85% of the California strawberry crop in the 2006–2008 seasons, falling to 50–60% in the 2009 and 2010 seasons. Information on how much of this amount was expected to be met from the stockpile in any given year is not available.[17] Actual use in 2006–2010 from the USDA and California PIP indicate that farmers used methyl bromide on 67% and 40% of the acres dedicated to strawberries, respectively, assuming no growth in acreage (EPA assumed strawberry acreage stayed at 2000 levels). If growth had been assumed – California acreage dedicated to strawberries increased significantly over time (see Figure 5) – then the proportion of farmers using methyl bromide would be even smaller (e.g., based on actual growth methyl bromide was used on about 50% and 30% of California acreage dedicated to strawberries in 2008, respectively).

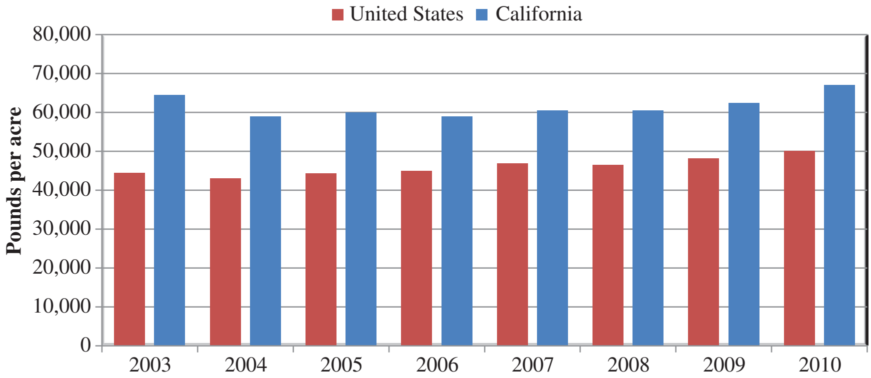
5.2 Baseline information

Typically the baseline identifies what emission-reducing technologies or process changes would have been adopted absent regulation. Voluntary adoption of emission-reducing practices by industry is not typically attributed to the cost of the regulation (US EPA, 2010). In the case of CUEs, this manifests as switching to a MBr alternative for economic reasons, in which case there would be no reason to request a critical use exemption. That said, proper characterization of baseline conditions is still important for evaluating costs associated with switching away from MBr use. In particular, estimates of yield loss associated with alternatives are predicated on assumptions about strawberry yields when using methyl bromide.

The EPA's *ex ante* MBr baseline yield of 43,000 pounds was only about 10% lower than the national average yield of about 47,000 pounds per acre between 2006 and 2010 (see Figure 2). However, USDA data also indicate that California strawberry farmers were generally much more productive than the average during this time period: The average yield for a California strawberry farmer between 2006 and 2010 was 62,000 pounds per acre. While using the national average underestimates baseline yields for the "typical" California farmer, it does not affect the net bottom-line financial assessment since operating costs and gross revenues both scale with yield and are therefore equally affected. Our ability to draw conclusions about baseline yields is limited since we have no information

17 However, USDA data (from 2002) cited in the CUE for the 2006 season indicate that approximately 55% of California strawberry acreage used methyl bromide at the time.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press



Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381; See table04.xls.

Figure 2 Fresh strawberry yield per acre in the US and California, 2003–2010.

on how yields vary by farmer. It is possible that farmers seeking CUEs are less productive on average. For instance, yields may be lower or production costs higher due to hilly terrain, complicating the transition away from methyl bromide.

5.3 Methods of compliance

A key input into estimating the cost of a regulation is the types of technologies or approaches used to comply. In the case of critical use exemptions, were identified MBr alternatives used as frequently as expected? Did any new alternatives become available that were not anticipated by the EPA at the time of the *ex ante* analysis? We also assess the rate of continued MBr application since it is possible that farmers found a way to use less than anticipated. Finally, we examine the role of state regulatory restrictions in slowing the transition to some MBr substitutes.

Use of methyl bromide alternatives. Recall that EPA analyzed three alternatives to methyl bromide in its 2006–2010 CUE nomination packages, 1,3-D+PIC, PIC+MS, and MS alone. It identified 1,3-D+PIC as the lowest cost MBr alternative. *Ex post* data confirm that 1,3-D+PIC is the most commonly used alternative to methyl bromide for strawberry production in California over this time period. The California PIP data show that nearly 10,000 acres were reportedly treated with 1,3-D+PIC, while another 1700 acres were treated with chloropicrin in 96 and 100% formulations in 2006. Acreage treated with 1,3-D+PIC rose to almost 16,000 acres in 2010, while the amount treated with chloropicrin grew to more

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

than 4700 acres. Metam sodium use by California strawberry growers was not widely used.

It is also possible that other alternatives not analyzed by the EPA have since become available. As of March 2011, 10 methyl bromide alternatives were registered at the Federal level for use in the US (see Table 5). The alternatives analyzed in the CUE nomination packages for the 2006–2010 planting seasons are highlighted in dark grey. Alternatives that were recognized at the time of the CUE but either not analyzed or not registered at the Federal level are highlighted in light grey.[18] The UNEP (2010) also notes that several chemicals that showed initial promise were no longer considered viable alternatives to methyl bromide, such as propargyl bromide and sodium azide. However, federal-level registration is not sufficient for use: fumigants must also be approved via a state level registration process in California. Of the chemicals listed in Table 5, 1,3-dichloropropene – with or without chloropicrin-, chloropicrin, metam sodium, dazomet, and methyl iodide were registered for use in California as of 2010.

The MBTOC observes that much progress has been made in replacing methyl bromide in pre-plant uses, "particularly due to improved performance of new formulations of existing chemical fumigants (e.g., 1,3-D+PIC, PIC alone, metam sodium) and new fumigants (e.g., methyl iodide, dimethyl disulfide), but also due to increased uptake of non-chemical alternatives" (MBTOC, 2010).[19] However, the California PIP data demonstrate that only three potential chemical alternatives to methyl bromide were used in California between 2006 and 2010, 1,3-D, PIC, and metam sodium, and that strawberry farmers did not recombine them in new or novel ways (e.g., they did not utilize a three-way fumigant system of 1,3-D+PIC+MS, increasingly common in Florida).

