Social Costs of Herbicide Resistance: the Case of Resistance to Glyphosate

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Abstract

Unlike in the pesticide and antibiotic resistance literature, potential social costs and externalities associated with herbicide resistance have not generally been considered by economists. The economics of managing herbicide resistance in weeds has focused on cost-effective responses by growers to the development of resistance at the individual farm and field level. Economic analyses of optimal herbicide use have focused on optimising farmer returns in the long run. Weeds have been considered less mobile, compared to insects and diseases, suggesting that externalities resulting from resistance spread will be minimal and any consequent social costs low. Glyphosate is the world's most widely used broad-spectrum non-selective herbicide. Declining glyphosate prices, the adoption of no-till and minimum-till systems and the adoption of glyphosate-tolerant crops, have combined to cause a rapid increase in the use of glyphosate, and resistance is now appearing. In this paper we argue that the increasing possibility of widespread glyphosate resistance, exacerbated in some situations by spread through resistance mobility, presents a case where social costs associated with glyphosate resistance need to be considered when assessing optimal use of this herbicide resource at the farm level. Possible social costs associated with the loss of glyphosate efficacy include potential failure of herbicide-resistant crop systems, reduced use of conservation tillage techniques, and potentially more reliance on herbicides with greater environmental and health risks.

Key words: glyphosate resistance; herbicide resistance; social costs; externalities; resistance mobility

Introduction

Weed resistance to herbicides is an increasing problem world-wide, affecting the efficacy of major herbicides. Herbicide resistance is defined as *"the inherited ability of a weed population to survive a herbicide application that is normally lethal to a vast majority of individuals of that species* (Powles *et al.*, 1997). Whereas externalities and social costs associated with resistance to pesticides and antibiotics have been considered by economists (e.g. Miranowski and Carlson, 1986; Laxminarayan, 2003a), this is not so for herbicide resistance. Failure to consider externalities in analyses of optimal herbicide use is often justified by the higher mobility of many insects and diseases relative to weeds, and the consequent risk of off-site effects (e.g. Mullen *et al.*, 2005).

Economic concerns of pesticide and antibiotic resistance are that individuals may use products with insufficient concern about negative impacts of current use on future efficacy of the product for others. If externalities are not taken into consideration then individual optimal use may be too high. Economists suggest the use of economic and regulatory incentives to ensure that individuals and firms act in a manner that is consistent with societal objectives to conserve pest and disease susceptibility.

In this paper we discuss the case of the evolution in weed species of resistance to glyphosate, a valuable and widely used broad-spectrum non-selective herbicide first developed by Monsanto in the early 1970s. Some authors (e.g. Powles, 2003; Mueller *et al.*, 2005) have argued that glyphosate is such a unique herbicide that its current and future value to society should be taken into consideration when considering its optimal use by individuals. We explore this idea: discussing the factors affecting the development of glyphosate resistance; outlining the concept of herbicide efficacy as an exhaustible resource; and considering resistance mobility and economic issues associated with the loss of glyphosate as a herbicide resource.

Factors affecting the use of glyphosate and resistance development

The number of crops and situations in which glyphosate can be safely used has increased rapidly, such that it has become the most widely used herbicide worldwide (Baylis, 2000), and a key component of weed control used by farmers. Amongst its many advantages, glyphosate is considered to be an environmentally 'safe' herbicide: it has very low toxicity to animals, including humans, and degrades rapidly (Roy, 2004). Additionally, despite extensive long-term use worldwide, weeds have been slow to develop resistance to glyphosate and evolved resistance has been comparatively rare. This is thought to be largely because the natural frequency of glyphosate resistance genes is lower than for some herbicide groups to which resistance has evolved relatively rapidly (Neve *et al.*, 2003a).

Glyphosate has been off-patent in all major use countries since 1995-2000, and the price has fallen steadily since coming off-patent, with generic product now supplied by a number of manufacturers. The fall in glyphosate price and ready availability has resulted in further increased use. A major factor contributing to increased glyphosate use has been the development and rapid adoption of genetically engineered glyphosate-tolerant crop varieties: Roundup Ready® canola, maize, soybean and cotton. In 2005, glyphosate-tolerant crops constituted a massive 87 percent of soybean area, 61 percent of cotton area and 26 percent of maize area in the United States (USDA, 2005). Since 2003, 98 percent of soybean plantings in Argentina have been glyphosate-tolerant (Dill, 2005). Worldwide, more than 58.5 million hectares are planted to glyphosate-tolerant crops, with the majority of this being soybeans in North and South America (ISAAA, 2004). Additionally, no-till and minimum-till cropping systems are heavily dependent on glyphosate for knock-down weed control (Neve *et al.*, 2003b; D'Emden and Llewellyn, 2004) and the increased use of these conservation tillage techniques has contributed to increased use of glyphosate. The combination of glyphosate used on glyphosate-tolerant crops, often combined with minimum tillage, provides a comparatively reliable and simple-to-implement weed control system for farmers.

