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COLLABORATIVE PROJECT

Assessing and Monitoring the Impacts of Genetically modified plants on Agro-ecosystems

D10.6: Modelling the economic impact of new GM traits

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Authors: Ian McFarlane and Julian Park

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Objectives

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2. To utilise a Delphi survey to identify the likelihood of availability and cultivation in the EU of a range of second generation GMOs through to 2025
3. On the basis of the above, to identify the range of scenarios to be assessed
4. To explore the above future scenarios via our existing static and dynamic economic models
5. To draw conclusions on the likely economic impacts of new events within the EU through to 2025.

Introduction

At the start of the AMIGA project is was clear that there was considerable potential for 'second generation' GMOs with properties having economic impacts for a wider range of stakeholders than the set of developers, farmers and farm suppliers who have been associated with 'first generation' GMOs. 'Second generation' GMOs include traits, often multiple traits, not only to help to manage biotic and abiotic crop stresses but also with quality-preserving, nutritional and therapeutic advantages. Although development of these traits has continued since the inception of the project, few have become available commercially.

Although Bt MON810 maize remains (at the time of writing) the only GM crop commercially grown in Europe, a number of GM crops grown elsewhere have been approved for import, and large quantities are imported into EU as ingredients for high-protein feed. Second generation crops are now being grown elsewhere in sufficient quantity to allow the economic benefits of relief from crop stresses to be quantified, for instance Fernandez-Cornejo et al (2014) reported that stacked seeds (seeds with several GE traits) have higher yields than conventional seeds or seeds with only one GE trait. Conventional corn seeds had an average yield of 8.4 t/ha in 2010. By contrast, seeds with two types of herbicide tolerance (glyphosate and glufosinate) and three types of insect resistance (corn borer, corn rootworm, and corn earworm) had an average yield of 10.7 t/ha.

There is also evidence of consumers' willingness-to-pay for nutritional or bio-fortified foods (Ureña et al, 2008; Markosyan et al, 2009). In some cases these varieties can have yields lower than the equivalent conventional varieties or are more costly to grow. In this report we describe methods to explore the potential economic consequences of utilising these crops if they were to be commercially available.

1. Review of existing literature re future scanning

Based on novel events reported since the commencement of the AMIGA project a small number of second generation events have been selected taking into account those discussed in reviews by Ricroch and Henard-Damave (2015), Hefferon (2015) and De Steur et al (2015). Account has also been taken of data made available by United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) (who publish the petitions made for deregulation from Biotechnology Regulatory Services) and by FAO GM Foods Platform (FAO, 2015). On that basis we consider 6 groups of traits, as outlined in the following paragraphs.

1.1 Drought-tolerance

Drought does not occur in Europe as frequently or severely as it occurs in other cereal growing regions. Use of gene editing to alter the response of cereal crops to drought stress has been tested for wheat cultivation in Australia; Farooq et al (2014) noted that several genes induced under drought have been isolated and characterized, and concluded that new developments in sequencing, marker development, and genome analysis had created opportunity to tackle specific components of drought resistance. Yadav et al (2015) found that overexpression of the TaNF-YB4 gene in transgenic wheat significantly improves grain yield .Trials resulted in a 20-30% increased grain yield compared with untransformed control plants. Under water-limited conditions transgenic lines maintained parity in yield performance. Aschonitis et al (2015) described studies which have indicated that drought effects during the seedling stage and the reproductive stage of wheat varieties accounted for the highest yield reduction, not only in arid and semi-arid areas but even in temperate climate conditions. At the time of writing, there does not seem to be any drought-tolerant variety of wheat available for testing in Europe.

There is a stronger prospect of a drought-tolerant variety of maize becoming available for Europe. Ferrero et al (2014) reported reduction in the uncertainty associated with climate change impacts on maize productivity by applying new understanding of key processes; they concluded that rain-fed agriculture may be at risk as heat waves will be more intense, more frequent and longer. Irrigation permitted some tolerance to warming. Drought-tolerant maize MON87460 was grown on 275 kha in USA in 2014 (James, 2014), and it was reported that growers saw an average yield increase of 300 kg/ha during drought compared with competitive drought-tolerant commercial hybrids (Waltz, 2014).

1.2 Frost-tolerance

The risk of frost damage to emerging crops is familiar in most of Europe. Winfield et al (2010) identified a cereal-specific protein, Wheat Low Temperature–Responsive 10 (WLT10), that is induced by cold and had been shown to differentiate hardy and tender wheat cultivars. A freezing-tolerant winter cultivar, M808, accumulated mRNA more rapidly and over a longer period than a tender spring variety. Zheng (2015) commented that Post-head-emergence frosts (PHEF) are catastrophic in wheat, with a single frost event having the potential to devastate individual crops by damaging stems and killing whole heads, and that PHEFs are common in subtropical areas, but can also occur in Mediterranean and temperate regions, including South America, Canada, Russia, the USA, and Australia. Zheng noted an additional advantage of frost-tolerance in enabling seed to be sown earlier, thus extending the growing season.

Hlaváčková et al (2013) discussed processes of winter barley, monitoring and comparing the response of leaves and crowns to various periods of cold and frost. Observing that protein and nitrogen metabolic processes were influenced by low temperatures to a similar extent in both tissues while catabolism, carbohydrate metabolism and stress response were more affected in crowns, they concluded that crowns are crucial for whole plant survival. Amongst the proteins which showed large changes in abundance, and therefore might play substantial roles in frost tolerant winter barley response to low temperature, AAA ATPase in leaves or HSP70 in crowns have been found. Chloroplast proteins were frequently observed as differently accumulated.

1.3 Stacked HTIR traits

Sanahuja et al (2011) described in detail the beneficial effects of including multiple functionality in GM crops; they concluded that novel Bt strains and toxins with potent and specific effects reduce opportunities for the evolution of resistant strains without harming beneficial insects or soil organisms. Multi-trait HTIR maize accounted for 67% of maize crop area planted in USA in 2013 (Fernandez-Cornejo et al, 2014). Fernandex-Cornejo et al noted that the yields of herbicide-tolerant or insect-resistant seeds may be lower than the yields of conventional varieties; however, by protecting the plant from certain pests, GE crops can prevent yield losses to pests, allowing the plant to approach its yield potential.

Event TC1507 maize, available to farmers as Herculex I, was developed to control certain key lepidopteran larval pests while tolerating glufosinate herbicidal active ingredients. It has been registered for commercial cultivation in the US since 2001; Baktavachalam et al (2015) reported that this event prevented significant yield loss due to S. frugiperda infestation compared with non-Bt maize; they noted that in trials in the Philippines, two TC1507 maize hybrids lowered insect damage and higher yields were obtained.

