

Assessing the potential economic benefits to farmers from various GM crops becoming available in the European Union by 2025: results from an expert survey

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1 **Assessing the potential economic benefits to farmers from various GM crops becoming**
2 **available in the European Union by 2025: results from an expert survey**

3 **1. Introduction**

4 Evidence is being presented in many quarters that genetically modified (GM) crops have
5 delivered net benefits for farmers, both small and large scale, and consumers, in the countries
6 where cultivation has been permitted (e.g. Brookes & Barfoot, 2016 and James, 2014).
7 Depending on the crop and trait, these benefits might be agronomic, economic and/or
8 environmental in nature, resulting from yield improvements, better management of pests and
9 diseases, reduced input use and nutritional improvements. While there are a growing number
10 of commercially-grown GM crops in the world, only one GM crop is currently permitted for
11 cultivation in the European Union (EU) i.e. Bt maize. While Bt maize cultivation occurred in
12 five EU countries in 2014, the areas cultivated were very small, with only Spain and Portugal
13 producing more than a few thousand hectares i.e. 131,537 ha (MAGRAMA, 2014) and 8,542
14 ha (Ministry of Agriculture and Sea of Portugal, 2014) respectively. As the House of
15 Commons (2015) points out, the fact that there is only one GM crop approved for cultivation
16 is largely due to the extremely slow and cumbersome EU GM approvals process, which
17 requires majority member state approval in the European Council, resulting in an effective
18 moratorium on further authorisations in the EU. As a consequence of this extremely arid
19 policy environment, private sector investment in GM technology has moved out of the EU
20 and consequently there is very little research being undertaken specifically focused on the
21 needs of EU agriculture or consumers. It is, therefore, unsurprising to note that some
22 commercial biotech companies have started to withdraw pending applications for EU
23 authorisations for GM technologies that they have developed (EC, 2016a).

24

25 However, this ‘informal’ moratorium on GM authorisations within the EU might soon
26 be lifted, as a consequence of recent changes to legislation. Directive (EU) 2015/412
27 of the European Parliament and of the Council of 11 March 2015, amending Directive
28 2001/18/EC, provides the means for the Member States to restrict or prohibit, on
29 certain grounds, the cultivation of genetically modified organisms (GMOs) in their
30 territory, even when these have been judged by the EU’s regulators to pose no risk to
31 human health or the environment (European Parliament and Council, 2015). Allowing
32 Member States to unilaterally ban GM cultivation may not sound like much of a
33 breakthrough for GM authorizations, but the rationale for allowing Member States to
34 ‘opt out’ of GM cultivation in this way, is that they will not need to block agreement
35 on GM authorisations within the European Council to maintain their own GM-free
36 status, thereby making EU-level authorisations easier to obtain.

37

38 Outside of the EU, the development pipeline continues to produce new
39 commercialized GM crops. The USDA Animal and Plant Health Inspection Service
40 (APHIS), which regularly publishes lists of successful petitions for unregulated release
41 of GM events into the environment in the USA, announced in September 2015 that the
42 117th such petition, for a potato with blight-resistance (Pathogen Tolerant - PT) and
43 other properties, was approved for trials (APHIS, 2015). While there has been no
44 incentive for commercial biotech companies to develop crop-trait combinations
45 targeted at agronomic conditions prevailing in Europe, Stein and Rodriguez-Cerezo
46 (2009) have noted that some GM crops already commercialized outside the EU, or
47 within the development pipeline, are both agronomically suitable and may offer
48 potential benefits for farmers or consumers in the EU. With a potential unblocking of
49 the EU GM crop authorisation process now a distinct possibility, leading to some

50 countries in the EU (such as an independent post-Brexit UK) considering adoption of
51 GM crops, it is timely to review the GM crop-trait combinations that were currently,
52 or soon to be available, to identify their suitability for cultivation in the EU and
53 examine the nature of the benefits that they might offer to either farmers and/or
54 consumers.

55

56 Almost all past evaluations of the benefits offered by potential uptake of GM technologies in
57 the EU have focussed on the farm-scale economic benefits offered by the most common GM
58 crops (soybean, maize, cotton and canola) and traits (herbicide tolerance [HT] and insect
59 resistance [IR] (Kathage et al., 2016). This concentration on crop-trait combinations already
60 commercialised (see, for example, Demont and Tollens, 2004; Demont et al., 2007; Brookes,
61 2007; Demont et al., 2008; Dillen et al., 2009; Carpenter, 2010) has occurred for the practical
62 reason that these cases provide some data on the benefits obtained from adoption available
63 from non-EU settings, or at least from field-scale trials. As Kathage et al. (2016) pointed out,
64 the availability of data remains the primary constraint to evaluation of the impacts of GM
65 crops in the EU setting. An exception to this trend is Flannery et al. (2004) who included
66 some ‘hypothetical’ crop-trait combinations in a benefits evaluation for Ireland. For the
67 study detailed here, it was concluded that because the policy and regulatory changes required
68 to ‘open up’ EU member states to GM crop production was likely to take a number of years,
69 the scope of this analysis could not be confined to GM technologies already commercialised,
70 but must also have to take into account crop-trait combinations still in development, that are
71 likely to be available in the near future, say by 2025.