Falling glyphosate prices, the adoption of no-till and minimum till systems and the adoption of glyphosate-tolerant crops, have combined to cause an exponential increase in the use of glyphosate (Roy, 2004). Worldwide, glyphosate sales exceed the sales of the next ten herbicide groups combined. Glyphosate and glyphosate resistance crops have become so cost-effective and dominant in major markets that the development of new herbicides has been de-emphasised in some discovery corporations (Mueller *et al.*, 2005; Duke, 2005). There are resistance implications from this high dependency with a loss in diversity in other weed control tools. Weed resistance to glyphosate, first reported in 1998 by Powles *et al.* (1998), continues to be identified (Heap, 2006; Preston, 2006). The selection pressure for glyphosate resistance in weeds created by the use of glyphosate in HR crops, where it is applied as a post-emergent herbicide, is much greater than when it is used pre-seeding (Neve *et al.*, 2003b; Powles and Preston, 2006). In Australia, where glyphosate is mainly used pre-seeding, the number of weed populations resistant to glyphosate in broadacre cropping is 24 (Preston, 2006). In the United States where the uptake of HR crops is widespread, a conservative estimate is one million hectares of cropland infected with glyphosate resistant *Conyza*, and isolated resistant populations of a number of other important weed species (Powles, personal observation).

Herbicide efficacy as an exhaustible resource

Hueth and Regev (1974) first formulated the idea of treating pesticide efficacy as a potentially exhaustible resource. Using this approach, pest susceptibility is viewed as biological capital, a resource stock that can be managed, and pesticide application (i.e. selection for resistance) the analogy for extraction of the resource. Llewellyn *et al.* (2001) extended this exhaustible resource approach to herbicide efficacy, adapting a framework developed by Miranowski and Carlson (1986), to optimise farmer management of the herbicide resource over time. In most situations, the number of herbicide treatments (selection intensity) is approximately linearly related to the development of resistance (Pannell and Zilberman, 2001). The approach used by Llewellyn *et al.* (2001) did not take account of either externalities arising from possible mobility of resistant weeds or genes, or possible social/environmental costs arising from herbicide resistance.

The seriousness of a resource exhaustion problem depends on the likelihood of technical progress and the ease with which other factors of production can be substituted for the resource being exhausted (Solow, 1974). In this case, new herbicides can be developed, but the likelihood of development of a herbicide capable of replacing glyphosate is low (Holmburg, 2004) and increasing restrictions on the registration and development of new chemicals are making herbicide R&D more costly (Laxminarayan, 2003b). With regard to factor substitution, Solow (1974) suggests that there is usually considerable substitutability between exhaustible resources and renewable or reproducible resources. Indeed, other herbicides and techniques can be substituted for a loss of a specific herbicide efficacy, and strategies for glyphosate resistance management in no-till systems in Australia emphasise many of these (e.g. Neve *et al.*, 2003b), but they are generally associated with increased costs.

Maximisation of farmer returns in the long term has been the focus of herbicide use studies (Pannell and Zilberman, 2001) and two recent studies have used a long term NPV approach to assess whether farmers should manage glyphosate use preemptively or reactively in the context of developing resistance (Weersink *et al.*, 2005; Meuller *et al.*, 2005). In studies such as these, choice of the discount rate becomes important (Solow, 1974), as does information on whether glyphosate technology will be replaceable, and the costs associated with this or the loss of the resource. For example, uncertainty exists about the speed with which the evolution of glyphosate-resistant weeds will compromise the use of glyphosate (Duke, 2005).

Resistance mobility through spread of pollen, seeds and weeds

The risk of resistance spread through weed mobility has been treated in economic analyses as if it were negligible (e.g. Weersink *et al.*, 2005). In reality, the risk needs to be assessed on a case-by-case basis. Some weeds are very mobile (e.g. *Conyza*). Although resistance has been shown in many cases to have evolved as multiple evolutionary events (Valverde and Itoh, 2001), rather than by spread, there is also a varying likelihood of resistance mobility through the spread of pollen, seed and weeds themselves. Rieger *et al.* (2002) have shown in canola the pollen movement of HR genes to be at least 2.6 km. Resistance has been shown to have spread from a single weed source in irrigation-based agriculture (Fischer *et al.*, 2004); and research in Australia suggests that some separate glyphosate-resistant ryegrass populations in New South Wales are likely to have occurred through seed movement (Stanton *et al.*, 2004). In the USA, most cases of glyphosate resistance are reported in horseweed (*Conyza canadensis*), a weed whose parachute-type seeds are readily dispersed by wind, and some resistant populations show a common inheritance of resistance mechanism (Powles and Preston, 2006).

