The Economics of Atrazine

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It is often claimed that atrazine is of great economic benefit to corn growers, but support for this claim is limited. Some cost–benefit studies have assumed that atrazine boosts corn yields by 6%; an extensive review found a 3%–4% average yield increase; other research suggests only a 1% yield effect. Syngenta, the producer of atrazine, also makes mesotrione, an alternative herbicide that does about the same amount for corn yields as atrazine. Italy and Germany both banned atrazine in 1991, with no decrease in corn yields or harvested area. Even if atrazine leads to 6% more corn production, it is not certain that this would justify its continued use; a 1%, or perhaps zero, change does not warrant large-scale exposure of humans and the environment to this potentially hazardous chemical. *Key words*: atrazine; economics; agriculture; herbicides; reproductive health; groundwater; environmental contamination; policy.

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> In nearly 50 years of use, atrazine has proven cost effective, reliable, flexible and safe when used in accordance with federal label instructions. . . . If atrazine use was discontinued in Illinois, losers would include corn growers, Illinois' economy and the environment.—University of Chicago economist Don Coursey[1]

> I'm not saying it's safe for humans. I'm not saying it's unsafe for humans. All I'm saying is that it makes hermaphrodites of frogs.—University of California biologist Tyrone Hayes[2]

Atrazine, one of the most widely used pesticides in the United States and the world, is an effective weed killer, applied to most of the U.S. corn crop each year. Without it, say its defenders, the economy of corn-growing states would be devastated. Recent estimates of the cost of an atrazine ban have ranged as high as one sixth of gross receipts from the sale of corn—although, as shown below, these estimates are not universally accepted.

Atrazine is also the pesticide most frequently found in groundwater in the United States. It was often found in groundwater in Europe, in the years when it was used there. It is a possible cause of several types of cancer, and, according to many researchers, a proven endocrine disruptor—with visible effects, such as hermaphrodism in frogs, even at extremely low levels of exposure. One study even suggests a correlation between exposure to atrazine and low sperm quality among men in an agricultural area of the United States.[3]* The health and environmental evidence, however, continues to be debated, with the U.S. Environmental Protection Agency (EPA), among others, arguing that there are no proven harms if atrazine is used in accordance with regulations.

The dilemma posed by these contradictory aspects of atrazine applies to many other chemicals as well. Modern agriculture is extraordinarily dependent on pesticides. We enjoy vast quantities of food at low prices in part because crops are routinely sprayed with chemicals that control weeds and insects. But the harm that these pesticides sometimes do is not entirely accidental: designed to kill living organisms, they are often harmful to humans and other species, as well as the targeted pests. David Pimentel estimates, based on 1990s data, that U.S. farmers spend $10 billion per year on pesticides, and face $3 billion of other costs resulting from pesticide use, in order to grow $40 billion of crops protected by pesticides.[4] By his calculation, the public health and environmental damages resulting from pesticide use are worth at least $9 billion—an amount comparable to part, but not all, of the benefits of pesticides to farmers. For an individual pesticide, of course, the balance could be much better, or worse, than this average would suggest.

How should public policy respond to the economic benefits vs health and environmental risks of a pesticide such as atrazine? Answers to this question have been widely varied. The European Union has banned atrazine, on the basis of its persistent contamination of groundwater. Meanwhile, the United States has renewed the registration of atrazine, rejecting the claims that it causes serious risks.

Evaluation of the rival perspectives on the subject might seem like an ideal application for cost–benefit analysis: how do the economic benefits of atrazine compare to the health and environmental damages? However, there are at least two categories of problems with cost–benefit analysis in this case (echoing some of the general limitations of cost-benefit analysis of health and environmental policy).[5]

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*The study establishes the correlation between atrazine exposure and low sperm quality (i.e., low sperm counts and motility), but does not assert or prove a causal relationship.

First, it is difficult or impossible to put prices on the health effects of agricultural chemicals, as well as on the broader environmental implications of current agricultural practices. For example, the hidden costs of large-scale monoculture, and its implications for problems such as erosion and runoff, tend to be lost in such an analysis. Indeed, one might reasonably question the urgency or desirability of maximizing corn production: do we really need to produce more beef, and more high-fructose corn syrup? Is corn-based ethanol a sensible way to produce liquid fuels?

Second, even if the first group of problems were somehow resolved, cost–benefit analysis would require a resolution to the ongoing debate about the probability of harm. With a significant but uncertain probability of inflicting serious damages, atrazine is instead a candidate for precautionary policymaking.

Lacking any way to estimate the average or expected value of harm, precautionary decisions reflect society's judgments about the risks associated with worst-case outcomes. For instance, how bad would it be if atrazine remained in use, while its critics ultimately proved to be right about its harmful effects? Conversely, how expensive would it be if atrazine were banned, and later turned out to be harmless?