Methyl iodide (also called iodomethane) has long been recognized as a "near perfect substitute" for methyl bromide, meaning it results in little or no yield loss when compared to methyl bromide (e.g., Goodhue, Fennimore, Klonsky, & Ajwa, 2004; Hueth, McWilliams, Sunding, & Zilberman, 2000; Sances, 2000). While it was registered as a fumigant in the US in 2007, California did not register methyl iodide until December 2010 [and since that time,

18 At the federal level, methyl iodide was first registered for use as a fumigant in 2007. Dazomet was registered in 2008 for use in California only, while dimethyl disulfide was registered at the federal level in 2010, though it is not yet registered in California. See http://ucanr.edu/sites/PAWMBA/Nursery_Projects/Perennial/Challenges/.

19 Research into non-chemical alternatives (e.g., solarization, steam treatment, natural herbicides) has increased in recent years (e.g., Samtani et al., 2011). Preliminary data show that some alternatives hold promise with regard to yield performance and weed control, but it is unclear whether results will continue to hold on a larger scale.

Table 5 Federally registered and non-registered methyl bromide alternatives for strawberries.

Federally registered alternatives available	Known alternatives that are not federally registered
1,3-Dichloropropene	Furfural
Chloropicrin	Propargyl bromide
Metam sodium	
1,3-Dichloropropene + Chloropicrin	
1,3-Dichloropropene + Chloropicrin + Metam Sodium	
Metam Sodium + Chloropicrin	
Terbacil	
Dazomet (Basamid)	
Dimethyl disulfide	
Methyl iodide (iodomethane)	

Dark gray: alternatives analyzed in CUE nomination packages; Light gray: Alternatives recognized at the time of CUEs but not analyzed or not yet registered; White: Currently registered but not recognized in CUEs.

methyl iodide has been taken off the US market by its producer and therefore is unavailable (Rubin, 2012)].[20] Thus, it did not play a role as a MBr substitute in the time frame we analyze.

If methyl iodide was once again available on the US market, what role might it play going forward? While the CUE nomination package for the 2012 season continued to assume that 1,3-D+PIC was the most economical alternative to methyl bromide for California strawberries, methyl iodide was considered viable in the CUE for the 2013 growing season. The EPA estimated that methyl iodide would be financially feasible according to the criteria set out by the MBTOC (the per acre loss was estimated to be 6% of the gross revenue per acre compared to MBr, well below the 15–20% threshold the MBTOC suggests) and more attractive from a financial perspective than 1,3-D+PIC. The key reason for a predicted loss in gross revenue from methyl iodide use was higher costs stemming from additional input requirements (i.e., impermeable films are required with methyl iodide applications in California).[21] Fennimore and Ajwa (2011) also point out

20 In spite of the more favorable financial implications, recent experience suggests that public concern regarding associated health effects may continue to limit its use, at least in the near term. For instance, see www.panna.org/blog/ca-brings-heat-methyl-iodide.

21 While Noling (2005) note that virtually impermeable films were initially very expensive in the US due in part to high transportation costs and were sometimes subject to long delays because only a few European manufacturers produced them, Noling et al. (2010) report that over a dozen firms manufacturer virtually impermeable films, including several in the US and Canada.

that totally impermeable films have been approved for use with methyl iodide and that trial results show these films are effective at retaining the fumigant in soil. [22]

How methyl bromide is used. While it is possible that farmers that continue to rely on methyl bromide found a way to use less of it than anticipated while maintaining its effectiveness, *ex post* evidence indicates that this has not been the case for California strawberry farmers. In its assessment of the 2006–2010 growing seasons, the EPA assumed that MBr would be applied at a rate of 175 pounds per acre. USDA survey data demonstrates that it was applied to California strawberries at an average rate of about 190 pounds per acre in 2006 (the EPA underestimated the application rate by about 8%). USDA survey data indicate an average rate of 180 pounds per acre for methyl bromide applied to California strawberries in 2010, while California PIP data show that the average application rate for methyl bromide in 2010 was about 185 pounds per treated acre (an underestimate of 3–5%).

Regulatory and other restrictions. The nomination package for the 2012 growing season noted two factors that complicated California's ability to reduce the proportion of methyl bromide in a given formulation: first, for farmers who continued to use methyl bromide, California restrictions on chloropicrin mean that the lowest formulation likely allowed in California at the time was 57 parts methyl bromide to 43 parts chloropicrin. Data from the California PIP confirm that about 94% of the methyl bromide used on strawberries in the 2009 and 2010 growing seasons was formulated at 57:43 or higher. A small amount (about 5%) was available at a 50:50 or 45:55 formulation. Second, two new diseases emerged in fields treated with MBr alternatives, which resulted in some farmers using MBr once every 3 years to manage these diseases. The reason for these diseases is not known, but it has been posited that it could be the result of switching from broadcast to drip fumigation, the lower rates of fumigant applied via drip, or fundamental differences between methyl bromide and its alternatives.

The most recent technical assessment by the MBTOC points to a third possible reason why California farmers did not reduce methyl bromide at a faster rate (UNEP, 2010). It notes that low permeability barrier films allow for methyl bromide to be applied at significantly lower rates (25–50% less than when used

22 While there is far less data available to evaluate the experience of Florida strawberry farmers, they reportedly were successful at reducing the rate at which MBr was applied by relying on virtually impermeable films (US EPA, 2009). Also, methyl iodide was registered for use in Florida shortly after it was federally registered. The CUEs for the 2011–2012 seasons note that the uptake of methyl iodide could be rapid if early adopters met with success.

with conventional films) without loss of effectiveness or any discernible impact on yields (e.g., Noling, 2005; Noling, Botts, & MacRae, 2010).[23] Planting is typically delayed, however, to allow enough of the chemical to dissipate so that residues in the soil do not injure the plant. While required in the European Union, during our period of study California did not allow virtually impermeable films with methyl bromide due to worker exposure concerns.