72 The novel approach taken in the evaluation presented here i.e. extending the scope of the
73 analysis to include GM crops not yet commercialised, presented an obvious methodological
74 problem: that of obtaining data on the likely benefits from uptake of crops where no

75 observational data were available. Past approaches to estimate likely benefits from GM crops
76 grown in the EU have involved extensive surveys of non-EU production thus providing data
77 for transfer into the EU context. When such approaches were not possible i.e. where only
78 limited data were available, modelling exercises have been undertaken (see, for example,
79 Demont and Tollens, 2004), sometimes involving statistical approaches, such as stochastic
80 simulation techniques to overcome concerns about the accuracy or representativeness of the
81 data. However, for most crops considered here, because they are yet to be commercialised,
82 no data are available at all. To overcome this problem, we adopted the only remaining
83 approach that could supply credible benefits data – stakeholder consultation, where a panel of
84 experts in GM technologies provided estimates of likely future benefits of GM adoption.
85 This approach was also applied to crop-trait combinations that are commercialised outside of
86 the EU, as these individuals have the appropriate knowledge to make necessary adjustments
87 to non-EU data to account for differences in agronomic conditions between the data donor
88 and recipient countries. Stakeholder consultation seemed to provide a consistent data
89 generation process for all cases i.e. for technologies already developed and those still in the
90 development pipeline whether for input or output traits. The approach:

- 91 • could be informed by any economic evaluation that exists;
- 92 • could make adjustments to non-EU data to account for EU agronomic conditions; and
- 93 • could generate new ‘notional’ data where no observational data currently existed.

94

95 To maximise the quality of the data derived from the survey of stakeholders, the study
96 employed the so-called ‘Delphi’ technique, developed at the RAND Corporation (Dalkey and
97 Helmer, 1963). The Delphi technique takes information from a panel of well-informed
98 individuals and builds these data into a consensus about possible future change or
99 developments (Hsu and Sandford, 2007; Linstone and Turoff, 1975; Martino, 1993; Young

100 and Jamieson, 2001). The key characteristic of the Delphi process is that data gathering is an
101 iterative process, punctuated by feedback of the group results to all contributing individuals.
102 In light of this feedback individuals are then permitted to amend their judgements until an
103 acceptable measure of consensus is reached. Multiple iterations are sometimes required to
104 derive an acceptable level of consensus. Data can be collected in a group setting, or
105 anonymously, as this is an effective way of reducing the biasing effects of dominant
106 individuals operating in group settings such as focus groups (Dalkey, 1972; Scott, 2011).
107

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

118

119

120 In this paper, we report the results of a global Delphi survey consultation into the potential
121 agronomic and economic benefits that 12 prospective GM crop-trait combinations might
122 offer to EU farmers and/or consumers. In addition, the paper also addresses the question of
123 the significance of any estimated benefits identified i.e. asking the question ‘how much
124 difference would these benefits make to the competitiveness of adopters compared to non-

125 adopters?’ Past experience suggests that once these technologies are licensed for use in a
126 country, if they offer any worthwhile benefit, the vast majority of farmers quickly adopt
127 them. This assumption is based on observation of the very rapid and near complete market
128 penetration of Herbicide Tolerant (HT) canola in Canada (James, 2014). Some past studies
129 modelled the likely rate of uptake of GM technologies in various countries (e.g. Dillen et al.,
130 2009) but these estimates were based on simple assumptions of the speed and nature of GM
131 adoption patterns of similar GM technologies in non-EU countries. As such approaches can
132 be criticised, the simplifying assumption was made that, for each crop trait included in this
133 evaluation, maximum penetration had been achieved. For this reason, rather than examine the
134 potential benefits received by individual farmers of adoption of these GM technologies, it
135 made more sense to explore the issue of the competitive advantage conferred on countries
136 that adopt them, compared to competitors that do not. To do this, the input and output
137 impacts of the GM traits estimated in the stakeholder consultation were applied to standard
138 ‘representative’ crop cost models for a selection of EU countries (see Method section for
139 more detail). In this exercise it was assumed that these GM technologies are taken up in the
140 UK and the impact of this on the competitiveness of UK production, relative to a selection of
141 northern EU countries, is assessed. The choice of the UK as the experimental platform for
142 this competitiveness analysis is made more pertinent by the recent Brexit vote in the UK. As
143 a consequence of this public vote, the UK will find itself outside of the EU GM licensing
144 framework and free to follow its own GM licensing policy. Recent UK governments, guided
145 by scientific evidence, have been notably less sceptical of GM technologies than
146 governments in many EU countries and the European Commission and Parliament. It is,
147 therefore, likely that the effective moratorium on GM licensing seen in the EU will not be
148 replicated in an independent UK. It would, therefore, be instructive to explore what impact

149 the adoption of GM technologies would have on the relative competitiveness of the UK
150 agriculture sector.

151

152 **2. Method**

153 While there were many crop-trait combinations in the market, or under development, not all
154 of these would be suitable for EU agronomic conditions, or offer traits that would provide
155 benefits in the EU. A literature review was used to select appropriate candidates from within
156 this population of options through the identification of the need for a trait to meet a particular
157 EU agronomic challenge or, by identifying a particular crop-trait combination already
158 discussed in the literature which might offer benefits in the EU context, for example by
159 helping to overcome a common EU pest problem or climatic limitation (see Ricroch &
160 Hénard-Damave, 2016; Hefferon, 2015; De Steur et al., 2015; and the GM Foods Platform
161 (FAO, 2015)). Using these selection criteria, the EU FP7 AMIGA project team selected
162 relevant crop-trait combinations from three official government databases of applications for
163 release of GM material to the environment: the USDA APHIS database of field tests of GM
164 crops (USDA, 2015); the EU GMO Register (JRC, 2015); and the Australian Applications
165 and Authorisations for Dealings involving Intentional Release (DIR) database (OGTR, 2015).
166 The subset of crop-trait combinations selected is presented in Appendix 1, which classifies
167 crop-trait combinations into two broad types. First, those that have already secured USDA
168 de-regulated status and therefore either have, or legally could be, commercialised, and
169 second, those still undergoing trials and awaiting de-regulation.