The former question, on the potential health and environmental impacts of atrazine, has been extensively studied.[6,7] This article addresses the latter question, i.e., the costs of banning atrazine, finding that the costs could be surprisingly small. A review of the estimated impacts of banning atrazine from four major studies is followed by a description of a new alternative herbicide, which, according to one recent industry-funded study, does about the same amount for corn yields as atrazine. The European experience, where both Italy and Germany banned atrazine in 1991, without visible harm to corn production, is then described.

FOUR STUDIES OF ATRAZINE

Ideally, a study of the value of atrazine should compare the current economics of U.S. corn production using atrazine with the next-best alternative available to corn growers if atrazine were banned. The difference between these two scenarios is the appropriate measure of the value of atrazine. Three of the four studies discussed here offer a quite incomplete economic picture; thus it may be useful to start by outlining the components of a complete analysis.

In the scenario without atrazine, several aspects of farm revenues could change, with contradictory effects on farmers' bottom line:

1. Farmers would buy and apply other herbicides, potentially increasing costs per acre.
2. Yields per acre could decrease, if the other herbicides were less effective.
3. Acreage planted in corn could decrease, if corn production became less profitable.
4. The market price of corn could increase, if production decreased.
5. Acreage withdrawn from corn production could be used to grow other crops, generating additional revenue.

The first three effects represent losses for farmers, or decreases in net farm income. The last two, in contrast, represent increases in farm incomes. It is not clear, a priori, which effects will predominate: gains from the increased price of corn, plus revenues from expansion of other crops, might or might not outweigh the more obvious costs of doing without atrazine.

When growers receive the full market price, as they do at the relatively high corn prices resulting from the ethanol boom, all five of these factors affect farm income directly. The situation was slightly more complicated when growers received a fixed, subsidized price that was well above the market price, as was often the case for U.S. corn producers when prices were lower in the past. In that case, a price increase was a benefit to the government's price-support program, not to farmers: as the market price for corn increased, farmers' subsidized incomes were unchanged, while the difference between the subsidized price and the market price—the cost of the government subsidy—shrank. However, in either circumstance, the same five effects, as listed above, describe the impacts on suppliers as a whole, combining the effects on farmers and government support programs.

USDA

A relatively complete study of the economics of banning atrazine, estimating all five effects, was performed for a 1994 USDA report,[8] and was subsequently described in two academic articles.[9,10] Using 1991 data,[†] this study applied Iowa State University's CEEPES (Comprehensive Environmental Economic Policy Evaluation System) suite of models to simulate the effects of pesticide bans and other policies on a multi-state growing area that includes more than 80% of U.S. corn acreage.

For the ban on atrazine, the study projects

1. Increased herbicide costs of $1.08 per acre
2. Yield losses of 1.19%, or 1.3 bushels per acre
3. A decrease in corn acreage of 2.35%, or 1.7 million acres
4. A 1.83% increase in the price of corn
5. Increases of 1.5 million acres planted in soybeans and 0.1 million acres in wheat—almost exactly absorbing the reduction in corn acreage

[†]The base year for data is never explicitly stated. However, the study refers to "near-term" effects as occurring in 1993–96, and uses a baseline corn yield of 109 bushels/acre, the U.S. average in 1991.

The net loss to farmers (of ten major crops, not just corn) of $269 million is outweighed by gains of $287 million for government support programs; combining the two, there is an $18 million gain to suppliers as a whole (farmers plus the government) from banning atrazine. Thus the fourth and fifth effects—the benefits of the price increase and the expansion of other crops—were slightly more valuable than the revenue lost to increased herbicide costs, yield losses, and decrease in corn acreage. The study estimated the loss to domestic and foreign consumers, who would face higher prices for corn-based products such as beef and corn syrup, at $258 million. The aggregate economic effect on society is therefore a loss of $240 million—equivalent to $355 million in 2006 dollars.‡

Not all studies have been this complete. Three other, more recent, studies consider only the first two of the five effects, the costs of alternative herbicides and the impact on yields.

EPA

One example is an EPA study of the costs of partial or complete restrictions on atrazine.[11] Published in 2002, the study used 2000 economic data. For the crucial question of the effects of atrazine on yields, EPA relied on a 1996 report from the Triazine Network, which was said to reflect studies of pesticide performance published between 1986 and 1995.§ EPA estimated that

1. Substitute pesticides would cost an additional $5.43 per acre, while
2. Yields would decrease by 8.8 bushels per acre, a 6.4% drop from the average yield of 137 bushels/acre. The yield decrease was priced at $2.60 per bushel, the (fixed) support price received by farmers; it therefore amounted to $22.88 per acre.

