Welfare Analysis of the Prohibition of 2,4-D in the United States

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- The loss of access to 2,4-D would most certainly force applicators to switch to more expensive alternative herbicides and would likely result in decreased crop yields.
- Cost increases for agricultural uses associated with such a ban could be anywhere from $53 to $102 million.
- Cost increases for non-crop uses range from $130 to $510 million.

Introduction

2,4-Dichlorophenoxyacetic acid (2,4-D) was first marketed to control broadleaf weeds in 1945 and since that time has become one of the most widely used herbicides in the world. 2,4-D formulations include esters, acids, and several salts (WHO 1989). The dimethyl-amine salt (DMA) and 2-ethylhexyl ester (EHE) formulations account for approximately 90-95% of its total global use (Charles et al. 2001).

As an effective and relatively inexpensive herbicide to control weeds, 2,4-D is widely used in both agricultural and non-agricultural settings, such as cropland, pastureland, rangeland, fallowed land, rights-of-way, and turfgrass. As discussed in later chapters, a ban on the use of 2,4-D would leave fewer modes-of-action to be used and thus would increase the risk of weed resistance. In addition, users might not be able to find alternative effective weed control methods without incurring an increase in costs and/or suffering yield loss. While the impacts could be environmental and economic, this chapter will focus on analyzing economic effects. Specifically, it will focus on the impacts on several major uses, including small grains (wheat and barley), rights-of-way, turfgrass, pastures and rangeland which account for most uses of 2,4-D in the US.

Theoretical Framework

If 2,4-D were not available for use, applicators would have to switch to other herbicides that may cost more and may not work as well. Therefore, the average cost of production for users would increase and/or the yield would decrease. The cost increase and yield loss would shift and tilt the supply curve for the affected crops and uses and consequently change the market equilibrium to a higher price and lower quantity for supply and demand. Such a change would cause changes in both consumer and producer wellbeing. Economists estimate the monetary value of these changes using a measure called “surplus” or “welfare”.

The cost increase and yield loss would shift and tilt the supply curve and consequently change the market equilibrium to a higher price and lower quantity for supply and demand.

An increase in the cost of weed control under the non-2,4-D scenario implies a contraction or upward shift of the supply curve – producers would need a higher price to sell any given quantity to compensate for the increase in cost. Similarly, a decrease in per acre yield for the crop under the non-2,4-D scenario also implies a contraction or upward shift of the supply curve – farmers would again need a higher price to sell any given quantity since more acres would be needed to generate the same level of production.

Panel A in Figure 2.1 illustrates the key underlying economic concepts used in the analysis, assuming linear supply and demand curves. From a market-level perspective, which integrates and aggregates over all consumers and producers and all possible prices and quantities, the demand curve traces out the maximum consumer willingness to pay for a good such as corn, while the supply curve traces out the minimum farmer willingness to accept to sell the good. Consumer surplus is generated when consumers are paying less for a good than their maximum willingness to pay. For example, paying $1 for a good when you were willing to pay as much as $2, generates $2 – $1 = $1 of consumer surplus. The same concept holds from the producer side – selling the good for $2 when you were willing to sell the good for $1, generates $2 – $1 = $1 of producer surplus. Market equilibrium occurs at the price and quantity at which supply equals demand, so that the area above this equilibrium price (P_0) and below the demand curve out to the equilibrium quantity (Q_0) is consumer surplus (area CS_0), while the area below this equilibrium price and above the supply curve out to the equilibrium quantity is producer surplus (area PS_0). A key point to note is that these consumer and producer surplus measures are monetary measures – dollar denominated – which simplifies interpretation. In this case, producer surplus is farmer profit and consumer surplus is additional consumer purchasing power.