California regulations also limited the use of viable MBr alternatives. For instance, the EPA (2006) reported that township caps on 1,3-D were binding for 40–62% of California acreage planted in strawberries in 2005 and were one of the main reasons for granting continued critical use exemptions to strawberry farmers.[24] In addition to township caps on 1,3-D use, Noling and Botts (2010) also credit uncertainty regarding authorization for practices such as virtually impermeable films and bed shank fumigation with slowing the transition away from methyl bromide in California. The CUE nomination packages for the 2006–2010 and subsequent seasons also mention restrictions on application rates for volatile organic compounds (VOCs) such as chloropicrin and metam sodium, and buffer zone requirements for some chemicals (e.g., 1,3-D) in California as complicating factors.[25] Finally, farmers cannot use a chemical until it has also been approved for use in California.

5.4 Compliance costs

In this section, we examine the *ex post* evidence on compliance costs from switching away from MBr to other alternatives. Recall that the EPA *ex ante* cost analyses focused on net operating costs – they do not evaluate one-time or fixed costs of switching away from methyl bromide.

23 With more permeable films, 20–90% of methyl bromide escapes into the atmosphere. The wide range is due to the interaction between the chemical, soil and other environmental factors (Noling, 2005).

24 Carpenter et al. (2001) estimate demand for 1,3-D after the MBr phase-out absent township restrictions. Relative to annual township caps that are strictly enforced, demand for 1,3-D is estimated as 10 million pounds higher absent usage limits, affecting about 32% of total acreage. The vast majority of this demand is driven by strawberries.

25 California requires a buffer around an occupied structure and has maximum allowable application rates for fumigants to protect workers' health. Carter, Chalfant, Goodhue, Groves, and Simon (2004) examine the combined effect of 1,3-D township caps and buffer requirements. When township caps are binding, increasing buffers has little effect on fumigant choice.

5.4.1 Gross revenues

The accuracy of gross revenue estimates is driven by the ability to anticipate future strawberry prices and yields. *Ex post* assessment reveals that the EPA's estimates of strawberry prices received by California growers for the 2006–2010 harvest are a reasonable approximation of actual prices. However, recent literature indicates that it likely overstated yield loss associated with switching from methyl bromide to 1,3-D+PIC, overestimating the potential loss in gross revenues *ex ante*, all else equal.

Strawberry prices. In general, the prices for strawberries assumed in the *ex ante* analysis for the 2006–2010 seasons are consistent with historical (2000–2003) and contemporaneous (2006–2010) prices received by growers in California (Table 6). The EPA assumed strawberry prices would be $0.69 per pound in the nomination package for 2006 and $0.79 per pound in the nominating package for 2009. While the prices received by strawberry producers fluctuate year-to-year, the average price was $0.65 per pound and $0.86 per pound over the 2003–2006 and 2006–2010 time periods, respectively.

Yield loss associated with MBr alternatives. Recent studies on yield loss of MBr alternatives for growing open field strawberries demonstrate the possible availability of competitive substitutes. The MBTOC discusses recent evidence,

Table 6 Strawberry prices received by California growers (2000–2010).

Year	California grower's price (cents per pound)
2000	0.84
2001	0.77
2002	0.59
2003	0.71
2004	0.64
2005	0.60
2006	0.65
2007	0.80
2008	0.91
2009	0.90
2010	1.01
2000–2003 (average)	0.65
2006–2010 (average)	0.86
2000–2010 (average)	0.74

Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381 See table06.xls. Prices adjusted to 2006 dollars using BLS Producer Price Index for strawberries.

noting that 1,3-D+PIC, methyl iodide+PIC, and DMDS+PIC (and other chemical combinations) performed as well as MBr+PIC in field trials in the US, Australia, and Spain (UNEP, 2010). However, it also notes that California has restricted the maximum rates at which many of these chemicals can be used to a level lower than what was tested in field trials. Based on California field trials, Othman et al. (2009) suggest that 1,3-D+PIC (with or without a sequential application of metam potassium), chloropicrin alone, and iodomethane+PIC perform competitively with 67:33 MBr+PIC (measured as average total yield per acre) when used in conjunction with virtually or totally impermeable films. Fennimore and Ajwa (2011) examine the effectiveness of 1,3-D+PIC under standard and totally impermeable films in California. They find that fumigant retention is substantially higher with totally impermeable films, such that less 1,3-D+PIC (i.e., about 33% less than under standard films) is needed to achieve strawberry yields comparable to standard MBr+PIC applications.

The UNEP also sponsored a meta-analysis to summarize the literature on yield performance of various alternatives relative to methyl bromide for strawberries and tomatoes (Porter et al., 2006).[26] Forty-two studies published between 1997 and 2006 were identified for strawberries (representing 101 field trials). About 90% of the field trials took place prior to 2002. Twenty-eight percent of the trials were conducted in California. Because the authors could not express yield loss across studies using a common unit of measure, they expressed results in terms of within-study yield response of a given treatment (e.g., a given chemical formulation applied at a similar rate using a similar method) relative to methyl bromide. They then examined variation in relative yields of various treatments across studies.

Results show that about one-third of the treatment combinations had average relative yield estimates "either greater or not statistically different from the estimated yield for the standard [MBr-PIC at a 67:33 ratio] by more than 5%," including 1,3-D+PIC and methyl iodide+PIC.[27] The estimate for metam sodium was about a 22% reduction in relative yield on average, though when combined with other chemicals (e.g., 1,3-D or PIC) it was estimated as much more effective.

While consistent with other studies with regard to yield loss, it is difficult to translate the results of this study – expressed in terms of average relative

26 Note that while the studies evaluated in the meta-analysis are published, the meta-analysis has not – to our knowledge – been externally peer-reviewed. A review by the Office of Pesticides Programs found that some data points may not be correctly inputted into the statistical analysis.

