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Modelling *ex-ante* the economic and environmental impacts of Genetically Modified Herbicide Tolerant maize cultivation in Europe

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A B S T R A C T

Genetically Modified Herbicide Tolerant (GMHT) maize tolerant to the broad-spectrum herbicide glyphosate is a possible addition to the weed control toolbox of European farmers. We modelled *ex-ante* the economic and environmental changes associated with the adoption of GMHT maize in Europe. A dataset from a survey of maize farmers conducted in seven European countries was used to construct a baseline of current herbicide use and costs in maize cultivation. A stochastic partial budgeting model was used to simulate the impacts of adoption of GMHT maize on farmers' gross margin. We built a first scenario representing the initial years of introduction of the technology (low, fixed technology fee and an herbicide program for GMHT maize based exclusively on glyphosate). Assuming that all farmers who benefit from the technology will adopt GMHT maize, the model predicts very high adoption rates for all seven countries (60–98% of maize farmers depending on the country). We also calculated the Environmental Impact Quotient Index (EIQ) associated with herbicide use when switching to GMHT maize. In ES, PT and CZ, countries with a high baseline of herbicide use in maize, the majority of adopting farmers (60–79%) will also experience reductions in EIQ, realising the economic and environmental potential of the technology. In contrast, for countries such as FR, DE and HU, only a fraction (19–28%) of adopting farmers experiences a decreased EIQ. In this situation, a purely economic-driven adoption may result in increased EIQ for many adopting farmers. We also explored the effects of additional scenarios introducing more complex herbicide programmes for delaying weed resistance and changes in the technology fee of GMHT seeds. In these scenarios adoption levels decrease but the technology is still economically attractive for a large share of farmers (14–86%), showing that a sustainable use of the technology to lower the risk of weed resistance development is not in contradiction with its economic attractiveness. These scenarios do not change significantly the proportion of adopting farmers for which the EIQ decreases. The pattern of two groups of countries in terms of potential environmental effects remains and calls for a better identification of the subset of farmers with economic and environmental potential for the technology. Finally, our results confirm that farmers are the main economic beneficiary of GMHT maize introduction while the technology provider is not able to capture all the benefits generated by the technology due to heterogeneity within the farmer population.

1. Introduction

Maize (*Zea mays*) was first domesticated in South-West Mexico about 6000 years ago. With more than 880 million tonnes produced in 2011, it is now the crop with the largest production and constitutes the third most important staple crop for human after rice and wheat. Within the European Union, it ranks second in terms of volume of production after wheat – but third in harvested area only to wheat and barley (FAOSTAT, 2013). However, while demand for maize is on the rise, driven both by increasing preference of consumers for meat products that require maize feedstuffs and by the growing biofuel production, maize producers in the EU are facing an increasingly complex challenge regarding the weed control in maize plots.

Weed control is crucial for the profitability of maize cultivation. Young maize plants have a shallow root structure that makes them particularly vulnerable to weed competition until they reach the

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eight-leaf growth stage, about two months after emergence (Dewar, 2009; Johnson et al., 2000). Therefore achieving an optimal weed control in the first stage of the maize growth is an important objective for farmers. Within the EU, this is becoming a challenging task, for diverse reasons: (i) Weed control in maize relies mainly on chemical control. However, the number of active ingredients (AI) that are authorized is declining through an environmental review program under Directive 91/414/EC and Regulation (EC) 1107/2009; (ii) National policies aiming to rely on alternative – non chemical – weed control strategies or to reduce the use of herbicides in agriculture are being set up in the EU, under the impulsion of the Directive on sustainable use of pesticides (Dir 2009/128/EC) or the current "greening" of the Common Agricultural Policy (CAP); (iii) Weed control options for maize growers are also hampered by the increasing number of weeds that have developed a resistance to one AI (Heap, 2013), while on the other hand no major AI with novel site-of-action has been developed during the last decades (Beckie and Tardif, 2012; Weersink et al., 2005).

For the EU maize growing sector, the challenge is thus to develop new weed control strategies that have less negative effects to the environment but at the same time lead to no or minimum reduction in yield and farm profitability. The difficulty lies in finding the complex equilibrium between the three dimensions – social, environmental and economic – of sustainable development (Sadok et al., 2009).

An element of maize weed control extensively used in other parts of the world but not yet in the EU is the use of genetically modified herbicide-tolerant (GMHT) maize varieties.