The economic impacts of banning the use of 2,4-D are measured by changes in producer and consumer surplus. Changes in producer surplus are incurred by changes in the supply curve that would occur if 2,4-D were not available, assuming a ban of 2,4-D causing weed control costs to increase and yields of the affected crops to fall. Panel B illustrates the situation after cost and yield changes have been imposed on producers as a result of the non-2,4-D scenario. An increase in the cost of weed control under the non-2,4-D scenario implies a contraction or upward shift of the supply curve – producers would need a higher price to sell any given quantity to compensate for the increase in cost. With a linear supply curve, this cost change implies a parallel upward shift in the supply curve, from S_0 to S_1 in Panel B. Similarly, a decrease in per acre yield for the crop under the non-2,4-D scenario also implies a contraction or upward shift of the supply curve – farmers would again need a higher price to sell any given quantity since more acres would be needed to generate the same level of production. With a linear supply curve and a constant percentage decrease in per acre yields, this change implies an upward twist of the supply curve, from S_1 to S_2 in Panel B. The final equilibrium for the non-2,4-D scenario generates producer and consumer surplus of PS_2 and CS_2 in Panel B. Based on this new equilibrium, the benefit of 2, 4-D for consumers of this crop is the change in consumer surplus: $CS_2 – CS_0$, i.e., without 2, 4-D, consumer surplus would decrease to CS_2 from its original level of CS_0. Similarly, the benefit of 2, 4-D for producers of this crop is the change in producer surplus: $PS_2 – PS_0$, i.e., without 2, 4-D, producer surplus would decrease to PS_2 from its original level of PS_0. The net change in social welfare is then the sum of the net change in producer and consumer surplus, or $PS_2 – PS_0 + CS_2 – CS_0 = PS_2 + CS_2 – (PS_0 + CS_0)$.

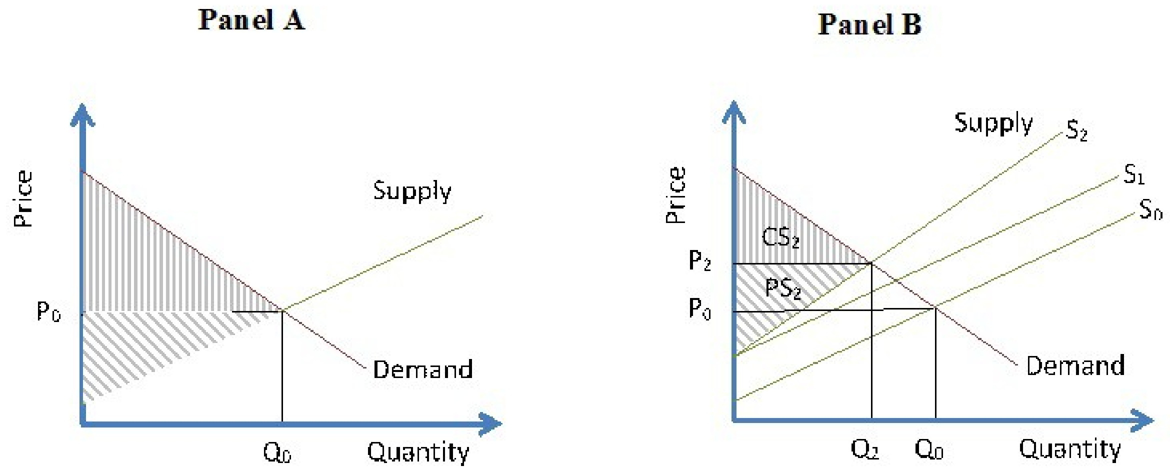

Figure 2.1. Producer and consumer surplus in a market (Panel A) and how a producer cost increase and yield decrease change supply and producer and consumer surplus (Panel B).

The producer surplus change shown in Figure 2.1 is aggregated for both users and non-users of 2, 4-D, as the figure shows the market equilibrium for the affected crop for all those in the market (all buyers and sellers). Therefore, the cost and yield changes are averaged across the whole affected crop industry, not just the 2, 4-D users. A higher equilibrium price that occurs under the non-2, 4-D scenario would benefit non-users - they would receive more for their crop even though they did not have to increase their cost.

The above analysis is a partial equilibrium analysis of the benefits, since the crop market is analyzed in isolation, without interactions with other crop markets. Therefore, the analysis should be viewed as an estimate of the short term effects of a loss of 2, 4-D.