1.4 Blight-resistance

Oosumi et al (2009) noted that infection by P. infestans remains a threat to potato growers worldwide; they reported identification of a gene that, in concert with additional genes from S. bulbocastanum or other potato relatives, may lead to a strong durable resistance to infection by P. infestans. Vleeshouwers et al (2008) reported a gene-modification technique to accelerate the development of blight-resistant variety, but (at the time of writing) no variety is as yet commercially available. Jo et al (2015) noted that marker-free transformation is less genotype dependent and less prone to vector backbone integration as compared to marker-assisted transformation; furthermore, the susceptibility or the narrow late blight resistance spectra of the selected varieties were upgraded to broad spectrum resistance after the successful introduction of two cisgenic late blight R genes.

Haesaert et al (2015) found that events harbouring three late blight R genes remained unaffected until the end of the growing season, potentially saving €5.2bn worldwide.

1.5 Biofortified crops

De Steur et al (2015) gave the example of increasing vitamin content in staple crops with genes originating from nonrelated organisms, such as Golden Rice (Paine et al, 2005), which led to the creation of other pro-vitamin A–enriched staple crops, such as corn, cassava, potato and wheat. A multi-biofortification approach was recommended by De Steur to address, for example, micronutrient deficiencies, an example being maize with enhanced b-carotene, folate and ascorbate levels (Naqvi et al, 2009). Regarding improvements in vegetable oils, omega-3 polyunsaturated fatty acid (PUFA) therapy continues to show great promise in prevention of cardiovascular diseases (Lavie et al, 2009) and Ruiz-Lopez et al (2015) reported the reconstitution of the LC-PUFA biosynthetic pathway in oilseed crops, producing transgenic plants engineered to accumulate omega-3 LC-PUFA to levels similar to that found in fish oil.

1.6 Crops with other traits

Preserving root crops in good condition post-harvest is an important aspect of food-chain management. For example, Hara-Skrzypiec, A., and H. Jakuczun (2013) commented that resistance to bruising is an important quality trait of potato, depending on multiple genetic and environmental factors; in particular, blackspot bruising is an undesired formation of discolorations under the potato tuber skin initiated by mechanical impact. They presented results indicating that blackspot bruise resistance was mainly influenced by genotype, and concluded that gene-editing for resistance to blackspot bruising could be very effective.

2. To utilise a Delphi survey to identify the likelihood of availability and cultivation in the EU of a range of second generation GMOs through to 2025

This section is presented as a paper that has been submitted to a journal on the work undertaken.

2.1 Introduction

There is growing evidence that genetically modified (GM) crops have delivered substantial economic benefits for farmers, both small and large scale, as well as environmental benefits, in the countries where cultivation has been permitted (e.g. James, 2014). At present, there is only one commercially available GM crop permitted for cultivation in the European Union (EU), Bt maize. While Bt maize cultivation occurred in five EU countries in 2014, the areas cultivated were very small, with only Spain and Portugal growing more than a few thousand hectares, i.e. 131,537ha (Ministry of Agriculture, Food and Environment of Spain, 2014) and 8,542ha (Ministry of Agriculture and Sea of Portugal, 2014) respectively. As the House of Commons (2015) points out, the extremely slow and cumbersome EU GM crop approvals process, which requires majority member state approval in the European Council, has resulted in an effective moratorium on additional authorisations in the EU. As a consequence of this extremely arid policy environment, private sector investment in GM technology has moved out of the EU and consequently there is no research being undertaken specifically focused on the needs of agriculture in the EU or consumers. Additionally, some commercial biotech companies are reported to have given up hope of securing some EU authorisations that are already pending and so have begun withdrawing them (EC, 2016).

However, the effective moratorium on authorisations within the EU might soon be lifted, as a consequence of recent changes to EU legislation. Directive (EU) 2015/412 of the European Parliament and of the Council of 11 March 2015 amending Directive 2001/18/EC provides the means for the Member States to restrict or prohibit, on certain grounds, the cultivation of genetically modified organisms (GMOs) in their territory, even when these have been judged by Europe's regulators as posing no risk to human health or the environment (European Parliament and Council, 2015). The hope is that by allowing member states to unilaterally 'opt out' of GM cultivation, it will be easier to secure majority member state agreement on GM authorisations within the European Council.

Outside of the EU, the pipeline of new GM crops continues to grow. The USDA Animal and Plant Health Inspection Service (APHIS), which regularly publishes lists of successful petitions for unregulated release of GM events into the environment in the USA, recently announced that the 117th such petition, for a potato with blight-resistance and other properties, was approved for trials in September 2015 (APHIS, 2015). As a consequence of the effective moratorium on EU GMO approvals, there has been little incentive for biotech crop developers, the great majority of whom are commercially focused, to develop crop-trait combinations that are specifically targeted at agronomic conditions in the EU. However, Stein and Rodriguez-Cerezo (2009) have noted that among the GM crops already commercialized in regions outside of the EU, and also within the development pipeline, including those awaiting field trials, there are a number of prospective GM crops of interest for EU arable farming. With a potential unblocking of the EU GM crop authorisations process now a distinct possibility, it would seem timely to undertake a review of the GM crop-trait combinations in this extensive global pipeline to: identify those that might be suitable for cultivation in the EU; and examine the nature of the benefits that they might offer. These crop-trait combinations would have to be suitable for climatic conditions in Europe, but further, they would also have to offer some benefits to either farmers and/or consumers. To make such judgements it will be necessary to identify both the nature and extent of the potential benefits that different crop-trait combinations may offer. As direct observation of the performance of a large number of future GM crop-trait combinations in the European setting is not possible, the study reported here makes judgements about the suitability of such crops, and the benefits that they may offer, on the basis of the observed performance of these same crops in non-EU settings. To ensure that these judgements were reasonable, the research sought the collective opinions of global experts in GM crop development and agronomics from various relevant sectors.

To maximise the quality of the data derived from the survey of stakeholders, the study employed the so-called Delphi technique, developed at the RAND Corporation in the USA in the 1950s largely by Dalkey and Helmer (1963). The Delphi technique takes information from a panel of well-informed individuals and builds these data into a consensus about possible future change or developments (Hsu and Sandford, 2007; Linstone and Turoff, 1975; Martino, 1993; Young and Jamieson, 2001). The key characteristic of the Delphi process is that data gathering is an iterative process, punctuated by feedback of the group results to all contributing individuals. In light of this feedback individuals are then permitted to amend their contributions until an acceptable measure of consensus is reached. Multiple iterations are sometimes carried out to help derive a final consensus position. Data is collected from subjects anonymously as an effective way of reducing the biasing effects of dominant individuals operating in group settings such as focus groups (Dalkey, 1972; Scott, 2011).

The Delphi technique has become a well-accepted means of using expert opinion to help anticipate future events in many technological, social and political fields. To a lesser extent it has also been used to explore a diverse range of issues in the area of food and agriculture, for example: agricultural policy forecasting (Fearne, 1986); anticipating trends in biotechnology (Menrad *et al,* 1999); a study of food supply chain developments in rural lagging regions (Ilbery *et al,* 2004); scoping the role of agriculture in flood management (Kenyon *et al*, 2008); analysis of the drivers of past CAP reform rounds (Cunha and Swinbank, 2009); examining sustainable upland rural estate management (Glass *et al*, 2013); prioritisation of management strategies to control zoonotic diseases (Stebler *et al*, 2015); and evaluation of vegetation management strategies under electric power lines (Dupras *et al*, 2016).