170

171 The traits identified in Appendix 1 are expressed as broad phenotype classes. However,
172 within these broad classes, several specific technologies might exist. For example, the
173 phenotype class HT captures multiple technologies providing tolerance to a number of

174 different herbicide compounds. Because of this, the counter-intuitive phenomenon is seen in
175 Appendix 1 that field trials are still being undertaken in a phenotype class even though some
176 representatives of that class have already achieved USDA deregulated status. Continuing the
177 use of the HT class as an example, this occurs where developers are trying to produce HT
178 crops tolerant either to different herbicides, or multiple herbicides as stacked traits. In the
179 APHIS database, not only have some individual technologies been de-regulated, but they
180 have also been commercialised, and so are currently available for uptake by farmers in some
181 countries. To illustrate, 67% of the area of maize grown in the USA in 2013 was stacked
182 herbicide tolerant/insect resistant (HT/IR) (Fernandez-Cornejo *et al*, 2014), while drought
183 tolerant maize was grown on 275k ha (0.3% of the total area) in the USA in 2014 (James,
184 2014).

185

186 The shortlisted crop-trait combinations identified by means of this review process, had the
187 following characteristics:

- 188 • the technology had either achieved USDA de-regulated status, or was undergoing
189 field trials towards that objective, either in the USA, the EU or Australia;
- 190 • the technology is agronomically suitable for EU agriculture; and
- 191 • examples of this technology are either already available in the global marketplace, or
192 stand a very good chance of being so by 2025.

193 The subset of 12 crop-trait combinations were further classified on the basis of whether their
194 traits offer benefits on the input side to the farmer or grower, i.e. improved agronomic
195 properties or, on the output side, that enhance, or modify the harvested product qualities, as
196 shown in Appendix 1.

197

198 To carry out the Delphi study, a panel of stakeholders was recruited with expertise in GM
199 issues from various professional sectors such as: crops research and development; arable
200 farming; crop protection; and farm management. Invitations to participate in the study were
201 sent to 212 individuals that had either been engaged in GM research i.e. authors of GM-
202 related papers in peer-reviewed journals, or who were participants at recent GM-related
203 conferences and technical meetings. These 212 individuals were drawn from a range of
204 institutional backgrounds, with the largest group being university academics (43%), followed
205 by commercial or government research scientists (20%) and government officials (20%). In
206 terms of geographical location, 68% of the experts were based in Europe, 24% in North
207 America, and 8% from other parts of the world.

208

209 An explanatory recruitment letter and a one-page questionnaire were e-mailed to the panel of
210 experts in August 2015, and a reminder sent 30 days later, as a means to increase response
211 rate. A total of 51 replies were received, 26 of which were sufficiently complete to be
212 included in the final panel (an effective response rate of 12.3%). Twenty five responses were
213 unusable, for the following reasons: 10 said they had no relevant knowledge; while 15
214 declined to participate for other assorted reasons. The response rate of experts working in
215 commercial companies was much higher than for the other categories and so their weight in
216 the final panel is greater than in the original sampling frame.

217

218 Whilst the research team would have preferred to have had a Delphi panel of more than 26,
219 we can say, without revealing confidential details of the panel, with a degree of certainty that
220 they were very experienced and possessed expert knowledge of the subject matter under
221 investigation. As such they were both an appropriate and relevant panel for the study.

222

223 The second round consultation document was sent out to panel members 60 days after the
224 first mailing. In the second round, each panel member, after being reminded of their own and
225 the panel's average first round estimates, was invited to confirm or amend their original
226 estimates. Of the 26 panel members, 13 replied in the second round, of whom seven made
227 revisions to their first round estimates, while the remainder indicated that they were happy
228 with their original estimates. For those who did not respond to the second round consultation,
229 we could only assume that they were content to retain their original estimates. Under this
230 assumption, the sample sizes in rounds one and two remained the same.

231

232 While more than two iterative consultation rounds are permissible in the Delphi approach, a
233 third estimation round was not considered useful in this case because, as elaborated in the
234 results section below (see Tables 1 and 2), the standard deviation scores associated with the
235 group mean did not change significantly between rounds one and two, suggesting that further
236 significant reductions in the heterogeneity of the estimates would be very unlikely. The
237 estimates that the stakeholders were asked to make related to: (i) the impacts of the GM
238 technologies on crop yield and production costs for input-side traits; and (ii) production costs
239 and potential market price premia for the output-side traits. These estimates were expressed
240 in percentage terms, referenced against those for conventional crops in 2015. Price effects
241 can, therefore, be assumed to be expressed in constant price terms.

242

243 The analysis of the impact of these GM technologies on competitiveness was undertaken
244 through application of revised costs i.e. estimates by the consultees of GM impacts on yield,
245 production costs and product prices, as shown in Tables 1 and 2, to models of the cost of crop
246 production for a number of countries using a partial budgeting approach. As data for the full
247 costs of production were available, the impact of the uptake of GM technologies on enterprise

248 Net Margin was estimable. This relatively simple approach to benefits estimation, which was
249 chosen due to constraints on data availability, was adopted in several past studies which also
250 had the same relatively narrow focus on the estimation of producer economic benefits e.g.
251 Flannery et al. (2004). Data for these representative cost models was derived from official
252 sources i.e. EC directorates and national Departments and Ministries of Agriculture, as well
253 as Government Agencies and commercial providers of benchmarking data. These data
254 represent country-wide ‘average’ costs of production for non-GM crops in the case-study
255 countries and were derived from representative survey data.