No change in corn acreage or price was included in the study—although a 6.4% change in supply would be expected to affect prices, and the change in profitability would be expected to affect corn acreage.¢ The combined effect of higher costs for substitute pesticides and lower farm revenues from diminished yields implied a loss of $28.31 per acre. This loss, applied to 55.8 million acres of corn treated with atrazine, amounts to a national total of almost $1.6 billion. Adjusted for inflation, this is equivalent to $1.8 billion in 2006 dollars, or five times the estimate from the USDA study.

Fawcett (Triazine Network)

A similar cost estimate can be found in Fawcett's Triazine Network study of the effects of atrazine on corn yields.[13] The Triazine Network is a coalition founded by agricultural trade organizations in 1995, in order to bring farmers' views on the regulation of triazine herbicides to the attention of EPA. (Atrazine is the most widely used, but not the only, triazine herbicide.)

The study, performed for the Triazine Network by Iowa consultant Richard Fawcett, is a review of other research. It lists 236 studies performed from 1986 through 2005, each of which contained evidence on corn yields with and without atrazine. Documentation and citation of the studies are incomplete, and the same investigators appear repeatedly; see the appendix for discussion of the quality of Fawcett's data.

Fawcett estimates that

1. Non-atrazine alternatives would increase herbicide costs by $10.07 per acre.
2. The 11 studies he cites from 2005 imply that giving up atrazine would cause an average yield loss of 6.1 bushels per acre; at the $2.60 per bushel support price, this is worth $15.86 per acre. (For those 11 studies from 2005, the mean yield loss is 3.8%, and the median is 3.1%.)

Fawcett's combined estimate for 2005 is therefore a loss of $25.93 per acre, or $1.45 billion nationwide for the 55.8 million acres of corn treated with atrazine.

Coursey (Syngenta)

Another recent study again restricts itself to the same two effects, but arrives, apparently mistakenly, at a much larger "bottom line" impact. In 2007, Don Coursey completed a study of the value of atrazine to the Illinois economy, performed for Syngenta, the principal producer of atrazine.[1] Coursey is an economist at the University of Chicago's Harris School of Public Policy; although his atrazine study describes itself as a Harris School working paper, it was released and distributed by the Illinois Farm Bureau.

In terms of the effects of an atrazine ban on farm revenues, Coursey projects that

1. Herbicide costs would increase by $4.86 per acre; and
2. Yields would decrease by 4–7.6%, or 5.8–11 bushels/acre. The midpoint of Coursey's range is a yield loss of 5.8%, or 8.4 bushels/acre. At $1.95 per bushel,

‡These are the estimates from Lakshminarayan et al.[10] The USDA report based on the same analysis highlights the sum of (private) producer and consumer impacts, excluding the gains to government support programs, resulting in a larger total loss.[8]

§The Triazine Network's 1996 work is cited in the EPA report on p.20, but does not appear in the list of references at the end of the report. It is presumably referring to the predecessor to the more recent Triazine Network report, which is discussed below.

¢Detailed studies are available on the expected effects on acreage of small economic changes; see, for instance, Lin et al.[12]

the price used in the study, the midpoint yield loss is worth $16.48 per acre.

Combining these two effects, Coursey's midpoint estimate is a cost of $21.34 per acre. As with the EPA and Fawcett studies, no estimate is included for reduction of corn acreage, price increases, or revenues from other crops that might replace some corn acreage. Most of the difference between Coursey's midpoint estimate and the EPA and Fawcett calculations is due to the use of different prices of corn. If Coursey had used the same corn price, $2.60 per bushel, his midpoint estimate (combining herbicide costs plus yield losses) would have been $26.70 per acre, compared with EPA's $28.31 and Fawcett's $25.93. It seems appropriate, therefore, to describe these studies as roughly agreeing on the costs of banning atrazine.

Coursey's strong point is his detailed, up-to-date data on the costs of alternative herbicides. He finds that banning atrazine would increase herbicide costs by almost $5 per acre, or about $.03 per bushel of corn at today's yields.

However, in his estimates, as in EPA's and Fawcett's, the bulk of the cost impact comes from yield losses—an area where Coursey's work is less thorough. Although he mentions the existence of 16 studies of the effects of atrazine on corn yields, he includes citations sufficient to locate his sources for only five of them.** All of the studies that have dates are from 1997 or earlier, including a mistaken citation to the Fawcett study discussed above.†† Coursey's high and low estimates of yield loss are based solely on four of the 16 studies. Of the four, only the Fawcett study appears to be readily available. [Two e-mails to Coursey requesting complete citations and copies of his sources received a terse response, just before this article was published, containing a location for only one of the sources, namely the Fawcett study.]