In this section, we report the results of a global Delphi survey into the likely future availability, for EU agriculture, of GM arable crops, which would offer advantages to farmers and/or consumers. These advantages could be agronomic, economic and/or environmental in nature, resulting from yield improvements, better management of pests and diseases, reduced input use and nutritional improvements. To limit the scope of the investigation, a pre-selection process was undertaken to identify a shortlist of the crop-trait combinations most prospective for EU agriculture. The global panel of experts were asked to provide their opinions on two issues: first, the likelihood of these GM crops being available for use in the EU within a given time-frame, i.e. before 2025; and second the nature and scale of potential benefits that these might bring to farmers and wider society. However, the expert panel was also given the opportunity to add to the list any additional crop-trait combinations that they felt were also prospective for EU agriculture, although relatively few actually did so. This shortlist of crop-trait combinations was selected by a team from the EU FP7 AMIGA project, from a number of databases and journal sources, including, Ricroch and Henard-Damave (2016), Hefferon (2015) and De Steur *et al* (2015), APHIS (2015) and the FAO GM Foods Platform (FAO, 2015). Crop-trait combinations were selected from this ‘pipeline’ of innovative crops on the basis of existing published assessments that they were suited to EU agronomic conditions and that they may be of benefit to either EU farmers of citizens. For a list of these crop-trait combinations, along with the sources of information used to assess their potential benefits, see Table 1.

2.2 Method

To carry out the Delphi study, a panel was recruited with expertise in GM issues from various professional sectors such as: crops research and development; arable farming; crop protection; and farm management. Invitations to participate in the study were made to 212 individuals involved in research globally, or drawn from participant lists from recent GM-related conferences and technical meetings. More specifically, these sources were: lists of attendees at recent conferences on GM crops; authors of GM-related papers in peer-reviewed journals, such as AgBioForum; and the professional contacts of the research team. These 212 individuals were drawn from a range of institutional backgrounds, with the largest group being university academics (43%), followed by independent research institutes (20%) and government officials (20%); 8% were from non-governmental organisations. In terms of geographical location, most experts were based in Europe (68%), 24% were located in North America and the remainder from elsewhere in the world.

An explanatory letter and the one-page questionnaire were sent out electronically in August 2015. To increase the response rate, a reminder e-mail was sent after 30 days and these actions resulted in 51 replies. Of the 51 replies, 26 were sufficiently complete for the respondents to be retained as part of the panel (an effective response rate of 12.3%). Of the remaining unusable 25 responses, 10 said they had no relevant knowledge, 9 declined to complete the questionnaire on the grounds that legislation would prevent any 'new' GM crops becoming available to EU farmers; while 6 declined for other reasons. The response rate of experts working in commercial companies was much higher than for other categories and so their weight in the final panel has grown, compared to the sampling frame. The geographical distribution of the panel was not greatly different from that of the original sampling frame.

The second round consultation document was sent out to the panel members 60 days after the original mailing. Each panel member was reminded of their own first round estimates and also given the average panel estimates. They were then invited to confirm or amend their original opinion or estimate. Of the 26 panel members, 13 replied, of whom seven made revisions to their original estimates, while the remaining six indicated that they were happy with their original estimates. Those who did not respond were also assumed to be content to retain their original estimates.

It was decided that a third iterative consultation round was not necessary because, as elaborated in the results section below and shown in Tables 2 and 3, significant convergence had been achieved as a result of the second round of consultation and it was believed that a third round would not lead to significant marginal improvement.

The expert panel were asked for their opinions on 17 GM crop-trait combinations (see Table 1). These fell broadly into two groups based on whether the putative impacts were on the input-side (i.e. impacts primarily affecting the farmer), or output-side (i.e. providing impacts primarily on the consumer).

Respondents were asked for their views on two types of issue. First, on the likelihood that the crop-trait combinations provided would be available to EU farmers before 2025. Respondents were asked to express their likelihood estimate using a 6-point Likert-type ranking scale from 0 'not likely' to 5 'very likely'. Second, respondents were asked for estimates of likely impacts of the traits on crop yield and production costs for input-side traits and production costs and potential market price impacts for the output-side traits. These estimates were expressed in percentage terms, referenced against conventional crops in 2015. Price effects can, therefore, be assumed to be expressed in constant price terms.

2.3 Results

2.3.1 Introduction

The results from the Delphi survey are presented, in summary form, in Table 2 (input-side traits) and Table 3 (output-side traits). These data represent the mean scores for the whole panel for both rounds of consultation, together with a measure of the change in the variability found in these estimates from first round to second round, expressed as change in standard deviation (SD) score. As can be seen from Table 2 and Table 3, when the panel's round one and round two estimates were tested for differences, no statistical significant changes were found.

When SD change scores are negative, this implies that the SD of the sample estimates (i.e. the variation between individual estimates) is decreasing between rounds as the panel closes in on consensus. When SD change estimates are small, this means that there is relatively little change in the SD estimates between rounds and this in turn implies that convergence has already largely been reached and that further iterations would only yield very small marginal improvements in convergence. As can be seen from Tables 2 and 3, the SD change scores are generally negative and small, implying that there would be only limited benefit, in terms of convergence of opinion, from additional iteration rounds, even if the panel would be prepared to take part in the study again.

2.3.2 GM crops with input traits

Looking first at the availability estimates in Table 2, the first point to note is that all estimates are relatively low. Based on the ranking scale used, a score of 5 represents 'very likely', while a rank of zero represents 'not likely'. On this basis, a mid-point rank of 2.5 might be interpreted as a 50% likelihood estimate, i.e. the zone of uncertainty. Few of the likelihood estimates rise above this midpoint, suggesting an expectation of relatively low likelihood of any of the crop-trait combinations being available for use by EU farmers by 2025. The panel felt that the crop-trait combination most likely to be available to EU farmers by 2025 is maize with stacked traits for herbicide tolerance and insect resistance, with a mean rank score of 2.76. The crops thought next most likely to become available are HT soybean with a rank score of 2.48, then HT sugar beet (2.39) and pathogen tolerant (PT) potato (2.27).

Table 2 also reveals that the trait that the panel thought least likely to become available before 2025 was frost tolerance, both for barley (0.74) and wheat (0.78). Also given very low likelihood rankings are drought tolerance in wheat (1.3) and insect resistance in potato (1.33).