256

257 **3. Results**

258 3.1 Introduction

259 Summary results from the Delphi survey are presented in Table 1 (input-side traits) and Table
260 2 (output-side traits). These tables present the mean estimates from the whole panel of
261 consultees for both rounds of consultation, together with a measure of the change in the
262 variability found in these estimates from first to second round i.e. the change in standard
263 deviation (SD) score.

264

265 When SD change scores are generally negative, this implies that the SD of the sample
266 estimates (i.e. the extent of variation between individuals) is decreasing between rounds as
267 the panel closes in on consensus. When the SD change estimates are also small, this suggests
268 that there is relatively little change in the SD estimates between rounds, i.e. convergence has
269 already largely been reached and that further iterations would only yield very small marginal
270 reductions in variation. Statistical testing, using the Paired Comparison Students’ t test at the
271 5% level, confirmed no significant difference ($p>0.05$) in the variability between the mean
272 estimates of the two rounds, thus signalling no need for a further round of consultation.

273 Table 1. Experts' views on the likely effect of adopting various GM crops with input traits
 274 on farmers' costs and the yields obtained.

	Mean farmers' cost change (%)					Mean farmers' yield change (%)				
	1st round	SD	2nd round ²	SD	SD change ¹	1st round	SD	2nd round ²	SD	SD change ¹
Potato - insect resistant	-4.55	10.23	-4.47	6.49	-3.74	3.85	7.23	3.75	5.89	-1.34
Potato - pathogen tolerant	-6.38	15.58	-5.89	12.63	-2.95	9.26	8.56	9.14	7.58	-0.98
Wheat - drought tolerant	2.55	7.81	2.38	7.33	-0.48	6.85	9.40	8.00	8.32	-1.08
Soybean - herbicide tolerant	-5.75	12.85	-4.93	10.52	-2.33	4.28	6.34	4.07	5.04	-1.30
Sugarbeet - herbicide tolerant	-5.66	15.70	-4.70	13.18	-2.52	4.45	7.04	4.19	5.89	-1.15
Maize - drought tolerant	0.68	8.49	0.80	7.16	-1.33	6.08	8.32	6.73	7.15	-1.17
Maize - herbicide tolerant and insect resistant	-5.25	13.79	-4.90	12.41	-1.38	6.81	9.99	6.45	8.69	-1.30

275 Notes:

276 ¹ SD change is the SD value in the second round minus the value in the first round.

277 ² Differences in first and second round mean cost and yield changes were tested for statistical significance using
 278 the Students' t test at the 5% level, and no significant differences were found.

279

280 Table 2. Experts' views on the likely effect of adopting various GM crops with output traits
 281 on farmers' costs and prices for the crops received.

	Mean farmers' cost change (%)					Mean farmers' price change (%)				
	1st round	SD	2nd round ²	SD	SD change ¹	1st round	SD	2nd round ²	SD	SD change ¹
Wheat - with improved bread-making properties	5.29	5.42	5.47	5.22	-0.20	6.26	4.38	6.33	4.35	-0.03
Wheat - with reduced levels of protein linked to celiac disease	5.29	5.91	5.47	5.73	-0.18	9.06	7.48	9.50	7.38	-0.10
Soybean - with improved nutritional	5.13	4.99	5.26	4.81	-0.18	7.47	6.34	8.03	6.41	0.07

profile

Oilseed rape - producing Omega 3 oils as a dietary supplement	5.39	5.83	5.23	5.67	-0.16	9.21	6.07	8.93	5.32	-0.75
---	------	------	------	------	-------	------	------	------	------	-------

Oilseed rape - with a lower lower saturated fat content	4.87	4.81	5.00	4.62	-0.19	6.63	5.25	6.68	5.18	-0.07
---	------	------	------	------	-------	------	------	------	------	-------

282 Notes:

283 ¹ SD change is the SD value in the second round minus the value in the first round.

284 ² Differences in first and second round mean cost and price changes were tested for statistical significance using
285 the Students' t test at the 5% level, and no significant differences were found.

286

287 3.2 GM crops with input traits

288 Input-side traits offer the prospect of financial benefits to farmers from reduced input costs,
289 especially crop protection costs (such as less expenditure on herbicides and pesticides), and
290 increased revenue through improved (or protected) yields. Table 1 shows that the panel
291 anticipated cost savings from five out of seven input-side traits, but increases in production
292 costs in the remainder. Costs savings ranged from 4.47% to 5.89%, a relatively narrow range,
293 with these being somewhat larger in magnitude than the range of expected cost increases i.e.
294 0.80% to 2.38%.

295

296 The crop-trait combinations offering the largest savings in input costs are pathogen tolerant
297 (PT) potato (5.89%) and HT soybean (4.93%). At the other end of the spectrum, the panel
298 thought that drought tolerant wheat would raise farmers' costs by 2.38% due to the fact that
299 there would be no crop protection cost savings to compensate for higher seed costs. The
300 notion of increased production costs for drought tolerance makes perfect sense because, with
301 the possible exception of reducing the need for irrigation, these traits do not replace any
302 inputs, such as sprays, but they may incur higher seed costs. However, these traits may still

303 prove financially advantageous if their yield protection benefits, in years of drought, offset
304 the higher seed costs when averaged over the longer term.