27 The average relative yield results for methyl iodide+PIC are much more variable across trials than for many other alternatives. Also, many of the 22 alternatives include perbulate, an herbicide that is no longer registered. Nine of the alternatives that fared well when compared to MBr+PIC do not include perbulate.

yield – into specific yield loss estimates associated with MBr alternatives analyzed by the EPA for the 2006–2010 seasons. The meta-analysis looks at the variability of treatment not at actual harvest weight. It is also not clear the extent to which the results are applicable to California farmers for two reasons. First, more than half of the studies were conducted in Florida, Spain or New Zealand. Second, the results compare average relative yields derived under specific conditions. It is possible that the field trials conducted in California are still not representative of the soils, terrain, pest profiles, and regulatory constraints of individual farmers requesting critical use exemptions.

What can we learn from the limited *ex post* evidence available on yield loss with respect to the likely impact of MBr alternatives on farmers? If switching to 1,3-D+PIC would have resulted in less yield loss than anticipated for this time period (recall that yield losses used by the EPA in its *ex ante* cost analyses for the 2006–2010 seasons were 14% and 30% for 1,3-D+PIC and metam sodium, respectively), then the *ex ante* and *ex post* estimates of the loss in net revenue would differ by 28–87% for a yield loss of 10% or 0%, respectively, for the 2006–2010 seasons.

5.4.2 Operating costs

Based on limited *ex post* information, *ex ante* operating costs for MBr use appear fairly accurate for a farm with a strawberries yield similar to the national average. Harvesting costs appear higher than *ex ante* estimates based on the California average, though this is driven by differences in yield assumptions.

Cost estimates when using methyl bromide. Sample costs from the 2006 and 2010 UC-Davis crop budgets use MBr+PIC as the default fumigant. Those developed for the South Coast region in 2006 represent a typical farm of 90 acres, while those developed for the Central Coast region in 2010 define a typical farm as 50 acres. Note that the 2006 and 2010 sample costs apply to different regions in California, while the EPA estimates are averages across regions applying for exemption. However, these assumptions are broadly consistent with what industry submitted to EPA for CUEs for the 2006–2008 growing seasons.

We compare the sample costs to the *ex ante* EPA cost estimates for the 2006–2008 seasons, as the EPA altered few of its underlying assumptions for the 2009–2010 CUE cost estimates. Recall from Table 3 that EPA estimated *ex ante* operating costs of $24,334 per acre for the 2006–2008 growing seasons. When we match the baseline yield from the CUE nomination packages to the sample cost studies we find that per acre operating costs are similar: for instance, operating costs for

Table 7 Operating costs per acre – UC-Davis sample cost study for South Coast Region[28]

	Yield (pounds per acre)						
	44,300	**50,600**	**56,900**	**63,200**	**69,500**	**75,900**	**82,200**
Cultivation	8446	8446	8446	8446	8446	8446	8446
Harvesting	13,095	14,982	16,869	18,757	20,644	22,531	24,419

Source: Takele et al. (2006). *Sample costs to produce strawberries: South Coast Region – Santa Barbara County*.

the South Coast region are estimated as $27,203 per acre or 12% higher than EPA estimates.

Though not available in the critical use exemption nomination packages, we obtained some detailed information from EPA on the breakdown of operating costs across categories that prove insightful. The EPA *ex ante* estimate of average cultivation costs – which does not vary by yield – was $16,000 per acre compared to $8500–$11,000 per acre as estimated by UC-Davis, 31–46% higher than UC-Davis cultivation cost estimates. (Table 7 presents sample costs for one of the two regions.)[29] No one category of costs stands out as the reason for this discrepancy. The EPA estimate of general material costs was about 14% higher, while MBr fumigation costs per acre were about twice that in the 2006 UC-Davis study.

Per acre harvesting costs, when matched to the baseline yield assumption used in the CUE nomination packages, are similar: UC-Davis estimated harvesting costs as $13,000–$15,000 per acre compared to EPA's estimate of $13,000. For a strawberry farm that produces at the California average instead of the national average, the UC-Davis researchers estimated harvesting costs to be about $19,000–23,000 per acre across the two regions (in 2006 dollars). They assumed that harvesting costs increase linearly with yield: the cost per pound of strawberries harvested did not change.

MBr Alternative fumigation costs. Did the EPA do a reasonable job of anticipating actual fumigant costs of MBr alternatives? Information on the cost of using MBr alternatives is scarce. Carter et al. (2005a) note that fumigation of strawberry fields prior to planting accounts for a substantial proportion of total production costs – about 10% for bed fumigation and 20% for flat fumigation. While the 2010

28 The UC-Davis sample costs include cost categories excluded from the table because they were not considered by the EPA in the CUEs – for instance, the cost of cooling picked strawberries and interest on operating capital. The EPA treated these as fixed costs. As we have no *ex ante* estimates to which we can compare, we exclude them here.

29 The EPA cost estimates are adjusted to 2006 dollars, assuming they are in nominal terms in 2003. To translate costs expressed on a tray per acre basis to pounds per acre, we use the UC-Davis average of 10 pounds per tray.

sample cost study for the Central Coast region suggests that a grower applying 1,3-D+PIC via drip irrigation would incur a cost of $900–$1600 per acre (in 2006 dollars), it does not evaluate the crop budget using this alternative. We can gather a bit more information from the 2011 sample cost studies for the South Coast region because they are based on using 1,3-D+PIC as the fumigant.[30]