Input-side traits are expected to offer financial benefits to the farmer from either reduced input costs, especially crop protection costs, and/or increased revenues, through improved (or protected) yields. Table 2 shows that the panel anticipated cost savings in six out of ten of the crop-trait combinations, but increases in production costs in the remainder. Costs savings ranged from 4.47% to 5.89%, a relatively narrow range, these being somewhat larger in magnitude than the expected cost increases, which range from 0.55% to 2.38%.

The crop-trait combinations offering the largest savings in input costs are PT potato (5.89%), HT winter oilseed rape (5.74%) and HT soybean (4.93%). At the other end of the spectrum, the panel thought that drought tolerant wheat would raise farmers' costs by 2.38% and frost tolerant barley by 1.05%.

It is notable that the traits expected to increase costs are frost and drought tolerance. This makes perfect sense because, with the possible exception of irrigation, these traits do not replace any inputs, such as sprays, but they may incur higher seed costs. However, these traits may still prove to be financially advantageous if their yield protection benefits, in years when weather conditions are unfavourable, offset the additional seed costs when averaged over the long term.

As Table 2 shows, the highest and lowest anticipated yield improvements are both recorded for potatoes, with yield improvement estimated to be just 3.75% for IR potato and as much as 9.14% for PT potato. This result suggests a panel consensus that current yield losses resulting from insect pests, such as Colorado and Flea Beetles, are considerably lower than yield losses from diseases, such as Brown Rot and Late Blight. Drought tolerance is estimated to offer greater potential yield benefits than the average, at 8% for wheat and 6.73% for maize, while frost tolerance traits are estimated to offer slightly below average yield improvements at 4.97% for both wheat and barley.

2.3.3 GM crops with output traits

In terms of crops with output traits, Table 3 shows that all likelihood ranks are again low, signalling a generally low expectation by the panel that any of the traits will be available to EU farmers by 2025.

The crop offering enhanced nutritional properties thought most likely to be available is oilseed rape, i.e. rape producing Omega 3 oils as a dietary supplement, with a mean rank score of 2.13, followed by rape with a lower saturated fat content (2.08). Soybean with improved nutritional profile was ranked some way behind these (1.75).

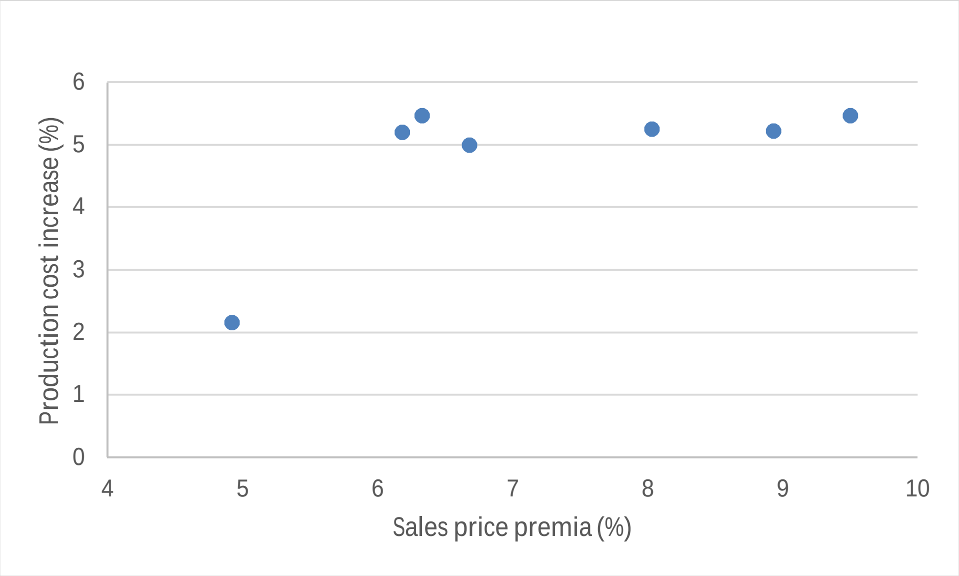
The crop offering altered nutritional properties viewed by the panel as least likely to be available is wheat, in particular wheat with reduced levels of protein linked to celiac disease (1.04), wheat with higher dietary fibre (1.08), followed by wheat with improved bread-making properties (1.26).

The panel anticipated that the cultivation of all of the crop-trait combinations under consideration will incur increased costs compared to the conventional equivalent (see Table 3). These cost increases will be due, almost in their entirety, to higher seed costs, as biotech companies attempt to recoup development costs. Interestingly, the crop viewed as being the least likely to be available in GM form, i.e. wheat with improved bread-making properties, is also expected to incur the largest increases in production (seed) costs, i.e. 5.47%. At the other end of the scale, the output crop-trait the panel anticipated having the lowest cost change for farmers was potato with bruising resistance (2.17%).

The nutritional profile changes identified for GM crops in this study were viewed by the panel as desirable and so all were expected to offer a price premium to the farmer. The crop-trait combination expected to offer the highest price premium, compared to its conventional counterpart, is wheat with reduced levels of protein linked to celiac disease, with a potential price premium of 9.5%. Oilseed rape producing Omega 3 oils as a dietary supplement was also expected to offer a substantial premium (8.93%). The crop with the lowest estimated premium was potato with resistance to bruising (4.92%). This relatively low premium may be due to the fact that this new trait offers no direct benefit to consumers, but rather benefits to intermediaries though reduced losses during transport and storage and perhaps also farmers during harvest.

Economic logic suggests that the price premium attaching to seed costs will be related to the size of the expected price premium available on the harvested crop itself. The larger the sales price premium, the larger the premium that farmers will be willing to accept on the price of seed. Figure 1 tests the extent to which the panel of experts has recognised this principle, whether consciously or not, in providing these estimates.

Figure 1. Relationship between experts' predicted sales price premia and input cost increase for GM crops with output traits.



As Figure 1 shows, while there seems to be some reflection of the likely lower sales price of the bruise-resistant potato in the estimated increase in production costs, there would seem to be no recognition of this relationship in the input cost estimates of the other crop-trait combinations. The basis on which these production cost increases have been estimated is therefore uncertain, but may reflect the panel's associated average experience for GM crops in other geographical regions.

When given the opportunity to suggest other crop-trait combinations that might be both available to EU farmers and offering societal benefits, there were only a small number of suggestions and these were dominated by crops with various types of biofortification. The rationale for such suggestions must be influenced in part by GM events in the current development pipeline but also, perhaps, by an assumption that there might be a more positive reception for such crops by EU consumers due to their health-promoting qualities. However, the generally negative expectations about future GM policy on authorisations in the EU was also apparent in these responses. Accordingly, some panel respondents declined to suggest novel GM crops, but rather pointed to the products of new plant breeding techniques (NPBTs) which do not use transgenesis, such as CRISPR as being more likely to be available to EU farmers. Although relatively new, techniques such as CRISPR are already being hailed (for example, see Belhaj *et al*, 2013 and Ledford, 2015) as the future industry standard tool for biotechnology, thereby supplanting the position of GM in plant breeding. While these NPBTs are currently still being debated by advisory bodies and regulatory authorities in the EU (Tagliabue, 2016), there is the possibility that because they produce plant gene modifications that are indistinguishable from both conventional breeding and chemical and physical mutagenesis approaches, they will be excluded from the scope of GM legislation such as Directive 2001/18/EU on Deliberate Release of Genetically Modified Organisms. This would make releases of such crops to the EU market much more routine.