Coursey comments that his estimates are also consistent with independent estimates of the value of atrazine, citing four estimates that range from $10 to $35 per acre. Of the four independent figures, one is the EPA estimate of roughly $28 per acre, discussed above; the other three are attributed only to his personal communications with other researchers.‡‡

Then, in a final calculation, he adds the independent estimates of the value of atrazine to his own estimates of yield loss without atrazine, as if they were separate impact categories (Tables 12 and 13, pp. 22–23). This is certainly double-counting in the case of the EPA estimate, which itself consists primarily of the value of yield loss, as seen above. It may be double-counting in the other cases as well.§§ This double-counting problem could explain how, with herbicide cost increases and yield decreases slightly smaller than EPA's, Coursey reaches a bottom-line estimate of losses nearly double the EPA figure. Coursey's maximum estimate of $555 million in losses amounts to 16% of gross receipts from Illinois corn sales, far above any yield-loss figures that he cites.

NEWER EVIDENCE ON ATRAZINE AND YIELDS

This review of rival studies highlights the critical question for economic analysis: by how much would an atrazine ban reduce corn yields?

Both the EPA estimate and Coursey's midpoint estimate, corrected for double-counting, assume that a ban on atrazine would decrease corn yields by roughly 6%. The Fawcett study suggests a smaller effect: as discussed in the appendix, its mean yield decrease is 4.0% for all observations, or 3.2% if a few extreme outliers are excluded; its median is 2.4% for all observations, or 2.3% without the outliers. (Its higher costs for substitute herbicides bring it into approximate "bottom-line" agreement with EPA and the corrected Coursey figure for the total economic value of atrazine.) The USDA study estimated even smaller yield losses, of about 1%; this, together with a more complete economic analysis, implied small net gains for producers as a whole, but higher corn prices for consumers. An academic review of earlier studies discusses estimated yield losses of 1–3% from a number of studies, suggesting that the USDA researchers were not alone in finding such small effects.[14]

Yet even if one granted the EPA/Coursey assumption that earlier studies implied a 6% yield loss from an atrazine ban, would this estimate still apply today? If more effective alternative herbicides have been developed, the gain in corn yields due to atrazine may be correspondingly reduced, since the next best alternative would now look better.

In fact, a powerful new herbicide has appeared in recent years, thanks to the work of researchers at Syngenta. In addition to producing atrazine, Syngenta now also produces mesotrione, a triketone herbicide, under the trade name "Callisto." The story began with a happy accident: a scientist working at a chemical company which is now part of Syngenta noticed that weeds did not grow around bottlebrush plants at his home in California. Research on this effect found that the bottlebrush or Callistemon tree produces leptospermone,

**Coursey's note 32, p.9, includes four complete references to journal articles, and one complete title of a government report. Another study is cited to a Web site address that is no longer valid. One citation reads, in its entirety, "Novartis regional models"; another is simply "AGSIM model."

††See Coursey's note 33, p. 9, citing a 1994 date for the Fawcett study and repeating the invalid Web address (see previous note).

‡‡They are described only as "notes on file with author" (notes 52–53, pp. 20–21).

§§Asked to comment on this problem in his work, Coursey (in the same e-mail mentioned above) said merely, "For the record, there is no double-counting in my analysis."

which acts as a weak natural herbicide. Further research led to development of a closely related compound, mesotrione, which is a more powerful herbicide.

When registering mesotrione, the U.S. EPA declared that it did not know of any toxic effects of the new herbicide.[15] As described by Syngenta's Web site, Callisto (mesotrione) is what every corn grower needs:

> The combination of excellent crop tolerance and the wide application window gives the farmer a product that he can rely on to perform whenever he uses it. CALLISTO is quickly degraded by soil micro-organisms (ultimately to carbon dioxide and water) and is therefore non-persistent in the environment. When used as directed, it is safe to wildlife, aquatic organisms and relevant, beneficial insects in corn. CALLISTO is suitable for use in Integrated Pest Management (IPM) programs and is an attractive solution to farmers due to its timing and mixing flexibility. It can be used in a wide range of climates and on different soil types and no instances of resistance to CALLISTO have been recorded, even in artificial studies designed to provoke resistance development.[16]

In the less eloquent words of EPA's 2001 conditional registration of mesotrione,

> Callisto Herbicide is an effective [sic] in controlling broadleaf weeds in field corn. It will replace atrazine and isoxaflutole herbicides.[15]

Others have been more cautious: the Pesticide Action Network (PAN) says that mesotrione is "not likely" to be a carcinogen, and is not a cholinesterase inhibitor, but finds insufficient evidence to judge four other categories of toxicity. Atrazine is known or suspected to be a problem in four of PAN's six categories, as shown in Table 1.

TABLE 1 Pesticide Action Network Rankings of Mesotrione and Atrazine

Hazard Category	Mesotrione	Atrazine
Acute toxicity	Unknown	Slight
Carcinogen	Not likely	Highly toxic
Cholinesterase inhibitor	No	No
Groundwater contaminant	Unknown	Highly toxic
Developmental/ reproductive toxin	Unknown	Unknown
Endocrine disruptor	Unknown	Suspected

Source: Pesticide Action Network <www.pesticideinfo.org>, as of June 12, 2007.