305

306 The highest and lowest anticipated yield improvements (Table 1) are both recorded for
307 potatoes, with IR potato estimated to lift yield by 3.75%, and PT potato by 9.14%. This
308 suggests a panel consensus that current yield losses from insect pests, e.g. Colorado and Flea
309 Beetles, are considerably lower than yield losses from diseases, such as Brown Rot and Late
310 Blight. It is informative to note that most of the recent GM potato trials globally have been
311 for late blight resistance. Drought tolerance is estimated to offer greater potential yield
312 benefits than the average, at 8% for wheat and 6.73% for maize. These estimates are high
313 considering that they represent yield protection averaged over a number of years. This
314 strongly suggests the stakeholder view that yield losses in drought years might be
315 catastrophic. Herbicide resistance traits are estimated to offer slightly below average yield
316 improvements for both sugar beet (4.19%) and soya bean (4.07%).

317

318 3.3 GM crops with output traits

319 The panel anticipated that all of the crops with output-side traits would incur increased
320 production costs compared to the conventional equivalent (see Table 2). These cost increases
321 would be due, almost in their entirety, to higher seed costs, as biotech companies attempt to
322 recoup their investment in product development. The stakeholder panel provided a pretty
323 narrow range of production cost increases across crop-trait combinations, with a range of just
324 0.47%. Interestingly, the crop expected to incur the largest increases in production (seed)
325 costs, is wheat, i.e. 5.47% for both output traits. Here, stakeholders may be factoring in the
326 fact that wheat is a relatively high value crop (per hectare), and so can better support higher

327 seed prices than some other crops. At the other end of the scale, the output trait with the
328 smallest increase in production costs was OSR with lower saturated fat content (5.0%).

329

330 All of the nutritional profile changes identified for GM crops were viewed as being desirable
331 to consumers and, so, all were expected to offer a price premium to the farmer. However,
332 they all represent niche markets so only a fairly small sub-set of farms would be able to grow
333 them. The highest price premium was anticipated for wheat with reduced levels of protein
334 linked to celiac disease (9.5%), although this would only be a niche market product. Oilseed
335 rape producing Omega 3 oils as a dietary supplement was also expected to offer a substantial
336 premium (8.93%). The crop with the lowest estimated premium, by comparison, was wheat
337 with improved bread making properties (6.33%). This slightly lower premium, in
338 comparison, may be due to the fact that the gains to bread and biscuit makers from the new
339 properties would be only marginal, as this trait would not allow for any new differentiation in
340 the market and so a higher retail price would not be obtainable. However, the panel did not
341 give any 'hard' evidence in this respect.

342

343 3.4 Impact of the 'new' crops on competitiveness

344 The significance of these GM technologies i.e. their impact on competitiveness, was explored
345 by comparing GB enterprise production costs and market returns (i.e. sales value without
346 subsidy), both with and without GM, to equivalent non-GM production in selected EU
347 countries. Figure 1 shows the impact of GM adoption on competitiveness, as expressed by
348 market returns and net margin for output-side traits, and operating costs and net margin for
349 input-side traits. The adopter country (i.e. where GM technologies have been applied) is GB
350 agriculture for six out of eight crop-trait combinations, but France had to be used in the two
351 grain maize cases, as grain maize production does not occur in GB.

352

353 Figure 1 suggests that, assuming widespread adoption, the selected GM traits could improve
354 the competitive position of GB agriculture compared to non-adopting EU counterparts. The
355 way in which this improvement in competitiveness is achieved varies according to trait. For
356 input-side traits, competitiveness is improved by reducing production costs. For example, in
357 the case of potatoes, current GB production costs are roughly equivalent to those in the
358 Netherlands. However, the adoption of GM pest control technologies for this crop i.e. HT and
359 pathogen tolerance (PT) would reduce average GB production costs by 4.5% and 5.9%
360 respectively (see Table 1) to a level significantly below that in the Netherlands. If these cost
361 savings could be passed on to consumers in the form of lower prices, GB potatoes could,
362 perhaps, compete for market share in the Netherlands, despite the additional transport costs.