2.4 Discussion and conclusions

The headline outcome of this survey of GM stakeholders is the rather low expectation that any of the 17 GM crop-trait combinations under consideration will be available to farmers in the EU by 2025, with the maximum likelihood of availability placed at around 50%. Because a broad range of crops and GM traits, operating on both the output and input side, was under consideration here, it can be inferred that there is only a modest expectation amongst the stakeholders consulted that any GM crops will be available to EU farmers within the time-frame considered. There are three possible reasons for these low 'availability' estimates. First, crop-trait combinations may still be at early stages of development and so may not be available for marketing within the time-frame considered. Second, the policy environment is expected to remain challenging for GM releases in the EU (effectively maintaining the current moratorium) even by 2025 and, third, there is such uncertainty surrounding the issue of availability that the stakeholders consulted were not able to arrive at a consensus. Each of these possibilities will now be examined in turn.

The possibility that the crop-trait combinations under consideration would not be ready for market by 2025 is a remote one, because crop-trait combinations were only included in the list for this consultation if they were already advancing along the development pipeline. Indeed, a number of the crop-trait combinations selected are already commercially available and are grown on large areas of land in regions outside the EU. For example, 67% of maize grown in the USA in 2013 was stacked HT IR (Fernandez-Cornejo *et al*, 2014), while drought tolerant maize was grown on 275k ha in the USA in 2014 (James, 2014). Consultees would therefore be unlikely to believe that the majority of these traits would not be available due to technical constraints. A much more likely explanation for the relatively low likelihood (of availability) estimates is that consultees considered that the policy environment operating in the EU over the study period would mitigate against the use of these various crop-trait combinations. The historic policy environment in the EU has resulted in an effective moratorium on GM releases to the environment. With the public, campaigning groups and politicians across the EU remaining quite hostile to GM, it is easy to see why our consultees would presume a maintenance of the current moratorium, in spite of recent policy developments intended to unblock the GM authorisations process. This view is reinforced by the observation that a further 9 survey respondents declined to complete the questionnaire on the grounds that, in their view, the policy environment would prevent any GM crops being available in the EU by 2025.

The third possible explanation for these universally low expert likelihood rankings, stems not so much from universal pessimism about the policy environment, but from pure uncertainty about the future policy-market environment. Likelihood rankings reflecting low levels of uncertainty would result in considerable convergence in estimates. On the other hand, high uncertainty would be reflected in relatively low levels of convergence and high levels of statistical variance i.e. where consultees express both high and low likelihood estimates and these cancel each other. Variance scores for the estimates provided here are, in fact, relatively high, i.e. in all but one case in excess of 70%, suggesting relatively low convergence of estimates resulting from unresolved uncertainty.

This result raises an interesting methodological question. The Delphi technique was designed to help remove uncertainty in future forecasts by allowing consultees to see the estimates and hear the supporting arguments of their peers in the consultation. The rationale for this expectation is that if a consultee is uncertain about a particular issue, or lacks confidence in their knowledge, they will want to revise their estimates towards those who are better informed. The expectation is that multiple rounds of consultation and feedback will result in a convergence in the estimates around the mean. A common way of measuring this process of convergence is to calculate the change in standard deviation scores from one round of consultation to another. When this change appears to be small, convergence is deemed to have been achieved.

However, in the case of the study reported here, while change in standard deviation scores from round one to round two of the consultation is small, this does not actually reflect convergence so much as a hardening of diversity, albeit with some small-scale elimination of more extreme values. The Delphi process i.e. seeing what ranks others apply (or rather, the average rank) may not motivate individuals to modify their own estimates if they are confident in their own firmly fixed (divergent) view. As one consultee explained: 'As I do not know the other respondents or their expertise, and have no compelling new information, there is no basis for being swayed by their estimates or opinions. I will not amend my estimates'. Looking at the frequency distributions for the likelihood rank scores, there would seem to be two classes of responses. For some traits there are no values at all over the rank of three, signifying convergent negative likelihood estimates. However, in cases where there are ranks over 3, the likelihood of a rank of 4 or 5 seems as great as that of a zero or one. This means that the high, and low ranks, balance each other and the resulting mean score regresses towards the central value (i.e. uncertainty).

The conclusion to draw from this is that, while there might well be acknowledgement amongst consultees that these particular crop-trait combinations will be market-ready within the study time-frame, there is great uncertainty over whether policy and market conditions (i.e. food chain actors reacting to public sentiment) will allow the production of these crops in the EU. There are two obvious sources of this possible uncertainty. First, it is not known whether the recent changes to EU policy will make it easier for biotech firms to secure approval for cultivation at the EU level, or whether many states will execute opt-outs to the point that biotech companies decide that the size of the EU seeds market is too small to justify them making any new investment in this area. It is already known that 19 member states had applied for the opt-out prior to the 3 October 2015 deadline for applications to the Commission, including Germany, France, Italy, Austria, Greece, Hungary, Latvia, Lithuania and Poland (New Scientist, 2015). Second, even if authorisations begin to flow, it is not known whether GM crops would actually be accepted into these markets.

This uncertainty is reflected in the fact that some consultees took a positive view of the likelihood of availability, while others had a very negative view. To the extent that consensus exists, more of the consultees take the negative view than the positive and so few of the average likelihood estimates reach positive territory.

The uncertainty expressed here over the future market and policy environment will, of course, not be lost on biotech firms considering both the development of crop traits targeted at European agronomic conditions, or seeking authorisations for GM crops in the EU. The policy environment has long been recognised as the primary barrier to the release of GM crops in Europe and a disincentive to biotech companies to invest in GM crops targeted at EU agriculture. The study reported here suggests that the most recent changes to policy have, at best, moved perceptions from a position of extreme certainty that further GM releases will not be permitted in the EU, to a position of great uncertainty about the possibility of further GM releases in the EU. This will do little to change the attitudes of biotech companies towards the EU market. If this generally negative stakeholder outlook, in terms of the availability of GM crops in the EU by 2025, is replicated in reality, then the benefits associated with GM crops identified here must be viewed as the benefits foregone by both EU farmers and citizens through continuance of the current moratorium on GM event approvals.

Table 1. The various GM crops, and their traits, shortlisted for the Delphi survey.