This technology consists in the genetic modification of a plant in order to make it tolerant to a given herbicide. If this herbicide is a broad-spectrum one (e.g. glyphosate or glufosinate) its use will result in a more efficient control of all weed species in addition to an extended application window. Thereby, the use of the GMHT technology facilitates weed control and reduces the production risk in GMHT crop fields (Konduru et al., 2008; Qaim, 2009). Other agronomic impacts are closely associated with the adoption GMHT crops. In North and South America, a clear synergy between the planting of glyphosate-tolerant crops and the adoption of reduced or non-tillage practices is observed: the application of glyphosate before planting and at the first stages of the plant growth solves the issues of weed control that arise when tillage is reduced or eliminated (Beckie et al., 2006; Konduru et al., 2008; Trigo and Cap, 2006). Adoption of conservation tillage in turn leads to reduced herbicide, labour and fuel costs. In some regions, notably South America, adoption of glyphosate-tolerant soybean has also facilitated the increased use of double cropping of soybean following wheat in the same crop season, since the GMHT technology allows for early planting and fastens the seeding preparation (Finger et al., 2009). Such changes in agricultural practices – timing, mode and frequency of herbicide application, combination of AI, tillage system and crop rotation – may lead to positive or negative impacts to the agro-ecosystem (Graef et al., 2007).

So far no GMHT varieties have been authorized for cultivation in the EU, although favorable opinions have already been issued by the European Food Safety Authority (EFSA) for three glyphosate-tolerant maize varieties, opening the door for authorization (EFSA, 2009). Several GMHT crops, namely soybean, maize, rapeseed, cotton, alfalfa and sugar beet, have been largely adopted by farmers in other parts of the world. Overall, this high adoption is mainly driven by the non-pecuniary benefits described above, such as the facilitated weed control and the increased management flexibility (Qaim, 2009).

However, in the past years, farmers using GMHT crops (particularly glyphosate-tolerant soybean in North America) have faced increasing problems with weed populations resistant to the applied broad-spectrum herbicide. Weed resistance occurs when a biotype resistant to an AI, already present in a weed population but in a very small proportion, is selected under the pressure of recurrent applications of this AI (Beckie and Tardif, 2012). When the resistant biotype reaches a high frequency in the weed population, the efficiency of this weed control strategy decreases. Among factors that increase the risk of weed resistance development are: excessive reliance on a single mode of action herbicide in the whole crop rotation, non-diversified crop rotation, exclusive use of chemical solutions for weed control, high weed infestation, improper application rate or timing (Dewar, 2009; Vencill et al., 2012). Conversely, the best long term strategies to mitigate the evolution and the spread of herbicide resistance rely on a greater diversity in weed control practices, such as the combination of non-chemical weed management with non-selective herbicide, and the adoption of more diversified cropping systems (Beckie, 2006). The combined use of herbicides whose mode of action is the most diverse also allows for a significant reduction of the risk of resistant weeds (Neve et al., 2011). The availability on the market of crop cultivars with multiple herbicide-tolerant traits might provide farmers with an additional option for weed management (Beckie and Tardif, 2012).

The appearance of resistance in weed populations negatively affects the benefits from the GMHT technology, because farmers either face a partial yield loss due to the decreased efficiency of the broad spectrum herbicide or they bear the costs of additional weed control practices. As pre-emptive action to prevent the outbreak of resistance also entails a cost, farmers are faced with a complex dynamic problem involving a temporal trade-off when deciding about their optimal weed control strategy (Pannell and Zilberman, 2000; Weersink et al., 2005). The threat of weed resistance development will affect the adoption of GMHT maize as well as the potential economic and environmental impacts of this technology.

So far knowledge about the economic potential of glyphosate-tolerant maize for European farmers is limited (Areal et al., 2012, 2011; Demont et al., 2008a; Wesseler et al., 2007). None of the available studies incorporates the possible development of resistant weeds or the need for more complex weed control strategies over time. This paper attempts to add to this knowledge by providing an *ex-ante* assessment of the socio-economic and environmental impacts of glyphosate-tolerant maize as an alternative to the chemical weed control strategy in Europe. Different scenarios are developed to better understand how strategies to delay weed resistance impact the economic and environmental potential of glyphosate-tolerant maize for Europe. The economic framework which incorporates farmer heterogeneity and the strategic pricing decision by the technology provider is fed with data from a farm level survey conducted in 7 EU countries.

2. Methodology

2.1. Model specifications

The paper relies on a simulation approach initially developed by (Demont et al., 2008a; Dillen et al., 2009) and applied in a variety of studies assessing *ex-ante* the economic impact of novel technologies in agriculture (Demont and Dillen, 2008; Demont et al., 2009; Dillen et al., 2008, 2010a,b). Starting from a traditional partial budgeting model, this stochastic simulation approach reduces two types of bias typically present in the former; homogeneity bias and pricing bias. For more details on the model the reader is referred to the aforementioned papers; however, the present contribution goes beyond the previous studies by relying on original survey data, by using an endogenous calculation rather than expert opinions to determine the GMHT technology fee, by taking into account the possibility that farmers could use diversified herbicide