Partial Equilibrium Analysis

For the crops analyzed using a partial equilibrium framework for this report, the supply and demand equations are set up in a general linear form:

$$Q_S = a_0 + a_1X_1 + a_2X_2 + \ldots + aP + e_S \tag{1}$$

$$Q_D = b_0 + b_1Z_1 + b_2Z_2 + \ldots + bP + e_D \tag{2}$$

where Q_S and Q_D are the respective supply and demand of the crop; P is the crop price; X_1, X_2, …, and Z_1, Z_2, … are other variables that respectively impact supply and demand, such as fertilizer cost and consumer income; a_0, a_1, .., b_0, b_1, …, a, and b are parameters to estimate; and e_S and e_D are estimation errors. The supply and demand equations as specified in equations (1) and (2) are both linear in price. To simplify the derivation below, but not affect the analysis, define $A = a_0 + a_1X_1 + a_2X_2 + \ldots$ and $B = b_0 + b_1Z_1 + b_2Z_2 + \ldots$, so that $Q_S = A + aP$ and $Q_D = B + bP$.

The ban of 2,4-D has two effects on production – it changes the cost of production and yield, which both affect the supply curve as illustrated in Panel B of Figure 2.1. For this analysis, the cost of production change for the non-2,4-D scenario will be expressed as a dollar per unit of output change relative to the original 2,4-D case, while the yield change for the non-2,4-D scenario will be expressed as a percentage change in yield relative to the original 2,4-D case. The new supply function with a cost per unit of output change, k, can be expressed as

$$Q_S = A + a(P + k) = A + ak + aP.$$

Based on this equation, the new supply function with both a cost per unit of output change, k, and a yield percentage change, L, can be expressed as

$$Q_S = A + ak + a(1 + L)P. \tag{3}$$

Based on equation (3), we specify a system of linear supply and demand functions for the domestic market and the rest of the world (ROW), and then solve for the change in surplus for domestic consumers, consumers in the rest of the world, and for domestic producers. The algebra deriving these expressions is available on request for the authors; here we report the final equations. To make them easier to express, we define intermediate variables and express them in terms of standard supply and demand elasticities. Specifically, define $K = k/P_0$, so that K is now the cost change per unit of output as a proportion of the original price. Also, define $Z = -(P_1 - P_0)/P_0$., so that Z is the percentage reduction in price, and define $J = (1 - K)/(1 + L)$ to simplify expressions. Also, let ε be the domestic supply elasticity for the crop, η_D be the domestic demand elasticity and η_{RED} be the excess demand elasticity for the crop.

Based on these definitions, the change in domestic consumer surplus can be expressed as:

$$\Delta CS = P_0Q_{D,0}\,Z(1 + 0.5Z\eta_D). \tag{4}$$

The change in total welfare for the ROW (we do not separate the total welfare into consumer and producer for the ROW) can be expressed as:

$$\Delta TS = P_0Q_{D,0}\,Z(1 + 0.5Z\eta_{RED}). \tag{5}$$

Finally, the change in domestic producer surplus is can be expressed as:

$$\Delta PS = P_0Q_{D,0}\,[(K - Z) + \tfrac{1}{2}(1 - K - J) + \tfrac{1}{2}(1 - Z - J)(K - Z + L(1 - Z)\varepsilon]. \tag{6}$$

Equations (4)-(6) express the change in surplus for the non-2, 4-D scenario as a function of the initial price and quantity demand ($P_0Q_{D,0}$), the cost per unit of output change (k), the yield percentage change (L), and the domestic supply elasticity (ε), the domestic demand elasticity (η_D)

and be the excess demand elasticity in the ROW (η_{RED}). Also, note that equations (4)-(6) assume the domestic nation is a net exporter of the crop. If instead the domestic nation is a net importer, then substitute excess supply elasticity in the ROW (η_{SED}) for η_{RED}.

Welfare analysis for commodities without price elasticities

The above conceptual framework for the economic analysis of crops is applied to crops where production and cost changes can be measured. For non-crops such as turfgrass and rights-of- way, since there is no price and output change for the final products, only cost variations are estimated. In these instances, we assume that users would switch to herbicides that are as effective as 2,4-D but more expensive, i.e., there is only a cost change and no yield (or quality) loss. Therefore, the cost change for users would be the only change incurred by the ban of 2,4-D and the cost increase would be the net economic effect.