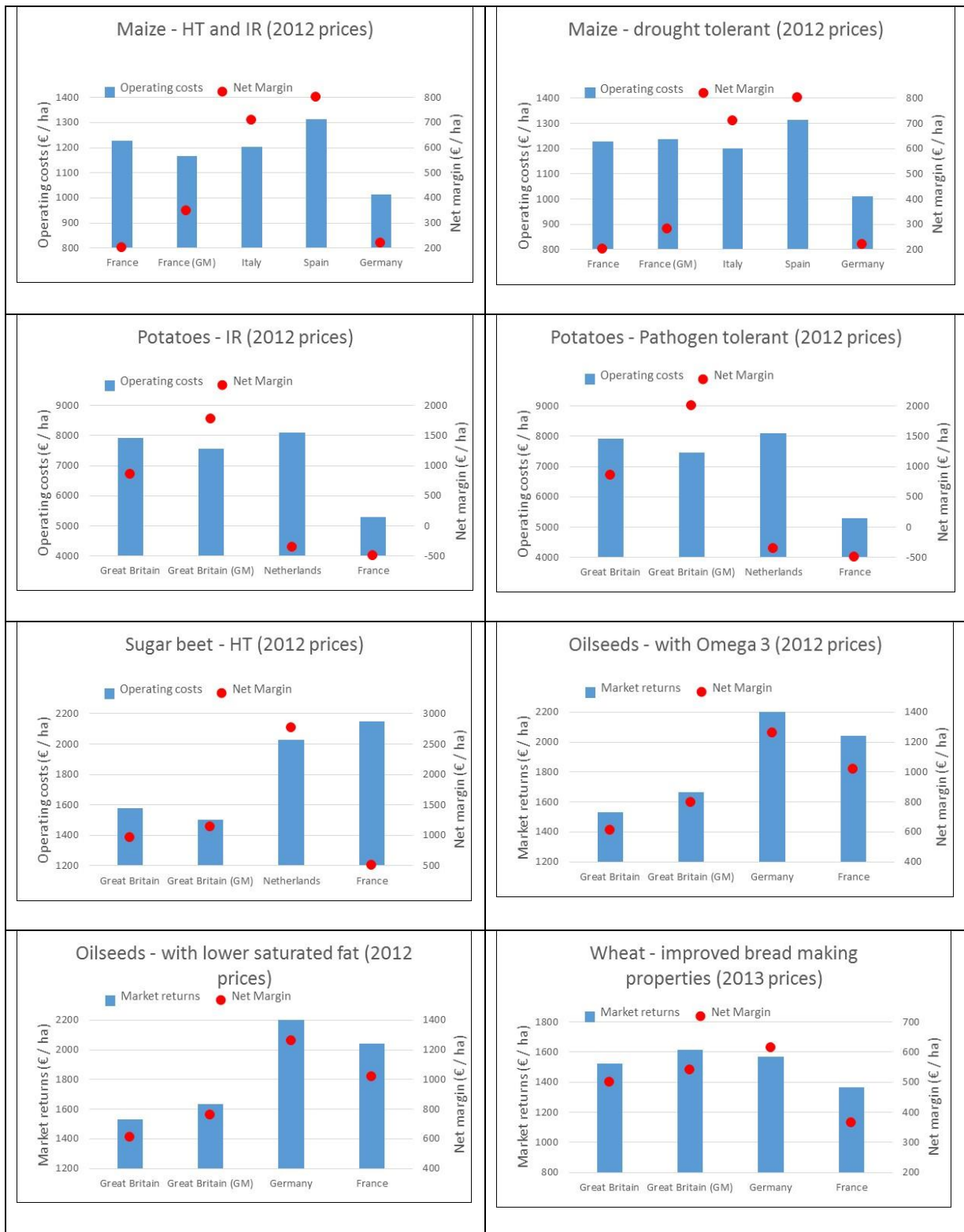
363

364 In the case of output traits, the panel thought that costs of production are, more often than not,
365 expected to increase, as in the case of OSR with enhanced Omega 3 content, where
366 production costs were projected to rise by 5.2% (see Table 2). Whilst this would lead to
367 higher consumer prices if consumers placed a higher value on this 'enhanced' product, they
368 would be willing to pay these higher prices. If the monetised value that consumers placed on
369 the enhanced product was greater than the production cost increases, then a producer (price)
370 surplus would be available, as indeed is projected in this case, with an expected rise in
371 producer price of 8.9% (see Table 2). Competitive advantage would also be improved
372 through gaining access to a niche market that non-adopters could not exploit.

373

374 Figure 1. Impact of the uptake of selected GM technologies on the competitiveness of crop
375 production in Great Britain and various EU countries.

376



377

378

379 Sources: EC (2016b); AHDB (2015); Defra (2013); Rezbova et al. (2013); USDA (2012); AgriBenchmark

380 (2016); and EC (2012).

381 Note: Wheat and grain maize enterprise data are based on FADN whole-farm data for farms specialising in
382 those crops.

383 Note: Potato prices are based on a 3-year average centred on 2012 to smooth out extreme annual variation.

384 Note: Data originally denominated in £ Sterling have been converted to Euros, assuming an exchange rate of
385 £1=€1.2.

386 Note: NL sugar beet production costs (2012) are assumed to be the same as in DE.

387 Note: The average EU rapeseed price (2012) has been used for DE and FR.

388

389 Competitiveness is also indirectly improved, for all traits considered here, through increased
390 profit (i.e. Net Margin). More profit means more capital is available for investment in:
391 technological innovation through new machinery purchases; land purchases to spread fixed
392 costs; or through enhanced training and advisory services. These investments drive increases
393 in technical and managerial efficiency, thereby securing further improvements in
394 competitiveness. Improvement in competitiveness of this kind is best exemplified by wheat
395 with improved bread-making properties (see Figure 1). GB adoption of this GM technology
396 would increase wheat production costs by 5.5% i.e. rising above average costs in Germany,
397 but would elevate profits by 8.1% through an increased price premium (of 6.3%), thereby
398 enhancing the prospect of additional future UK investments leading to improvements in
399 efficiency.

400

401 3.5 Identification of other crop-trait GM combinations that might become available

402 The selection of crop-trait combinations used in the study reported here was made on the
403 basis that the technologies were either already in the market, or well along the development
404 pipeline and would also offer potentially significant benefits to EU farmers or consumers.