At least one research study, funded by Syngenta, has reported on the effects of mesotrione on corn yields.[17] The study mentions the growing evidence of weeds that are resistant to atrazine, and suggests that "herbicides with other modes of action should be evaluated to reduce selection pressure on the weed community."

In the study, conducted in Virginia, researchers tested the effects on weeds and corn yields of ten different mixtures of three leading herbicides: mesotrione, acetochlor, and atrazine. Four of the ten treatments included atrazine, while six did not. For the three years of the study, 1999–2001, the average corn yield per acre under the best non-atrazine treatment was 101.8% of the yield of the best treatment including atrazine.[¢¢] That is, atrazine did almost 2% worse than the alternative! Atrazine's disadvantage resulted entirely from the first year of the study, 1999, which had anomalously low yields for all treatments, perhaps reflecting start-up problems and low rainfall; the first-year problem was particularly pronounced for the best atrazine treatment. For the second and third years, 2000–2001, yields were much higher throughout the study—somewhat above the national average, rather than far below it. For those two years, corn yields in the best non-atrazine treatment averaged 99.8% of the yield in the best treatment with atrazine. If those years are more typical, then there is virtually no effect on yields of switching between atrazine and mesotrione.

The same research team also studied the effects of mesotrione on no-till corn cultivation, finding it effective against most weeds; no yield data were presented in that study.[18] Other researchers studying the effect of mesotrione on weed species in the same years, in Illinois[19] and Arkansas,[20] reported that they found no significant difference in corn yields between mesotrione and atrazine treatments; neither study published any comparative numerical data on yields.

This recent research suggests that Syngenta's new product eliminates the benefit of using its older one; at least under the conditions of the Virginia study, and reportedly in the Illinois and Arkansas ones as well, atrazine does not increase yields relative to the best available alternative. Mesotrione remains more expensive than atrazine; one could still argue that atrazine produces the same weed-killing, yield-boosting benefit at lower cost than the alternatives. But this leaves atrazine with only a thin economic advantage: Coursey's calculation of the increased cost of herbicides needed to replace atrazine amounts to $.03 per bushel of corn, less than 1% of the market price of corn in early 2007.

EUROPE: LIFE AFTER ATRAZINE

Regulation of pesticides has followed a different path in Europe than in the United States, with important implications for atrazine. The divergence dates back at least to the European Union's 1980 Drinking Water Directive,[21] which specified 5 μg/L as the maximum

[¢¢]Yield data appears in Armel's[17] Table 3, p.286. The best non-atrazine treatment was mesotrione plus acetochlor pre-emergence, followed by mesotrione post-emergence. The best treatment with atrazine was atrazine plus acetochlor pre-emergence, followed by mesotrione post-emergence.

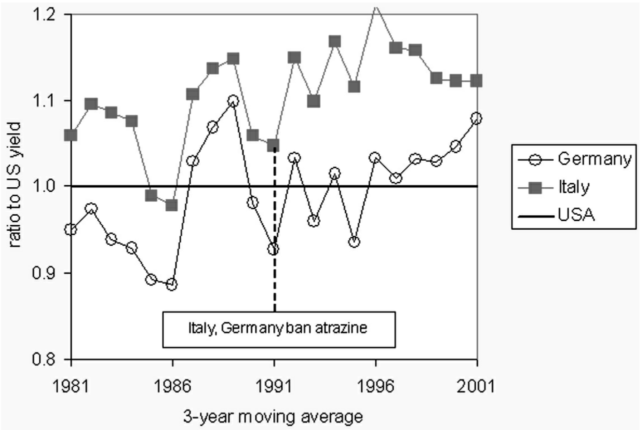

Figure 1—Corn yields, relative to United States

allowable level of any pesticide in drinking water. By 1998 the allowable limit had been lowered to 0.1 μg/L of any one pesticide and no more than 0.5 μg/L of total pesticides.[22] Meanwhile, a 1991 EU directive on pesticides curtailed the use of products suspected of harming human health, groundwater, or the environment. It also established a 12-year review period for products already on the market, such as atrazine, to determine their impacts.[23]

Twelve years later, in 2003, the scientific committee reviewing atrazine concluded that it had the potential to contaminate groundwater at levels exceeding the allowed 0.1 μg/L even when used appropriately.[24] This set in motion the process for a regulatory ban. In 2004 the Commission announced a ban on atrazine applying to all EU member states, which went into effect in 2005; a handful of extensions for limited uses expired in 2007.[25] As a result, Europe is now launching a continent-wide experiment in agriculture without atrazine.

Several European countries moved to ban atrazine on their own well before the EU decision. Sweden, Finland, and Denmark had all banned atrazine by 1994, but none of these countries is a significant corn (maize) producer. More remarkable, and more informative for economic analysis, is the fact that two countries that produce millions of tons of corn, Italy and Germany, both banned atrazine in 1991.