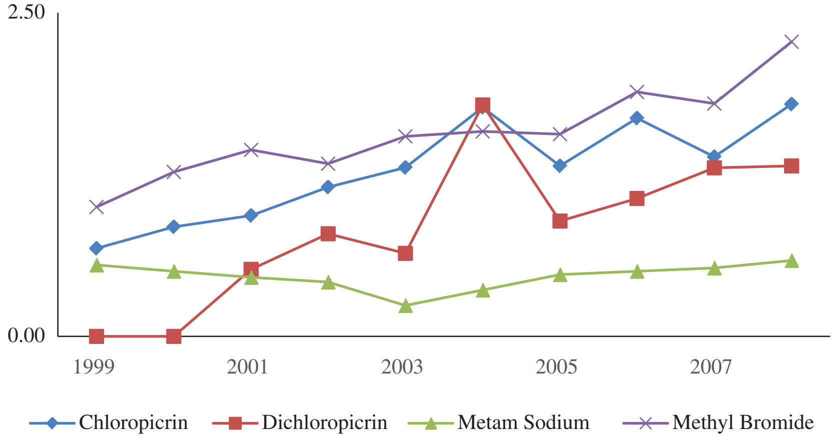
The direct fumigant cost for 1,3-D+PIC applied through drip irrigation was $1000–$1100 (adjusted from 2011 to 2006 dollars) across the two 2011 studies with the slightly higher value used for Ventura County. The 2006–2008 CUE nomination packages used a fumigant cost for 1,3-D+PIC – of about $1700 per acre – but assumed it was applied using a shank (or broadcast) system. Use of 1,3-D+PIC applied by drip irrigation reportedly requires less of the fumigant because the delivery system is more efficient than broadcast application (CSC, 2012b).[31] Unfortunately, the difference in method of application between the UC-Davis and EPA cost estimates makes it difficult to draw solid conclusions.[32]

Data indicate that 1,3-D+PIC was applied via drip irrigation with some regularity in counties where farmers sought critical use exemptions for the 2006–2010 growing seasons. According to the CUE for the 2014 growing season (EPA, 2012), 55% of strawberry acreage in Ventura and Oxnard counties in 2009 used a drip system for applying 1,3-D+PIC, decreasing to 30% in 2010 (some farmers returned to using methyl bromide every 3 years to control unanticipated diseases).

30 Goodhue, Fennimore, and Ajwa (2003) identified *ex ante* that 1,3-D alone or in combination with metam sodium had slightly lower costs per acre than methyl bromide based on the cost of fumigant application, weeding, and tarp material. Goodhue et al. (2004) found evidence from field experiments that drip-applied chloropicrin and 1,3-D "may potentially be economically feasible" compared to MBr+PIC (applied at a 67:33 ratio) for strawberry fields in California. The range of application rates over which they appear economically feasible increases with a change in tarp type (i.e., virtually impermeable films perform better than high-density polyethelyne films). At the time of the study, it was common to apply fumigants broadly with some of what is applied escaping from permeable tarps. The authors note that, if instead farmers use virtually impermeable film and apply fumigants through a drip system, substantially less fumigant would escape, allowing them to lower costs. The EPA estimated *ex ante* that the MBr alternatives analyzed had slightly lower operating costs per acre than MBr, consistent with these studies.

31 Sydorovych et al. (2006) noted that applying 1,3-D+PIC by a drip system lowers labor and machinery costs, but increases material costs relative to shank fumigation (this study examines use in North Carolina, not California).

32 Combined, cultivation and harvesting costs in Santa Barbara and San Luis Obispo counties are similar to UC-Davis estimates for 2006 when using MBr. The combined cultivation and harvesting costs for Ventura County when 1,3-D+PIC is used are higher. A recent *ex-post* estimate for Ventura County using MBr is not available. The 2006–2008 CUE nominations used a slightly lower harvesting cost while cultivation costs remained nearly identical for 1,3-D+PIC. Combined they added to about $28,000, $1000 less than what was estimated for MBr. However, it is difficult to draw conclusions given differences in assumptions about how the chemical was applied (shank vs. drip).



Source: Proprietary pesticide marketing data;data masked by index.

Figure 3 Real prices of fumigants in California relative to methyl bromide in 1999.

Fumigant prices. We obtain information on nominal fumigant prices in California from 1999 to 2008 from a proprietary pesticide marketing database. We convert these to real prices using the Producer Price Index and measure them against methyl bromide in 1999 (which receives a value of 1). Since these chemicals are often combined for use when applied to strawberry fields and the rates at which they are applied differ, the prices do not indicate the relative difference in cost between MBr alternatives. They are still instructive, however. First, note that methyl bromide has been consistently more expensive per pound than alternatives (Figure 3). Second, while several authors noted that MBr prices will begin to increase relative to other fumigants as exemptions decline and the stockpile is drawn down, it appears that a more than proportional increase in the price for methyl bromide relative to alternatives had not yet occurred. Prices for 1,3-D and PIC both increased by slightly more than methyl bromide over this time period.[33]

5.4.3 Indirect costs

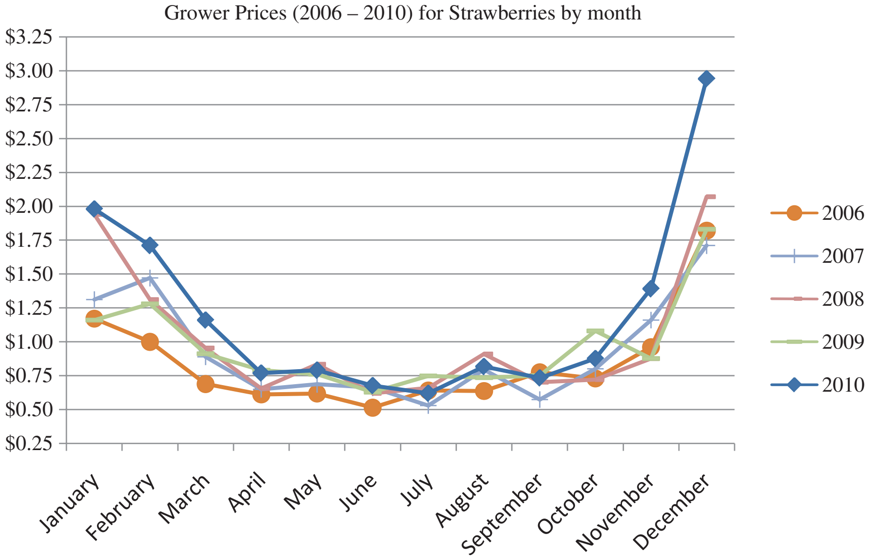
In the CUE requests for the 2006–2008 growing seasons, farmers argued that the use of MBr alternatives would delay planting by several weeks. Unlike broad-