Data and Estimates

Equations (4)-(6) are expressions for the changes in domestic consumer surplus, producer surplus and the impact on the ROW welfare in terms of three types of parameters: i) the original price, quantity produced and domestic consumption, ii) domestic supply and demand elasticities, and the ROW excess demand or supply elasticity, and iii) cost and yield impacts of the non-2,4-D counterfactual scenario. Data for crop prices, quantities sold and net exports are available from public sources, such as the US Department of Agriculture's Economic Research Service.

Data for the 2012 season are used for the original price, quantity produced and domestic consumption of wheat and data for 2011 season are used for barley, the most recent seasons having 2,4-D application data provided by the USDA. The required domestic elasticities for analysis are estimated using historical data, while ROW excess demand or supply elasticities of wheat are obtained from the published literature as the estimations using historical data are not statistically significant. The US was generally a net importer of barley, and so the ROW excess supply elasticity was estimated. The elasticities used in the analysis are reported in Table 2.1.

Table 2.1. Elasticities used in the analysis.

	Winter wheat	Spring wheat	Barley
Domestic supply elasticity	0.15	0.48	0.17
Domestic demand elasticity	-0.20	-1.26	-0.57
ROW excess demand (supply) elasticity	-0.80	-0.80	0.49

The cost and yield impacts of the non-2,4-D scenario are based on information from the respective chapters in this report. The cost impact is calculated as the difference of cost per unit of output between the utilization of 2,4-D and the non-2,4-D scenario. The cost per unit of output for using 2,4-D is calculated as the average cost of all the types of 2,4-D used in 2012, while the cost for non-2,4-D scenario is calculated for five possible cases: 1) using more expensive alternative herbicides and having no yield loss; 2) using more expensive alternative herbicides and having low yield loss (2%); 3) using more expensive alternative herbicides and having medium yield loss (5%); 4) choosing not to treat but with high yield loss (10%); and 5) choosing not to treat but with even higher yield loss (15%). The cost of more expensive alternative herbicides used is the average cost of all other herbicides currently used to control broadleaf weeds per acre basis.

Welfare analysis for wheat is separated into winter wheat and spring wheat. Winter wheat includes hard red winter, soft red winter, and white wheat; spring wheat includes durum and other types of spring wheat. The average cost of the three types of 2,4-D used in winter wheat is \$1.75/acre for treated acres, and the average cost of all other herbicides for broadleaf control is \$4.24/acre, the net cost increase is \$4.24 – \$1.75 = \$2.49 per acre (see Table 2.2). Since 24% of winter wheat acres are treated with 2,4-D, 24% x \$2.49 = \$0.60 per acre if 2,4-D were banned, once the cost increase is averaged over all winter wheat acres. These calculations are repeated for spring wheat and barley, but using the respective percentage of acres currently treated with 2, 4-D for each crop (12% and 18% for spring wheat and barley, respectively). Table 2.2 reports these results as well. There are five types of 2,4-D used to control broadleaf weeds for spring wheat, with an average cost of \$3.13/acre for treated area. But with the ban, the cost would increase to \$4.29 per treated acre or \$0.13/acre when averaged over all acres. The average cost of weed control using 2,4-D for barley would increase from \$1.90 per acre to \$4.61 if users switched to alternatives. The average cost increase would be \$0.49 per acre.

Table 2.2. Cost change if 2,4-D were banned.

	Winter wheat	Spring wheat	Barley
2,4-D cost per treated acre	\$1.75	\$3.13	\$1.90
Alternative herbicide cost per treated acre	\$4.24	\$4.29	\$4.61
Cost change per treated acre	\$2.49	\$1.16	\$2.71
Cost change per acre	\$0.60	\$0.13	\$0.49

For non-crop use of 2,4-D, as we do not have information on yield loss and demand elasticities, we can only estimate the cost change as the economic effect for pastureland, rangeland, turfgrass, and rights-of-way. The information for the cost increase incurred as a result of a ban on use of 2,4-D is from subsequent chapters.

According to Renz (Chapter 3), the use of 2,4-D in pastures, rangeland, alfalfa or wildland/natural areas ranges between 15 and 29 million lbs on 16 to 28 million acres. The use in pastures and rangelands accounts for most of the use, ranging between 12 and 20 million lbs. Renz (Chapter 3) estimates that users wishing to obtain similar results would spend 2-4 fold more, which is also the assumption we use in all estimation of cost increase for all non-crops.