Input-side traits			Output-side traits		
Crop	**Trait**	**Sources**	**Crop**	**Trait**	**Sources**
Winter oilseed rape	HT	Davis *et al* (2012) Ruffo *et al* (2015) An and Carew (2015)	Wheat	Improved bread making properties	Graybosch *et al* (2013)
Potato	IR		Wheat	Higher dietary fibre	Cakmak *et al* (2010)
Potato	Pathogen tolerant	Haeseart *et al* (2015) Jo *et al* (2014)	Wheat	Reduced levels of protein linked to celiac disease	
Wheat	Drought tolerance	Farooq *et al* (2014) Aschonitis *et al* (2013) Yadav *et al* (2015)	Soya bean	Improved nutritional profile	Sowa *et al* (2014)
Wheat	Frost tolerance	Zheng *et al* (2015)	Oilseed rape	Producing Omega 3 oils	Batista *et al* (2011)
Barley	Frost tolerance	Hlaváčková *et al* (2013)	Oilseed rape	Lower saturated fat content	
Sugar beet	HT	Dillen *et al* (2013)	Potato	Resistance to bruising	Hara-Skrzypiec and Jakuczun (2013)
Soya bean	HT	Brookes (2003)			
Maize	Drought tolerance	Ferrero *et al* (2014) Tolk *et al* (2016)			
Maize	HT and IR	Baktavachalam *et al* (2015) Ruffo *et al* (2015)			

Table 2. Experts' views on various GM crops with input traits being available before 2025 and, if available, the likely effect of adopting the crop on farmers' costs and yields obtained.

	Mean availability score[1]			Mean farmers' cost change (%)			Mean farmers' yield change (%)		
	First round	Second round[3]	SD change[2]	First round	Second round[4]	SD change [2]	First round	Second round[4]	SD change[2]
Winter oilseed rape - herbicide tolerant	2.17	2.17	-0.01	-6.10	-5.74	-1.83	4.60	4.43	-0.49
Potato - insect resistant	1.38	1.33	0	-4.55	-4.47	-3.74	3.85	3.75	-1.34
Potato - pathogen tolerant	2.23	2.27	-0.02	-6.38	-5.89	-2.95	9.26	9.14	-0.98
Wheat - drought tolerant	1.39	1.30	-0.20	2.55	2.38	-0.48	6.85	8.00	-1.08
Wheat - frost tolerant	0.91	0.78	-0.14	0.16	0.55	-0.83	3.97	4.97	-0.98
Barley - frost tolerant	0.87	0.74	-0.15	0.68	1.05	-0.84	3.97	4.97	-0.98
Soybean - herbicide tolerant	2.40	2.48	-0.07	-5.75	-4.93	-2.33	4.28	4.07	-1.30
Sugarbeet - herbicide tolerant	2.39	2.39	0	-5.66	-4.70	-2.52	4.45	4.19	-1.15
Maize - drought tolerant	2.13	2.04	-0.21	0.68	0.80	-1.33	6.08	6.73	-1.17
Maize - herbicide tolerant and insect resistant	2.72	2.76	-0.03	-5.25	-4.90	-1.38	6.81	6.45	-1.30

Notes:

[1] where 0 = 'not likely' and 5 = 'very likely'.

[2] SD change is SD value in second round minus value in first round.

[3] when differences in first and second round scores were tested for statistical significance using Wilcoxon's matched pair signed ranks test, no significant differences were found.

[4] when differences in first and second round cost and yield changes were tested for statistical significance using the Students' t test, no significant differences were found.

Table 3. Experts' views on various GM crops with output traits being available before 2025 and, if available, the likely effect of adopting the crop on farmers' costs and prices for the crops received.

	Mean availability score[1]			Mean farmers' cost change (%)			Mean farmers' price change obtained (%)		
	First round	Second round[3]	SD change[2]	First round	Second round[4]	SD change [2]	First round	Second round[4]	SD change[2]
Wheat - with improved bread-making properties	1.17	1.26	-0.05	5.29	5.47	-0.20	6.26	6.33	-0.03
Wheat - with higher dietary fibre	1.13	1.08	-0.43	5.03	5.21	-0.19	5.56	6.18	0.50
Wheat - with reduced levels of protein linked to celiac disease	1.13	1.04	-0.04	5.29	5.47	-0.18	9.06	9.50	-0.10
Soybean - with improved nutritional profile	1.75	1.75	0	5.13	5.26	-0.18	7.47	8.03	0.07
Oilseed rape - producing Omega 3 oils as a dietary supplement	2.08	2.13	-0.02	5.39	5.23	-0.16	9.21	8.93	-0.75
Oilseed rape - with a lower saturated fat content	2.08	2.08	-0.03	4.87	5.00	-0.19	6.63	6.68	-0.07
Potato - with resistance to bruising	1.70	1.65	-0.02	2.36	2.17	-0.33	5.17	4.92	-1.33

Notes:

[1] where 0 = 'not likely' and 5 = 'very likely'.

[2] SD change is SD value in second round minus value in first round.

[3] when differences in first and second round scores were tested for statistical significance using Wilcoxon's matched pair signed ranks test, no significant differences were found.

[4] when differences in first and second round cost and yield changes were tested for statistical significance using the Students' t test, no significant differences were found.

3. Identification of the range of scenarios to be assessed via modelling

The literature review and Delphi study presented above includes reference to papers that listed numerous examples of GM crops that are being evaluated. We selected from this ‘pipeline’ of innovative crops some examples that EU farmers may consider to be potentially profitable. These are listed in table 4.

Table 4. Selected second-generation events

crop	ref(s)
	crops with stress-relieving traits
DT winter wheat	Farooq et al (2014), Aschonitis et al (2015), Yadav et al (2015)
FT spring wheat	Zheng et al (2015)
DT grain maize	Ferrero et al (2014), Tolk et al (2015)
HTIR grain maize	Baktavachalam et al (2015), Ruffo et al (2015)
FT winter barley	Hlaváčková et al (2013)
HT rape	Davis et al (2012), Ruffo et al (2015), An and Carew (2015)
HT soya	Brookes (2003)
blight-resistant potato	Haeseart et al (2015), Jo et al (2015)
HT sugarbeet	Dillen(2013)
	crops with 'downstream' benefits
wheat, biofortified	Cakmak et al (2010)
wheat, Improved Bread	Graybosch et al (2013)
maize, biofortified	Pillay et al (2014)
barley, biofortified	Rodrigo et al (2013)
rape, Omega3	Batista et al (2011)
soya, biofortified	Sowa et al (2014)(conventional, via biosorption)
potato, bruise-resistant	Hara-Skrzypiec, A., H. Jakuczun (2013)
potato, low acrylamide	Rommens (2007), Zhu et al (2014)
potato, biofortified	Crowell et al (2008)

Scenarios in which one or more of the crops in table 4 could be adopted by EU arable farmers, possibly within their already preferred crop rotation cycles, have been explored using our economic models. A dynamic simulation tool, a Model of the Economic consequences of Transgenic crops in the EU (METE) was used previously in the AMIGA work to provide individual crop or rotational gross-margin output for novel crops with stress-relieving traits, and has been described elsewhere (McFarlane, Park and Ceddia, 2014). An additional spreadsheet model has now been devised to predict a selling price that would have to be available to make it worthwhile for farmers to grow transgenic crops with downstream benefits, taking account of their opportunity to cultivate a conventional crop and achieve a normal gross margin from that.