33 Prices for dichloropicrin begin in 2001 in the proprietary data while prices are not reported in 2000, 2004, and 2006 for metam sodium. Metam sodium prices in intervening years are linearly interpolated.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

cast fumigation, drip irrigation used to apply 1,3-D requires that equipment be set up for the entire field before applying chemicals (EPA, 2005).[34] As a result of the delay, farmers would receive lower prices for strawberries, all else equal. The EPA did not analyze the effect of a missed market window on California growers for the 2009–2010 growing seasons since the industry offered no evidence that it had actually occurred. However, it noted the possibility of a planting delay due to the use of tarps (i.e., it takes longer for the fumigant to dissipate). Carpenter et al. (2000) also indicate a planting delay of about a week could occur due to phytotoxicity concerns.

For the 2006–2008 growing seasons the EPA assumed that missing the market window would result in a 5% (or three cent per pound) penalty in terms of foregone revenue. This appears to be an accurate characterization of the average monthly differential in national prices received by producers between 2005 and 2009. However, it is worth noting that, because the harvesting season varies markedly by region in California, when a delay occurs could matter greatly from



Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381. See table08.xls. Reported in nominal prices.

Figure 4 National grower prices (2006–2010) for strawberries by month.

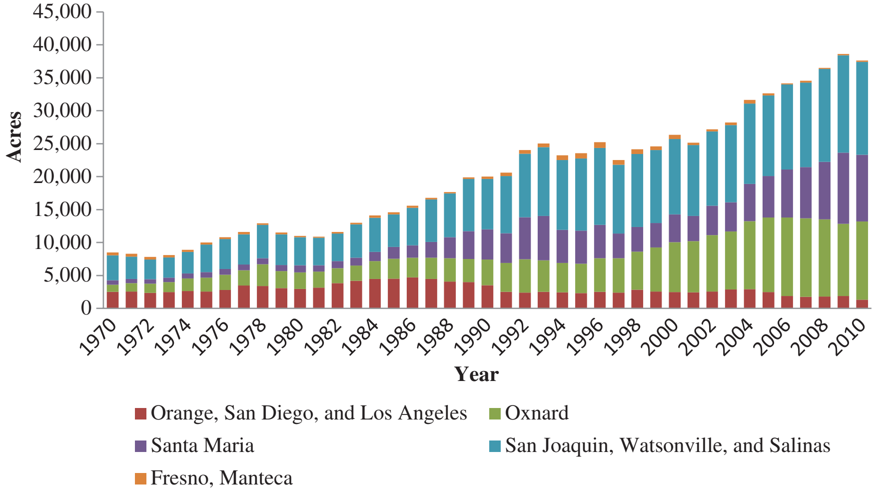
34 It could also delay planting of rotation vegetable crops planted after strawberries. Industry contends that this could result in a reduction from two rotation crops to one (US EPA, 2005).

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

the perspective of the individual farmer.[35] Figure 4 illustrates the differences in the prices growers receive by month for 2006–2010 (the same trend is also evident for earlier years). For instance, a delay from January to February could mean that farmers give up about 16 cents per pound on average. The difference between February and March is even larger: prices are on average about 43 cents per pound lower in March. Delaying harvest from April to May results in prices that are 4 cents higher per pound, on average. An unanswered question is how shifts in production across time affect monthly prices.

5.4.4 Opportunity costs

We next review the *ex post* evidence on overall strawberry production in California compared to organic production and imports from Mexico. While the CUEs for the 2006–2010 seasons did not directly speak to this issue, the *ex ante* literature makes predictions regarding the ability of farmers growing strawberries conventionally to compete with producers not subject to the MBr phase-out.



Source: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381. See table05.xls.

Figure 5 California strawberry acreage by major growing area: 1970–2010.

35 Data indicate that peak harvesting months in California are April–August for fresh strawberries (CSC, 2009; USDA, 2006). This masks considerable variation by region. Peak harvest in Orange and San Diego counties is March–April. Peak harvest in Santa Maria and Salinas-Watsonville is May–June, and July–August, respectively.

https://doi.org/10.1515/jbca-2014-0025 Published online by Cambridge University Press

Overall strawberry production. If methyl bromide and its alternatives proved expensive enough, strawberry acreage could decline as farmers moved out of MBr-intensive crops or let land go fallow. *Ex ante* studies predict a decrease in strawberry production in California, though they also tend to analyze the effects of a complete and immediate MBr ban. For instance, VanSickle, Brewster, and Spreen (2000) predicted that strawberries would no longer be grown in northern California and that production would experience a decline in southern California. The EPA *ex ante* analyses assumed that the amount of California land planted in strawberries would remain fixed at 27,600 acres (the 2000 level).

Data indicate that land dedicated to growing strawberries in California continued to expand. Figure 5 illustrates longer-term trends in strawberry acreage in California from 1970 to 2010. Recall that the methyl bromide phase-out began in 1993 with a freeze at 1991 levels, reducing MBr until it was no longer in use in 2005 unless an exemption was granted. There are no obvious changes in the overall trend before or after the phase-out began, nor does growth in strawberry acreage seem impacted in the post-2005 period. Likewise, while some strawberry growing areas increased acreage and others decreased in strawberries over time, this trend appears unrelated to the timing of the phase-out. Perez, Plattner, and Baldwin (2011) point to strong US demand for strawberries as the largest driver of growth in production, which could disguise the incremental effect of the MBr phase-out.