405 These particular crop-trait combinations were chosen because they captured the most
406 important trait types, across a range of major crops. To guard against the possibility that
407 important crop-trait combinations had been omitted from the Delphi consultation, panel

408 members were asked to suggest any such alternatives that also met the selection criteria.
409 Only a small number of GM crop-trait combinations were suggested by the panel, these being
410 dominated by output-side traits i.e. various types of biofortification. Most of these output-side
411 traits would supply niche markets, which are by nature, small. Therefore, there would only be
412 very limited opportunities to tap into these markets to secure a price premia. Such traits,
413 therefore, offer only modest benefits for the broader farming sector and wider society. In light
414 of this it is, perhaps, not damaging to the analysis presented here that some GM traits of this
415 type have been omitted. Of course, some output-side traits, for example vitamin fortification,
416 might not be confined to niche markets but could, in theory, displace all conventional
417 production. However, while the potential market for such traits is, in theory, very large, the
418 scale of the benefits to both farmers and wider society within the EU are likely to be small.
419 There are two reasons for this. First, when a GM crop displaces its conventional equivalent,
420 even if some additional societal benefit is being supplied, market prices tend to drop to the
421 same floor as in the former conventional market. Second, in any developed country where
422 diets are already nutritious and where many fortified processed products already exist, the
423 price premium for a biofortified commodity would be small, reflecting the small marginal
424 societal gain.

425

426 A minority of the panel of stakeholders, when asked to identify prospective GM technologies
427 that were not included by our review, pointed away from traditional GM technologies instead
428 to the products of new plant breeding techniques (NPBTs), such as CRISPR, which do not
429 use transgenesis. Although relatively new, techniques such as CRISPR are already being
430 hailed (for example, see Belhaj *et al*, 2013; and Ledford, 2015) as the future industry standard
431 tool for biotechnology, thereby likely to supplant GM in plant breeding. While the status of
432 these NPBTs are currently still being debated by advisory bodies and regulatory authorities in

433 the EU (Tagliabue, 2016), the hope is that because they produce plant gene modifications that
434 are indistinguishable from both conventional breeding and chemical and physical
435 mutagenesis, they will be excluded from the scope of GM legislation such as Directive
436 2001/18/EU on Deliberate Release of Genetically Modified Organisms. This would make
437 releases of such crops to the EU market much more routine.

438

439 **4. Discussion and conclusions**

440 Our choice of a stakeholder consultation approach for generating estimates of likely yield,
441 cost and revenue changes resulting from future EU (or UK) adoption of GM crops allowed a
442 nuanced transfer of data from non-EU settings into the EU context where crop-trait
443 combinations have already been developed and has also allowed for the generation of ‘novel’
444 data where crop-trait combinations are still in development. The extent of the challenge
445 facing the consultees in transferring data from non-EU settings depended on several factors,
446 including perceptions of whether there are likely to be differences in seed costs, or agronomic
447 differences between the EU and non-EU settings that had to be accounted for, plus
448 differences in disease pressure and pest management practice.

449

450 Another important consideration that consultees had to account for was the likely costs
451 associated with required co-existence measures in adopter countries, as these could impact
452 considerably on production costs. The specific measures that might be put in place in the
453 adopter countries for individual crops could not, perhaps, be easily anticipated, so it is not
454 exactly clear how consultees handled this issue. However, it is likely that reference would
455 have been made to the impact of co-existence measures on production costs in countries that
456 had already adopted similar GM technologies. It is also worth pointing out that the existence
457 of co-existence measures in these non-EU countries has not acted either as a barrier to rapid

458 uptake, nor significantly eroded the financial benefits that the technology confers (see, for
459 example, Furtan et al, 2007), including the case of GM maize in Spain and Portugal.

460

461 The cross-country analysis reported here provides a useful indicator of the impacts that GM
462 crop adoption would have on national competitiveness. However, it should be recognised that
463 this analysis presents a somewhat simplified picture of possible future adoption decisions.
464 First, the analysis assumes near complete uptake of these GM technologies in the adopter
465 country. While this must be a reasonable assumption for some of these GM technologies
466 based on historic observation, for example PT potatoes would likely be widely adopted as all
467 growers could benefit. However, this might not be the reality for some crop-trait
468 combinations, for example where the GM technology targets a particular pest problem that is
469 not present in all regions within a country. A historical example of this would be the adoption
470 of IR maize in Portugal, where uptake has been confined to regions where
471 European/Mediterranean Corn Borer presents a significant commercial risk (Jones et al,
472 2017). For crops with limited potential for market penetration, for example DT maize, the
473 results of the competitiveness analysis should not be interpreted as indicating the impacts for
474 the competitiveness of the countries as a whole.

475

476 Second, the data used in the representative cost models are reflective of the central tendency
477 in each case-study country. In reality, a wide distribution of production costs exists in each
478 country, due to diversity in farmers' management ability, agronomic factors and geographic
479 location. This means that changes to the competitive advantage resulting from GM adoption
480 would not be uniformly experienced amongst producers in any country.

481

482 Third, the consultees' estimates of GM impacts in costs and yields are themselves also
483 measures of central tendency, obscuring a likely broad range of impacts experienced by
484 individuals, where some, due to their particular circumstances, may not receive significant
485 benefits from the technology. Finally, the possibility must be considered that the consultees,
486 in considering the impacts of the GM technologies on production costs, did not properly
487 factor in possible increases in costs associated with some potential negative externalities of
488 adoption of GM technologies, such as increase in pest resistance through the use of HT or IR
489 events (Green & Owen, 2011; Brookes, 2014). In such circumstances, additional
490 management actions are required to control the problem, perhaps involving applications of
491 alternative pesticides requiring more sprayer passes, or other approaches to pest control, such
492 as changed rotations, or use of deep mechanical tillage.