Furthermore, an Australian study revealed that farmers perceive that herbicide resistance spreads from farm to farm through seed and pollen movement (Llewellyn and Allen, 2006). Nearly all farmers thought that weeds on their farm would become resistant to glyphosate eventually, even if they didn't apply any more glyphosate themselves. Perceptions such as this may result in farmers using herbicides as if there were weed mobility, and effectively having less incentive to conserve the resource themselves (by reducing selection pressure for resistance) as they believe the benefits in doing so cannot be captured.

Costs associated with the loss of glyphosate as a herbicide resource

The costs of herbicide resistance usually considered when assessing optimal farmer use of the resource are those associated with the risk of poor weed control and hence loss of crop yield, especially in situations where the existence of resistance is not realised; and the extra costs associated with weed control, both in situations where resistant weeds are more expensive to treat or where management to prevent resistance is more expensive. This approach is defendable when externalities (e.g. resistance mobility) are low, or potential social costs are low. In cases where mobility is high, failure to recognise costs associated with externalities results in behaviour by individual agents that is myopic, and hence overuse of the resource.

The question then becomes focused on how important is conservation of the herbicide resource. This will depend on the herbicide. As previously discussed, some authors consider that glyphosate is a uniquely valuable resource. Glyphosate, especially in combination with HR crop technology, makes a major contribution to world food production (Baylis, 2000; Powles, 2003). In the Americas, glyphosate is closely associated with the use of HR technology for growing soybean, canola, maize and cotton over large areas. Cost savings from growing HR crops in the USA, based on comparisons with conventional crops for costs of herbicide purchases and applications, tillage and handweeding, have been estimated to be US$1.2 billion per year (Gianessi, 2005). The use of this technology can also significantly reduce the amount of active herbicide ingredients used on crops. Gianessi (2005) estimated for the USA a reduction of herbicide active ingredient on HR crops, as compared to conventional crops, of 17 millions kg per year. In Canada, where the area of RR canola increased from 10 percent of the total planted canola area in 1996 to 80 percent in 2000, the amount of herbicide active ingredient applied per hectare of canola declined by 43 percent between 1995 and 2000 (Brimner *et al.*, 2005). In Australia, it has been estimated that probability of exceeding water run-off quality guidelines under usual cotton growing practices was very much lower when using glyphosate and RR cotton, than when using diuron and trifluralin with conventional cotton (Crossan and Kennedy, undated). In developing countries where herbicides are often applied without adequate safety precautions, there are direct health benefits to farmers associated with the use of glyphosate in preference to some other more toxic alternatives.

Glyphosate is closely associated with the use of conservation tillage techniques (no-till and minimum till): practices that reduce soil disturbance and therefore reduce the probability of wind and water erosion. The cost-effectiveness of glyphosate has been identified as a factor influencing the increased adoption of conservation tillage in Australia (D'Emden *et al.*, 2005), and the increased profitability of no-till in Canada (Gray *et al.*, 1996). The adoption of glyphosate-resistant crops has been a factor in the rapid conversion to minimum tillage agriculture in the U.S. (Duke, 2005). The public cost of wind and water erosion is generally poorly understood. One study in Australia estimated the most likely cost, including health effects, of dust from wind erosion caused by agricultural land use in South Australia at AUD$23 million (Williams and Young, 1999). Costs included estimates of direct market values only, and made no attempt to estimate possible non-market values.

There is a further cost associated with herbicide resistance in general, relating to policies or strategies that aim to conserve the herbicide resource. Such strategies, particularly if they restrict or lessen the use of a product during the patent period, have an impact on the manufacturing industry and new product R&D (Laxminarayan, 2003b). Efforts towards managing the resource discourage product development; and the development of resistance may encourage product development, resulting in more product options to achieve management of the resource. These issues have so far largely been ignored in work looking at optimal pesticide use (Alix-García and Zilberman, 2005).

Conclusions

In this paper a case is proposed suggesting that optimal use of glyphosate by individuals should consider not only the direct costs and benefits to farmers, but also other possible social costs associated with the loss of glyphosate efficacy. In economic terms, "social costs" include the impact of resistance spreading to another farmer through mobility, and social costs relating to changes to less environmentally-friendly farming systems. Both no-till systems and the use of HR crops have environmental benefits, although the extent of these benefits is not easily quantifiable. The increased use of glyphosate in no-till and HR cropping systems increases the likelihood of the development of glyphosate resistance. Both these systems depend on glyphosate efficacy and have considerable economic value to farmers, and also to society through environmental benefits.

Further studies to determine actual levels of herbicide resistance mobility will help in determining the best policy approach, if any, to achieving socially optimal herbicide use. Modeling to investigate optimal glyphosate use under different situations of weed mobility, and accounting for social costs associated with loss of glyphosate efficacy is being pursued. Such analyses ideally would need to account for the effect on herbicide R&D of suggested policies to encourage optimal use from a societal perspective.

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