When we examine the data by region, we find that the majority of the growth in strawberry acreage from 2006 to 2010 stemmed from two districts, one in the south – Santa Maria – and the other in the north – San Joaquin-Watsonville-Salinas – both of which historically have grown a substantial portion of strawberries on hillsides where MBr alternatives are reportedly less effective (CSC, 2009). These districts were also presumably the main beneficiaries of critical use exemptions given the technical challenges of switching to another fumigant. Acreage dedicated to strawberries in two other southern districts – Orange-San Diego-Los Angeles and Oxnard – remained relatively flat over this time frame.[36]

Organic strawberry production. Goodhue et al. (2005) observe that opportunities for California farmers to switch from conventional to organic strawberry production are likely limited. Data confirm that farmers did not engage in large-scale switching to organic production in response to the MBr phase-out. According to the CSC (2005), about 300 acres were planted in organic strawberries in California in 2001. Organic strawberry production increased to almost 1800 acres by 2010. While the rate of increase was high, the total amount of land dedicated

36 The CSC (2006) notes that land development and rising property costs in Orange County resulted in lower strawberry acreage in 2006 vs. 2005.

to organic production was still relatively small, about 5% of total California strawberry acreage in 2010 (CSC, 2012a).

Strawberries imported from Mexico. USDA data show that imports of fresh strawberries from Mexico almost tripled from 124 million pounds in 2001 to 342 million pounds in 2010. However, domestic consumption of strawberries also increased substantially, from 1.2 billion to 2.2 billion pounds. Domestic production largely kept pace with demand over this timeframe, so that Mexico's share of total US demand only increased from 10 to 15%.[37] Without controlling for other factors, it is difficult to say what role the phase-out of MBr had in encouraging increased imports from Mexico, but it does seem far less than what some predicted (e.g., VanSickle and NaLampang, 2002) and in line with studies that pointed to factors that would limit growth in Mexican imports (e.g., Norman, 2005).

6 Overall implications and study limitations

Based on the *ex post* information available, we find that net operating costs on the typical California strawberry farmer from methyl bromide use restrictions for the 2006–2010 growing seasons was likely less than anticipated *ex ante* (see Table 7). It appears that a number of viable MBr alternatives – either new fumigants or new ways of applying existing fumigants – may have become available more quickly and resulted in lower yield loss than initially anticipated. Using what *ex post* information we have on yield losses associated with 1,3-D+PIC, for example, we find that the *ex ante* and *ex post* estimates of the loss in net revenue may differ by 28–87% for the 2006–2010 growing seasons, all else equal. Likewise, it appears that farmers who substituted away from methyl bromide did so without imposing large negative impacts on production in prime California strawberry growing areas.

We also confirm the effect of California regulatory restrictions in limiting the use of various economically competitive alternatives. Uncertainty about the effect of regulatory restrictions on the feasibility of some fumigant combinations makes it difficult to precisely identify the extent to which yield losses may have differed from EPA's *ex ante* estimates. It is also worth noting that unanticipated complications after switching away from MBr, such as new diseases, slowed the transition to alternatives, in particular 1,3-D+PIC applied via drip irrigation.

As previously mentioned, conclusions drawn from the *ex post* evaluation come with significant caveats. First, we are limited to an evaluation of per acre

37 See tables 12 and 16 at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1381.

costs. Second, we only have information on operating costs from crop budgets designed to reflect a typical farmer. Third, yield losses associated with MBr alternatives are based on field trial research. Fourth, while we have detailed annual data on what fumigants farmers used, we do not have information on other management practices such as the type of tarp used. Fifth, the prices of specific fumigant formulations are not publically available. Finally, it is analytically challenging to evaluate the counterfactual: what would farmers have done if they had not received the same level of MBr exemptions for the 2006–2010 seasons?

Acknowledgments: The author thanks Jeremy Arling, Christine Augustyniak, William Chism, Jim DeMocker, David Donaldson, Elizabeth Hill, Timothy Kiely, and Leonard Yourman for their helpful suggestions and technical expertise. The author also thanks members of Environmental Economics Advisory Board of the EPA's Science Advisory Board for their careful review of the draft report upon which this article is based, which can be found at: http://yosemite.epa.gov/sab/sabproduct.nsf/c91996cd39a82f648525742400690127/3a2ca322f56386fa852577bd0068c654!OpenDocument.

References

Bolda, M., Tourte, L., Klonsky, K., & De Moura, R. (2010). *Sample costs to produce strawberries*. Central Coast Region: Santa Cruz and Monterey Counties. University of California Cooperative Extension.

California Strawberry Commission. (2005). *Strawberry review: 2005 acreage survey results*.

California Strawberry Commission. (2006). *Strawberry review: 2006 acreage survey*.

California Strawberry Commission. (2009). *California strawberry revised 2009 acreage survey*.

California Strawberry Commission. (2012a). *Strawberry review: 2012 acreage survey*.

California Strawberry Commission. (2012b). *The facts about methyl bromide*.

Carpenter, J., Gianessi, L., & Lynch, L. (2000). *The economic impact of the scheduled U.S. phaseout of methyl bromide*. National Center for Food and Agricultural Policy.

Carpenter, J., Lynch, L., & Trout, T. (2001). Township limits on 1,3-D will impact adjustment to methyl bromide phase-out. *California Agriculture, 55*(3), 12–18.

Carter, C., Chalfant, J., Goodhue, R., Groves, K., & Simon, L. (2004). *Impacts of pesticide regulation on the California strawberry industry*. Working Paper.

Carter, C., Chalfant, J., Goodhue, R., Han, F., & DeSantis, M. (2005a). The methyl bromide ban: economic impacts on the California strawberry industry. *Review of Agricultural Economics, 27*(2), 181–197.

Carter, C., Chalfant, J., Goodhue, R., & McKee, G. (2005b). Costs of 2001 methyl bromide rules estimated for California strawberry industry. *California Agriculture, 59*(1), 41–46.