Italy adopted the European Union's Drinking Water Directive in 1985, earlier than many EU nations. It soon became clear that pesticides in the groundwater used for drinking in many areas exceeded allowable levels. This was particularly true in the fertile Po River Valley, where atrazine was commonly used on corn and rice.[26,27] Since more than 80% of farmers in northern Italy get their drinking water from groundwater, public concern about the safety of their water supplies may have been particularly strong.[28]

By 1987 the Italian government had to shut off drinking water to some parts of northern Italy to comply with the pesticide standards, resulting in public outrage.[26,27] Trying to lower pesticide concentrations, the government enacted several temporary bans on atrazine use, at first only in areas where the chemical was found in unacceptable concentrations. After a few years of temporary and/or local bans, the ban on selling atrazine became permanent, national policy in 1991.[26]

Germany, another corn producing nation, had also banned atrazine by 1991.[29] In addition to the EU mandate, Germany's decision may have been influenced by two large-scale chemical accidents that polluted the Rhine River in 1986, killing vast numbers of fish and seeming to undermine the long-term efforts to clean up the Rhine. One of the two accidents involved a company that is now part of Syngenta, which dumped 400 liters of atrazine into the river.

These public policy decisions provide a natural experiment: while Italy and Germany both banned atrazine in 1991, the United States continued to allow its use. If atrazine is crucial to corn yield or profitability, then the data for Italy and Germany should look worse, relative to the United States, after 1991 than before. More specifically, if the ban on atrazine had a negative effect on corn producers, then either yields or harvested areas, or both, should be depressed by the loss of that herbicide in Italy and Germany after 1991. Conversely, the United States, where atrazine remained available, should look relatively better on one or both of these measures after 1991.

As can be seen in Figures 1 and 2, a comparison of international data provides no support for the hypothesis that banning atrazine in 1991 harmed corn production in either Italy or Germany. Both graphs are based on the FAO's ProdSTAT database.***

For yields, the trend is upward in all three countries, but with wide fluctuations around the trend. Two stages of processing of the raw data are reflected in Figure 1. First, to smooth out some of the year-to-year variability, annual yield data for 1980–2002 were converted to three-year moving averages for 1981–2001.††† Second, in order to highlight the international comparison, the values for each country for each year are expressed as a ratio to the U.S. value for the same year. As a result, Figure 1 graphs German and Italian yields relative to the U.S. yields; on this scale, the U.S. yield is equal to 1 every year by definition. Figure 1 shows no sign of yields dropping in Germany or Italy after 1991, relative to the U.S. yield—as would be the case if atrazine were essential.

Figure 2 shows the changes in harvested areas. Because the areas involved are so different in the three countries—in 1991 almost 28 million hectares of corn were harvested in the United States, compared to

***Data downloaded December 2006. Data for Germany before 1990 are totals for East plus West Germany.

†††More recent data are also available, but the 2003 data are strongly affected by that year's European heat wave, a factor extraneous to this analysis.

860,000 in Italy and 280,000 in Germany—each country's data series is converted to an index number, with its own 1991 area set equal to 100. Far from showing any slowdown after 1991, both Italy and (especially) Germany show faster growth in harvested areas after banning atrazine than before. The United States, in contrast, shows no upward trend in the decade after 1991. This is just the opposite of the pattern that would be expected if atrazine made a major contribution to profitability in corn.

Of course, soil and climate conditions in the United States and Europe are different; the populations of weeds may also differ in ways that are relevant to the efficacy of atrazine. It is logically possible that atrazine could be of little value in Europe, but more important for corn production under U.S. conditions But the total lack of response to the ban on atrazine in Italy and Germany, shown in both figures, at least suggests that atrazine is not a magical, one-size-fits-all, solution to the problems of productivity in corn production.

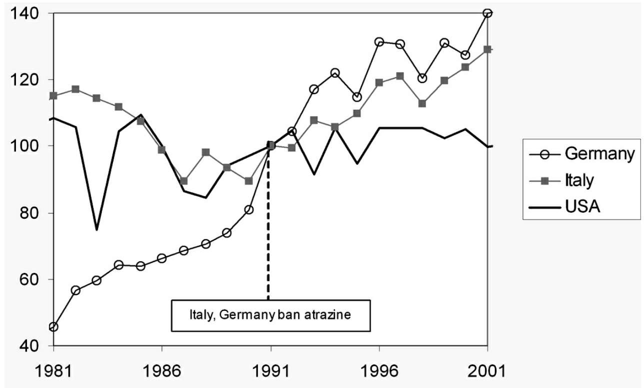

Figure 2—Corn: area harvested (1991 = 100).