4. To explore the above future scenarios via our existing static and dynamic economic models

4.1 Economic model assumptions

The dynamic model includes look-up tables that contain economic data (seed price, other input costs, control costs, selling price) specific to each country in EU and to each crop cultivated in that country, and other tables of coefficients that represent the rate of stress development month by month applicable in that geographic region.

a. Alleviation of biotic and abiotic stresses

Concerning biotic stresses (pests and weeds) it is assumed in the model that:

- farmers make decisions monthly as to the need to apply treatment, given information as to the extent of stress prevailing at that time, irrespective of whether the crop is conventional or one with stress-relieving trait(s)
- suppliers charge a premium for GM seeds set at a level that allows the farmer to achieve sufficient net margin under typical stress conditions
- co-existence regulations and GM crop management practice require that buffer zones and/or resistance-limiting refuge areas limit the proportion of land available for a GM crop
- GM insect-resistant crops (that are toxic to a range of pests) have the effect of lowering pest pressure in the vicinity of the crop, as well as within the crop itself.
- GM herbicide-tolerant crops with associated application of herbicide (usually glyphosate or glufosinate) lower the prevalence of weeds to the extent that reduces the tillage required prior to drilling a subsequent conventional crop.

Concerning abiotic stresses (drought, frost) it is assumed that:

- under severe stress the crop is damaged in a short period of time
- protection afforded by DT or FT traits delays the onset of irreversible damage.

b. Downstream benefits

The static economic model includes equivalent economic data. In addition, it is assumed that:

- gene-modification is likely to lead to diminished crop yield
- value-added to the crop by nutritional traits is shared with downstream beneficiaries
- the benefit to the farmer must be at least sufficient to compensate for opportunity cost.

There is a large potential demand for biofortified crops to alleviate malnutrition in developing countries (De Steur et al, 2015). Malnutrition resulting from unavailability of nutrients is not a significant problem in EU, but consumers are known to be willing to pay for special diets thought to be health enhancing (Menrad, 2003).

4.2 Scenario/model outcomes

The models are capable of exploring a wide-range of scenarios and a few examples are provided here:

4.2.1 *Crops that alleviate biotic and abiotic stresses*

Model predictions for the drought-tolerant wheat and maize if those crops were to be cultivated in drought-stressed regions of EU are shown in Table 5, in comparison with similar conventional varieties.

Table 5. Gross margins predicted for DT wheat and DT maize

relative stress (0=none, 100=maximum)		yield (t/hectare)	gross margin (€/ha)		yield (t/hectare)	gross margin (€/ha)
		wheat			DT wheat	
0		7832	875		7838	857
20		7518	828		7527	811
40		7122	768		7209	763
60		5975	596		6745	695
80		1634	-55		5633	530
		maize			DT maize	
0		8615	1181		8623	1120
20		8270	1119		8281	1059
40		7834	1040		7941	999
60		6572	813		7523	924
80		1797	-47		6731	783

Model predictions for frost-tolerant wheat and barley cultivated in regions vulnerable to frost are shown in Table 6, in comparison with similar conventional varieties.

Table 6. Gross margins predicted for FT wheat and FT barley

relative stress (0=none, 100=maximum)		yield (t/hectare)	gross margin (€/ha)		yield (t/hectare)	gross margin (€/ha)
		spring wheat			FT spring wheat	
0		5880	714		5978	712
20		5103	578		5658	656
40		4632	496		5393	610
60		4239	427		5148	568
80		3896	367		4917	528
		spring barley			FT spring barley	
0		5292	845		5390	764
20		4593	701		5074	700
40		4169	614		4822	648
60		3815	541		4592	601
80		3506	477		4377	558

4.2.2 *Stacked HT/IR traits*

Bt maize MON810 remains (at the time of writing) the only GM maize cultivated in Europe, but in USA MON810 has long been superseded by maize with 'stacked' traits, and mentioned in 3.3 above. Model predictions for yield and gross margin if varieties of maize with alternative and/or multiple traits are allowed to be grown in maize growing regions of EU are shown in Table 7, using data based on multiple reports summarised by Fernandez-Cornejo et al (2014).

Table 7. Gross margins predicted for stacked HT/IR maize varieties if cultivated in Europe

	relative stress (0=none, 100=maximum)		yield (t/hectare)	gross margin (€/ha)
combined typical stresses:			grain maize	
	0		8780	1025
	20		7670	841
	40		6809	698
	60		6122	584
	80		5561	491
weed stress:			HT grain maize	
	0		8760	988
	20		8745	985
	40		8729	982
	60		8714	980
	80		8699	977
pest stress:			IR grain maize	
	0		8760	978
	20		8739	974
	40		8719	971
	60		8698	967
	80		8678	964
combined stresses:			HTIR grain maize	
	0		8740	934
	20		8579	907
	40		8423	881
	60		8273	856
	80		8129	832

4.2.3 *Crops that provide nutritional benefits*

We assessed the break-even selling price for ‘second-generation’ GM crops that provide nutritional benefits, with results summarised in Table 8. The final column of the table shows the price at which the crop must be sold to earn at least as much per unit area as the conventional crop (i.e. at least as much as the opportunity cost of not changing), using the calculation:

$$breakeven = (convgrossmargin + newseedcost + newcontrolcost)/newyield \quad \text{€/t}$$

Table 8. Predicted ‘break-even’ farm-gate prices for nutritionally-enhanced crops

crop	yield t/ha	seed €/ha	control €/ha*	cropvalue €/t	gross margin €/ha	breakeven €/t
wheat						
conventional wheat	7	80	350	160	690	
wheat, biofortified	6	120	380			198
wheat - ImprBread	6.5	100	360			177
maize						
conv grain maize	9	200	600	165	685	
maize, biofortified	7.5	250	720			221
barley						
conv winter barley	5.5	60	360	170	515	
barley, biofortified	4.5	75	400			220
rape						
conv winter rape	3.5	45	400	350	780	
rape Omega3	2.8	55	450			459
soya						
conventional soya	3	60	300	450	990	
soya, biofortified	2.5	75	345			564
potato						
conv maincrop potato	50	1000	1400	140	4600	
potato - Low-bruise	48	1100	1450			149
potato low-Acrylamide	45	1200	1500			162
potato, biofortified	45	1500	1600			171

*'control' includes crop protection, fertiliser and labour;
another cost, that of compliance with co-existence regulations, is also included

Table 8 shows that crops with nutritional benefits have to command a farm-gate value about 10 to 30% greater than the conventional equivalent crop for it to be worthwhile for the farmer to grow the novel variety. This is a significant but not unreasonable expectation for the increased value to the farm of cultivating these novel crops.