2,4-D is important in industrial/government vegetation management, including parks and school playgrounds, golf courses and sports fields, commercial and institutional landscapes and cemeteries, as well as road, rail, electric utility and pipeline rights-of-way (see Byrd Chapter 9). Total sales of 2,4-D were 6.3 million lbs for application to industrial vegetation management on rights-of-way – 0.65 million lbs for highways, 0.26 million lbs for rail, and 9 thousand lbs to electric and pipeline right-of-way vegetation management in 2013 (Byrd Chapter 9; Kline and Company 2014).

We assume that the use of 2,4-D on turfgrass by both industry and government is the total industrial vegetation management use after deducting the use on rights-of-way. Consequently the amount of use on turfgrass by industry and government was about 5.3 million lbs in 2013. The information about the amount of 2,4-D used in home and garden settings in 2013 is unavailable. But based on 2007 data (Gruel et al. 2011) and the information in later chapters, we assume that the use of 2,4-D in home and garden settings in 2013 was about 5 million lbs. Therefore, the total use of 2,4-D on turfgrass was about 10.3 million lbs in 2013.

Basing on the information about the application of 2,4-D from previous chapters, we assume that the application rate of 2,4-D is between 0.35-0.95 lb/acre for turfgrass and 0.25-0.75 lb/acre.

Results: Crops

Welfare and crop price impacts of banning 2,4-D are listed in Tables 2.3, 2.4, and 2.5 for winter wheat, spring wheat, and barley, respectively. The relatively high proportion of areas being treated with 2,4-D and more expensive alternative herbicides make the welfare loss the largest for winter wheat compared to spring wheat and barley. For all three crops, leaving areas untreated after the 2,4-D ban is not a rational choice as the welfare loss is much larger than switching to alternative herbicides.

If users switched to a more expensive alternative herbicide without incurring yield loss in winter wheat, the crop price would only increase 0.05%, but cause a $5.3 million loss in consumer surplus and $12.4 million loss in producer surplus. The higher price would also decrease the importing ROW's welfare by $1 million. If there were a yield loss along with a cost increase, the welfare loss would be much larger. The domestic welfare loss would be $45 million and $86 million for the scenarios with both cost increase and 2% or 5% yield loss, respectively (Table 2.3).

Table 2.3. Estimated annual changes in welfare ($ million per year) and crop prices for winter wheat with different cost and yield impacts for the non-2,4-D scenario.

	Cost Increase ($0.60/A)			Untreated	
	No yield loss	Low yield loss (2%)	Medium yield loss (5%)	High yield loss (10%)	Very high yield loss (15%)
Change in consumer surplus	-$5.29	-$22.32	-$47.95	-$81.85	-$125.11
Change in producer surplus	-$12.43	-$22.34	-$37.60	-$42.67	-$70.44
Total domestic welfare change	-$17.72	-$44.66	-$85.56	-$124.52	-$195.55
Price increase	$0.00	$0.02	$0.03	$0.06	$0.09
Price increase (%)	0.05%	0.21%	0.46%	0.78%	1.19%
ROW welfare change	-$1.04	-$4.40	-$9.46	-$16.14	-$24.65

Welfare change in spring wheat would be smaller compared to winter wheat. If there were only a cost increase, the domestic welfare change would be $1.6 million. Similarly, the welfare loss would be greater if a yield loss also occurs – $5.6 million and $11.7 million with both a cost increase and a 2% or 5% yield loss, respectively (Table 2.4). Effects on the ROW welfare are less than $1 million with only a cost increase and $1.8 million and $4.2 million for the 2% and 5% yield loss added to the cost increase. For barley, the cost increase alone implies a $1.1 million loss in total surplus and $2.6 million and $4.9 million if the cost increase is also accompanied by a 2% or a 5% yield loss (Table 2.5). As the US is mostly a net importer of barley in the world market, the ban of 2,4-D would increase domestic price and benefits the ROW as an exporter to the US, although the net effect is quite small.

Table 2.4. Estimated annual changes in welfare ($ million per year) and crop prices for spring wheat with different cost and yield impacts for the non-2,4-D scenario.