CONCLUSION

Policymaking for atrazine is inevitably a process of decision making under uncertainty. Conventional cost–benefit analysis is inadequate to the task both because health and environmental harms do not always have meaningful monetary values and because it is unrealistic to expect consensus on precise estimates of those harms. There is a growing, but still contested, body of research on those harms, enough to raise the question of the appropriate policy toward atrazine—but apparently not enough to settle the question. Indeed, the question has been answered in opposite ways in the United States and in the European Union.

For the European approach to atrazine policy, the failure to meet minimum environmental standards is decisive. No calculation of economic benefits is involved. For the American approach, in contrast, economic analysis is central, since, presumably, no one would endorse the use of a potentially harmful substance unless it had economic benefits. Rather than attempting a precise cost–benefit analysis, it may be more helpful to compare the extremes of the debate. Borrowing financial jargon, one might ask, how great is the "value at risk" in the worst-case outcomes?

One of the extremes is, implicitly, evaluated in much of the scientific literature on the hazards of atrazine. If atrazine remains in use, and it turns out to be as bad as the leading scientific critics suggest, the result will be significant damages to human health and the natural environment, in exchange for the economic benefits of atrazine.

The other, less widely studied, extreme is addressed in this paper. If atrazine turns out to be harmless, but it is mistakenly banned, how much will be lost? Of the four studies discussed, USDA estimated the ban would reduce corn yields by about 1%, and would result in a slight gain to producers, but a larger loss to consumers due to higher corn prices. The EPA study, and the more recent Syngenta-sponsored Coursey study, using a less extensive analytical framework than USDA, estimated 6% yield losses due to an atrazine ban, and per-acre costs to producers of about $28 (EPA) or $21 (Coursey mid-point estimate). Adjusted for the same price of corn, EPA and Coursey are in reasonably close agreement, representing a common, worst-case estimate for the economics of an atrazine ban. The Fawcett study, sponsored by the Triazine Network, had an intermediate estimate of yield loss (a mean estimate of 4.0%, or a median of 2.4%), but a higher estimate of the costs of substitute herbicides, again producing a similar cost per acre.

However, these estimates are deficient in at least two respects. EPA, Coursey, and Fawcett do not include the full range of economic impacts that were (appropriately) included in the USDA study—some of which represent increases in farm income, partially or wholly offsetting the losses. With a 6% decline in corn output—if that is what an atrazine ban would cause—what would be expected to happen to corn prices? The assumption of no change in prices, implicit in the studies other than that of USDA, is simply not credible. Opinions could differ on *how much* the price would increase, but a 6% cut in supply of a basic grain is not likely to leave the market price unchanged.

Second, the EPA and Coursey studies, despite 2002 and 2007 publication dates, rest on much older (and inadequately cited) data on corn yields. Since the times when those data appeared, Syngenta has introduced an alternative herbicide, mesotrione—and sponsored research suggesting that mesotrione is fully as effective as Syngenta's older product, atrazine. Fawcett's massive but incompletely documented tabulation of past studies does not appear to include any of the recent comparisons of atrazine vs mesotrione. Moreover, the experience of Italy and Germany, two countries that banned atrazine in 1991, does not support the hypothesis that atrazine is essential to corn yields or profitability. In the decade after banning atrazine, both countries matched or surpassed the U.S. performance, both in yields and in planted areas.

The most important single number in the economic analysis of atrazine is the effect on corn yields. If an atrazine ban would lose 6% of corn output, there would be visible economic consequences—although not as great as EPA and Coursey suggest, once the offsetting effects of increased prices are included. At a 6% yield loss, it still might be the case that the economic risks of banning atrazine look less serious than the health and environmental risks of continuing to use it. EPA's cost estimate for an atrazine ban, based on a 6% yield loss, was less than $2 billion for the United States as a whole; Fawcett's estimate and the corrected Coursey mid-point estimate are somewhat lower than that of EPA. An estimate corrected for the ensuing price increase would be smaller still.

If, on the other hand, the yield impact is on the order of 1%, as USDA estimated, or close to zero, as suggested by the newer evidence discussed here, then the economic consequences become minimal. The USDA study, with a 1% yield loss, found a slight net economic benefit to producers; the entire economic loss in that study came from the impact on consumers, due to the increase in corn prices of almost 2%. This would likely translate into a smaller percentage increase in the price of corn-based products such as beef, corn syrup, or now ethanol.‡‡‡ The newer evidence, both from the study of mesotrione and corn yields and from the experience of Italy and Germany, suggests that there might be no effect on yields; the only economic impact would then be the increased price of herbicides, raising the price of corn by less than 1%.

Could the "need" to prevent such tiny price increases in corn-based products justify the continued use of a chemical about which such serious scientific doubts have been raised? The ethanol boom has already raised corn prices by a vastly greater amount, leading to rapid expansion of U.S. corn production. It is hard to believe that this suddenly booming industry could not withstand the—remarkably small—economic impacts of banning atrazine.