5. Discussion

The model could be potentially used to explore a wide range of scenarios. We have utilised the model here to look at three broad scenarios. The results summarised in tables 5 and 6 confirm the findings we reported earlier (deliverable 10.4) that crops modified to tolerate biotic and abiotic stresses tend to offer net benefit at all but the most minor incidence of pressure affecting crop yield. The results summarised in table 7 indicate that stacked traits offer positive benefits partly because they protect against development of resistance, consistent with reports of the performance of stacked traits elsewhere (Que et al, 2010; Carpenter, 2010). Concerning results for novel crops with various nutritional and other downstream benefits, the results shown in table 8 are based only on estimates of likely farm-gate selling price required to compensate for likely seed premium payable combined with possible lower yield. These values do not seem unreasonable given the added value offered to food processors and consumers.

Wherever possible, we have verified the values allocated to parameters in our static and dynamic economic models using data public sources (e.g. Eurostat, FAOSTAT) supplemented with data from publications, such as the John Nix Farm Management Pocketbook (Nix, 2015) and European arable crop profit margins reported by Brookes (2011). Even with well-documented historic data, there will always be uncertainty associated with weather patterns on one hand, and economic cycles and shocks on the other hand. There are 4 key areas of uncertainty:

a. Crop value variability

The largest uncertainty arises from the unpredictability of crop selling price from year to year. Table 9 shows the percent annual standard deviation of relative real (i.e. inflation-adjusted) prices for selected crops by region.

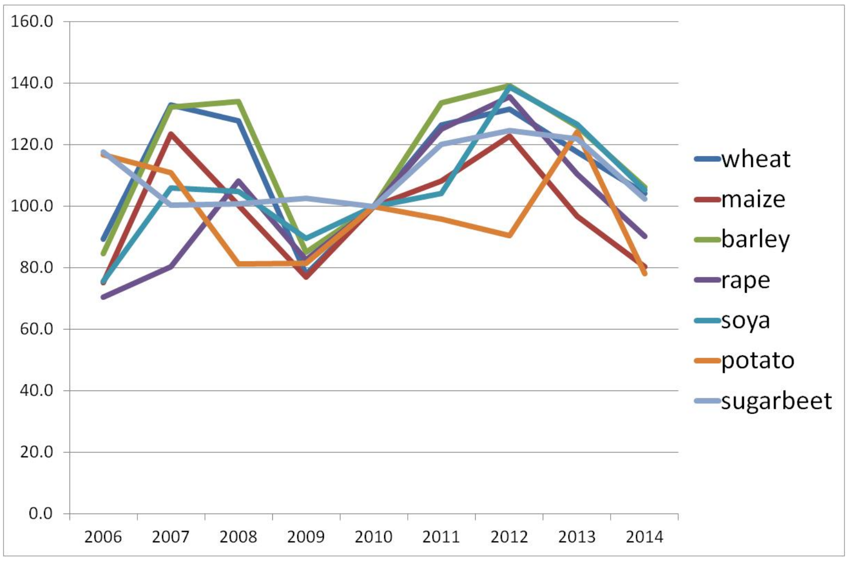
Table 9. Variability of annual crop prices

	years 2006-2014						
	per cent standard deviation of annual crop price (year 2010 = 100):						
	wheat	maize	barley	rape	soya	potato	sugarbeet
region:							
1	21.2	22.9	21.7	14.8	29.5	18.7	14.0
2	21.5	13.9	24.3	16.7	13.1	25.8	13.5
3	19.4	21.8	20.7	22.1	15.7	14.0	11.1
4	18.9	17.2	19.8	19.8	19.0	16.1	10.7
5	18.2	22.0	20.1	19.7	12.9	18.1	18.7

Source: Eurostat

The movement of price indexes in the years 2006-2014 relative to year 2010 is shown in figure 2.

Figure 2 – Real crop prices in EU relative to price in 2010



The pattern of movements in relative prices illustrates that there is price correlation among cereal crops, as is expected when goods are partial substitutes for one another. Rape and soya prices show some correlation with cereal prices, perhaps arising from market speculation in commodity prices, while the root crops potato and sugarbeet move more independently. The span of season-to-season price movement in each crop in this nine year period consistently displays random movement between seasons of more than 10% of the average crop price.

b. Seed premium

There is some evidence (Gomez-Barbero et al, 2008) that seed prices set by suppliers depend on farmers' willingness to pay for more expensive seed which, itself, will depend on biotic stresses prevalent in particular areas.

c. Biotic and abiotic stress effects on yield

In the dynamic model described above, we simulate progressive severity of pest, weed or drought stress in stages covering the entire range of pressures experienced at representative farms in each geographic region.

d. Labour costs

Some indication of variation in arable farm labour costs between EU member states was published by Brookes (2011) as part of 'other variable costs', although Brookes commented that "one farm's fixed cost might be another farm's variable cost". Where shown separately, labour costs were typically reported to be about 15 to 20% of all variable costs.

6. To draw conclusions on the likely economic impacts of new events within the EU through to 2025.

There is a contrast between the almost total absence of direct economic impact of GM crops in Europe arising from the stalemate in EU legislation regarding authorisation of cultivation, and the very rapid progress being made:

- in multi-trait GM crops authorised elsewhere in the world
- in gene-editing technology for other applications.

The EU has tacitly acknowledged the economic importance of GM crops by fairly rapidly approving GM feed ingredients for import; without that concession, the high protein feed currently used in almost all EU livestock farming would be very much more expensive. There are more than 40 GM crops listed by the European Commission (*http://ec.europa.eu/food/dyna/gm_register/index_en.cfm*) as approved for import for use in food, food ingredients and feed, including GM varieties of maize (25), oilseed rape (4), soybean (12) and sugarbeet (1).

There are two elements to the work presented here. First, the expert panel consulted in our DELPHI study had low expectation of GM crops becoming available to EU farmers before 2025, and there has been no further progress in resolving the stalemate in the European Parliament since the survey was conducted. EU farmers continue to be denied the opportunity to utilise GM crops, and seed companies continue to lack any incentive to develop GM crop traits specifically for the soils and environment of EU arable farming. The second phase of the work in this deliverable has highlighted a number of GM possibilities in the pipeline and has illustrated how our models could be used to explore the economic impacts of adoption if that were to come to fruition.

However, gene-editing technology is developing quickly and some techniques are now so refined that it has become impossible to identify subsequently whether creation of a novel sequence did or did not involve inserting genetic material from a 'foreign' source, making the distinction between GM and conventional crop varieties impossible to define (Gaj et al, 2013). Some suggest that public antipathy to GM crops may wane when the medical profession come to point out the very important and diverse range of health benefits that are offered by foods biofortified by gene-editing techniques (De Steur et al, 2015).

However, the conclusion from this work is that despite the range of possible advances in production, nutrition and health that could arise within the EU from the use of GM, the current view of many experts is that the field scale use of such crops by 2015 will be limited.

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