	Cost Increase ($0.13/A)			Untreated	
	No yield loss	Low yield loss (2%)	Medium yield loss (5%)	High yield loss (10%)	Very high yield loss (15%)
Change in consumer surplus	-$0.32	-$2.26	-$5.17	-$8.85	-$13.72
Change in producer surplus	-$1.26	-$3.35	-$6.52	-$7.24	-$12.69
Total domestic welfare change	-$1.57	-$5.61	-$11.69	-$16.09	-$26.40
Price increase	$0.00	$0.01	$0.02	$0.03	$0.04
Price increase (%)	0.01%	0.08%	0.19%	0.33%	0.51%
ROW welfare change	-$0.26	-$1.82	-$4.18	-$7.16	-$11.11

Table 2.5. Estimated annual changes in welfare ($ million per year) and crop prices for barley with different cost and yield impacts for the non-2,4-D scenario.

	Cost Increase ($0.49/A)			Untreated	
	No yield loss	Low yield loss (2%)	Medium yield loss (5%)	High yield loss (10%)	Very high yield loss (15%)
Change in consumer surplus	-$0.25	-$0.92	-$1.93	-$3.20	-$4.89
Change in producer surplus	-$0.86	-$1.71	-$3.01	-$3.74	-$6.00
Total domestic welfare change	-$1.1	-$2.63	-$4.94	-$6.95	-$10.90
Price increase	$0.00	$0.01	$0.01	$0.02	$0.03
Price increase (%)	0.03%	0.11%	0.22%	0.37%	0.57%
ROW welfare change	$0.01	$0.042	$0.09	$0.15	$0.22

Results: Non-crops

Renz (Chapter 3) suggests that that leaving areas untreated for pastures and rangelands may result in increased costs in the future to manage weed populations as established weed infestations cost substantially more to manage. Based on this insight, the economic effects of banning the use of 2,4-D on non-crops are reported in Table 2.6. The results are based on the assumption that users will switch to other herbicides that are as effective as 2,4-D, but 2 to 4 times more expensive.

Table 2.6. Estimated economic effects of a ban of 2,4-D in non-crop areas.

	Acreage treated (million acres)	Total 2,4-D Used (million lbs)	Annual use rate (lb/A)	Cost change in previously 2,4-D treated area ($/A)	Total economic loss ($ million)
Pastureland, rangeland, alfalfa, and wildland and natural areas	16-28	15-29[a]	0.75-1.1[a]	4.53-13.59[a,b]	100-299
Turfgrass	9-19[c]	8-12	0.35-0.95	3.18-9.55[b]	29-181
Right-of-way	1-4[d]	0.92[d]	0.25-0.75[e]	2.45-7.35[b]	2.5-29

[a] Information from Chapter 3 by Renz;
[b] Calculated as the product of annual use rate and average 2,4-D price, $4.90/lb ai;
[c] Calculated by dividing the amount used by the annual use rate;
[d] Estimate based on information Chapter 9 by Byrd;
[e] Based on information in several latter chapters.

Given the current amount of 2,4-D used on pastureland, rangeland, alfalfa, and wildland and nature areas, banning of 2,4-D would cause a substantial cost increase, ranging between $100 to almost $300 million annually. Turfgrass weed control cost would increase between $29 and $181 million. However, because alternative products have become more popular for right-of-way weed management, the loss caused by a 2,4-D ban would be much smaller, from $2.5 million to almost $30 million.

Conclusions

2,4-D is a low cost and effective herbicide. A ban on the use of 2,4-D would cause weed control cost increase and/or yield loss of crops. This chapter provides welfare and economic analysis for such a ban under different scenarios. The cost increase alone would imply an estimate welfare loss of $20 million for the small grains, which would increase to $53 million to $102 million for a 2% and 5% yield loss added to the cost increase. For non-crop uses, the estimated cost increases that would occur range $130 million to as much as $510 million. All scenarios suggest that an economic loss would occur in the US if there was a ban of 2,4D.

The cost increase alone would imply an estimate welfare loss of $20 million for the small grains, which would increase to $53 million to $102 million for a 2% and 5% yield loss added to the cost increase. For non-crop uses, the estimated cost increases that would occur range $130 million to as much as $510 million

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