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‡‡‡For instance, if the cost of corn inputs made up as much as half of the price of a consumer product, a 2% increase in the price of corn would be expected to cause a 1% increase in the price of the consumer product.

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APPENDIX

The Fawcett Report on Yield Research

Richard Fawcett's report, "Two Decades of Atrazine Yield Benefits Research," is described as a North Central Weed Science Society Research Report, prepared for the Triazine Network and available on its Web site. It updates a similar 1996 study by Fawcett; both were prepared as part of the Triazine Network's submissions to EPA in regulatory hearings on triazine herbicides.

Fawcett's 2006 report lists 236 studies performed in the North Central region from 1986 through 2005, each of which contains information on corn yields with and without atrazine. Most of the studies are from Iowa, Illinois, Minnesota, Nebraska, and Wisconsin; a handful come from Indiana, Kansas, and South Dakota. The principal data tables list the studies by number and state, and provide yield data, in bushels per acre, with and without atrazine. A list of the 148 studies for 1996–2005 gives the study number, title, principal investigator's name, and academic institution. (The 88 studies from the first decade were listed in Fawcett's earlier report.) There are no citations to publications or Web sites; there is no description of research methods used to identify the studies or ensure completeness of coverage.

The titles of the 148 studies include strong hints of repetitiveness; by many standards, these would not be counted as 148 distinct pieces of research. In one case, each year of a four-year research project is reported as a separate study. More than a fourth of the studies (39) were performed by a few investigators at three test sites maintained by the University of Minnesota. The titles of many of the studies suggest repetition: "Herbicide performance in corn at Waseca, MN in 1996" was followed by separate studies with the same title (except for the year) in 1998, 1999, and 2000. For 2001 through 2005, there were two to four Waseca studies each year, separately examining herbicide performance in corn at Waseca's common cocklebur site, tall waterhemp site, common ragweed site, and giant ragweed site. All 20 of the "herbicide performance in corn at Waseca" studies were conducted by the same principal investigator. Indeed, the list of 148 studies includes only 34 different principal investigators.

Fawcett's discussion of the yield data focuses on absolute differences between atrazine and non-atrazine yields, measured in bushels per acre: yields per acre were higher with atrazine by 6.3 bushels in 1986–95, 5.4 bushels in 1996–2005, and 5.7 bushels for the 20-year period as a whole. However, these data span a period in which U.S. average corn yields changed significantly. Thus it may be more appropriate to examine the percentage change in yields due to atrazine in each study. The percentages reported here are the absolute difference divided by the yield with atrazine, i.e., the percentage of yield that would be lost by giving up atrazine.

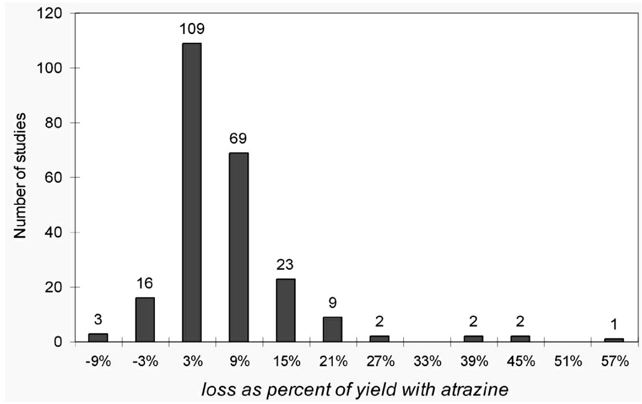

Figure A—Fawcett data on yield loss without atrazine.

For the 236 studies as a whole, the mean percentage is 4.0%, and the median is 2.4%. As the large difference between mean and median suggests, the distribution of yield data is skewed to the right. All but five of the observations fall between –11% and +23%; five outliers imply yield losses of 33% to 52%. The distribution of the data is shown in Figure A.* If the five outliers are excluded, the mean yield effect of losing atrazine shrinks to 3.2%, while the median becomes 2.3%. The standard deviation is 7.8% for the whole sample, or 5.6% with the five outliers omitted. Thus Fawcett's data would resoundingly fail conventional tests for demonstrating an effect significantly different from zero.

There is no significant time trend in the percentage yield data, with or without the outliers. Four of the five outliers are in Illinois, implying a significantly higher effect of atrazine in that state. This could have influenced the work of Coursey, whose analysis focused specifically on the effects of atrazine in Illinois. With the outliers removed, there are no significant differences in the mean effects by state. None of the outliers occurred in 2005, the year of Fawcett's calculations reported in the text.

To rely on estimates from Fawcett's extensive data tabulation, it would be necessary to understand his selection criteria in greater detail, to consolidate many of the repetitive entries in his table, and to carefully examine the validity of the few outliers that have such a substantial impact on the mean.

*Labels on the horizontal axis are the upper limit of each category; there are 69 observations between 3% and 9%, and no observations between 27% and 33%.