Dara, S., Klonsky, K., & De Moura, R. (2011). *Sample costs to produce strawberries*. South Coast Region: Santa Barbara and San Luis Obispo Counties: University of California Cooperative Extension.

Daugovish, O., Klonsky, K., & De Moura, R. (2011). *Sample costs to produce strawberries.* South Coast Region: Ventura County. University of California Cooperative Extension.
DuPois, E., & Gareau, B. (2008). Neoliberal knowledge: the decline of technocracy and the weakening of the Montreal Protocol. *Social Science Quarterly, 89*(5), 1212–1229.
Fennimore, S., & Ajwa, H. (2011). Totally impermeable film retains fumigants, allowing lower application rates in strawberry. *California Agriculture, 65*(4), 211–215.
Ferguson, W., & Yee, J. (1997). Phasing out registered pesticide uses as an alternative to total bans: A case study of methyl bromide. *Journal of Agribusiness, 15*(1), 69–84.
Goodhue, R., Fennimore, S., & Ajwa, H. (2003). *Economic feasibility of methyl bromide alternatives: field-level cost analysis.* White Paper.
Goodhue, R., Fennimore, S., Klonsky, K., & Ajwa, H. (2004). *After methyl bromide: the economics of strawberry production with alternative fumigants.* Working Paper. Giannini Foundation of Agricultural Economics.
Goodhue, R., Fennimore, S., & Ajwa, H. (2005). The economic importance of methyl bromide: does the California strawberry industry qualify for a critical use exemption from the methyl bromide ban? *Review of Agricultural Economics, 27*(2), 198–211.
Hueth, B., McWilliams, B., Sunding, D., & Zilberman, D. (2000). Analysis of an emerging market: can methyl iodide substitute for methyl bromide? *Review of Agricultural Economics*, *22*(1), 43–54.
Kopits, E., McGartland, A., Morgan, C., Pasurka, C., Shadbegian, R., Simon, N., Simpson, D., & Wolverton, A. (2014). Retrospective cost analyses of EPA regulations: a case study approach. *Journal of Benefit Cost Analysis*, *5*(2), 173–193.
Mayfield, E., & Norman, C. (2012). Moving away from methyl bromide: political economy of pesticide transition for California strawberries since 2004. *Journal of Environmental Management*, *106*(15), 93–101.
Noling, J. (2005). *Reducing methyl bromide field application rates with plastic mulch technology.* Paper ENY046. Institute of Food and Agricultural Science, University of Florida.
Noling, J., & Botts, D. (2010). *Transitioning to methyl bromide alternatives: a current U.S. assessment.* White Paper. Available at: http://mbao.org/2009/Proceedings/002NolingJBottsDMBAO2009TransitioningtoMethylBromideAlternatives.pdf.
Noling, J., Botts, D., & MacRae, A. (2010). *Alternatives to methyl bromide soil fumigation for Florida vegetable production.* Vegetable Production Handbook. University of Florida, IFAS Extension.
Norman, C. (2005). Potential impacts of imposing methyl bromide phaseout on U.S. strawberry growers: a case study of a nomination for a critical use exemption under the Montreal Protocol. *Journal of Environmental Management, 75*, 167–176.
Othman, M., Ajwa, H., Fennimore, S., Martin, F., Subbarao, K., Browne, G., & Hunzie, J. (2009). *Strawberry production with reduced rates of methyl bromide alternatives applied under retentive film.* Proceedings for 2009 Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.
Perez, A., Plattner, K., & Baldwin, K. (2011). *Fruit and tree nuts outlook.* FTS-347. National Agricultural Statistical Service, U.S. Department of Agriculture.
Porter, I., Trinder, L., & Partington, D. (2006). *Validating the yield performance of alternatives to methyl bromide for pre-plant fumigation.* Special report commissioned by the Methyl Bromide Technology Options Committee, Technology and Economic Assessment Panel, UNEP.

Rubin, S. (2012). Arysta to pull methyl iodide from U.S. *Monterey County Weekly*. March 22.
Samtani, J., Ajwa, H., Weber, J., Browne, G., Klose, S., Hunzie, J., & Fennimore, S. (2011). Evaluation of non-fumigant alternatives to methyl bromide for weed control and crop yield in California strawberries. *Crop Protection, 30*(1), 45–51.
Sances, F. (2000). *Conventional and organic alternatives to methyl bromide on California strawberries*. Working paper. Presented at Methyl Bromides Alternatives Conference.
Sydorovych, O., Safley, C., Ferguson, L., Poling, E., Fernandez, G., Brannen, P., Monks, D., & Louws, F. (2006). Economic evaluation of methyl bromide alternatives for the production of strawberries in the southeastern United States. *HortTechnology, 16*(1), 1–11.
Takele, E., Klonsky, K., & De Moura, R. (2006). *Sample costs to produce strawberries*. South Coast Region: Santa Barbara County, Santa Maria Valley. University of California Cooperative Extension.
UNEP (United Nations Environmental Programme). (2006). *Handbook for the Montreal Protocol on substances that deplete the ozone layer*. 7th Edition, United Nations.
UNEP. (2010). 2010 *Report of the methyl bromide technical options committee*.
U.S. Department of Agriculture. (2000). Economic implications of the methyl bromide phaseout. Economic research service. *Agriculture Information Bulletin, 756*.
U.S. EPA. (2004–2013). *Methyl bromide critical use nomination for preplant soil use for strawberries grown for fruit in open fields*. Submitted for 2006–2015 seasons.
VanSickle, J., Brewster, C., & Spreen, T. (2000). Impact of a methyl bromide ban on the U.S. vegetable industry. University of Florida, Institute of Food and Agricultural Science. *Bulletin 333*.
VanSickle, J., & NaLampang, S. (2002). *The impact of the phase out of methyl bromide on the U.S. vegetable industry*. Policy Brief 02-1. University of Florida. International Agricultural Trade and Policy Center.

Article note: The views expressed in this article are those of the author and do not necessarily represent those of the U.S. EPA.