493

494 Whilst resistance problems can be controlled by careful use of conventional management
495 techniques, the need to undertake them can remove some, or all, of the cost saving benefits
496 from the use of the technology (Green & Owen, 2011). Numerous other studies have claimed
497 a range of environmental and social dis-benefits arising from the widespread adoption of GM
498 technologies, such as gene-flow to non-GM crops (Mallory-Smith & Zapiola, 2008) and wild
499 relatives (Warwick, et al., 2008; Reichman, et al., 2006), damage to wildlife (Garcia &
500 Altieri, 2005) and even economic risks to non-GM producers through adventitious
501 contamination (Blakeney, 2016). There is insufficient space to critique these studies and
502 claims here, although it is worth noting that several authors have cogently argued that the
503 environmental and socio-economic benefits of GM crops far outweigh any negative
504 externalities (Brookes & Barfoot, 2016). Whilst this lack of detailed critique may seem
505 unsatisfying to some, it should be pointed out that for the analysis here there is the
506 requirement to do so, as the focus of the study reported here is on the impacts of adoption of

507 GM technologies in the EU on potential producer surplus, rather than consumer, or wider
508 societal surplus.

509

510 The historic policy environment in the EU has resulted in an effective moratorium on GM
511 releases to the environment. With most consumers, campaigning groups and politicians
512 across the EU remaining largely hostile to the production of GM crops and the consumption
513 of their products, it is understandable that many of the stakeholders consulted were of the
514 view that the current informal moratorium on GM authorisations would remain in place for
515 the foreseeable future. While the GM policy environment has changed in the last few years,
516 there is still great uncertainty over whether this will make GM authorisations more likely, as
517 many states are likely to execute the opt-outs permissible under the new legislation. For
518 example, it is already known that 19 Member States had applied for the opt-out prior to the
519 3 October 2015 deadline for applications to the Commission, including: Germany, France,
520 Italy, Austria, Greece, Hungary, Latvia, Lithuania and Poland (New Scientist, 2015).
521 Additionally, even if authorisations begin to flow, it is not known whether GM crops would
522 actually be accepted into these national markets by retailers and consumers.

523

524 The uncertainty revealed here by our consultation over the future market and policy
525 environment will, of course, do little to change the attitudes of biotech companies towards
526 investment in biotechnologies targeted at EU agronomic conditions or, indeed, those seeking
527 authorisations for GM crops to be grown in the EU. If this generally pessimistic stakeholder
528 outlook is a harbinger of restrictive future EU policies, and is a disincentive to biotech
529 companies to invest in GM crops targeted at EU agriculture, then the benefits associated with
530 GM crops identified here must be viewed, in essence, as benefits that will be foregone by the
531 great majority of EU farmers.

532

533 In terms of the scale of these benefits foregone, the study reported here has shown that the
534 competitiveness of the agricultural sector in EU Member States could very well be improved
535 by adoption of GM crops. However, these improvements, when averaged over all farmers in
536 a country, would still be relatively small-scale, to the extent that existing large-scale natural
537 advantage, resulting from relatively durable macro-economic or environmental conditions, is
538 very unlikely to be overturned. For example, the adoption of HT/IR grain maize in France
539 would, in terms of country-wide averages, overturn the current small competitive advantage
540 that Italy holds, but would do little to eliminate the much more significant competitive
541 advantage (resulting from lower costs of production) held by Germany. Adoption of GM
542 crops would, therefore, not be a game changer for countries with high production costs,
543 although they would, based on the evidence generated in the study reported here, make a
544 positive contribution with respect to competitiveness in any country that adopts them.

545

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550

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

Crop	Phenotype class	Year of first field test notification (APHIS)	IP owners (trials in last 5 years)	No. of trials in last 5 years	USDA unregulated status granted (and IP owners)?	Sources used to identify suitability for EU agriculture
Maize	Drought tolerance	Unknown	Pioneer Hi-Bred International Inc; Monsanto.	>15	Yes Pioneer Hi-Bred International Inc.; Monsanto; BASF; Syngenta.	Ferrero <i>et al</i> (2014) Tolk <i>et al</i> (2016)
Maize	HT-IR stacked	1992 Pioneer Hi-Bred International Inc	Monsanto & Monsanto Europe, S.A.; Syngenta Crop Protection LLC; Pioneer H-Bred International Inc; Dow AgroSciences LLC; Genective SA; Bayer CropScience; Genective SA; Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA).	>15	Yes Monsanto; Pioneer Hi-Bred International Inc.; Syngenta; Aventis; Novartis Seeds.	Baktavachalam <i>et al</i> (2015) Ruffo <i>et al</i> (2015)
Potato	IR	1990 Monsanto	Michigan State University.	>15	Yes Monsanto; Frito Lay; USDA; Calgene.	Haeseart <i>et al</i> (2015) Jo <i>et al</i> (2014)

Crop	Phenotype class	Year of first field test notification (APHIS)	IP owners (trials in last 5 years)	No. of trials in last 5 years	USDA unregulated status granted (and IP owners)?	Sources used to identify suitability for EU agriculture
Potato	Fungal resistance (FR)	1990 Washington State University	J.R. Simplot Company; Michigan State University; Betaseed inc.; John Innes Centre, UK; Swedish University of Agricultural Sciences SLU; Wageningen University; Teagasc; BASF Plant Science GmbH; Queensland University of Technology.	>15	Yes USDA; Monsanto; Washington State; Frito Lay.	Haeseart <i>et al</i> (2015) Jo <i>et al</i> (2014)
Sugar beet	HT	2004 Syngenta	Betaseed inc; Ses Vanderhave NV; Syngenta Crop Protection AG; Plant Production Research Center Piestany, Bratislavská cesta; KWS SAAT AG; SESVANDERHAVE N.V.; Monsanto Europe SA.	5-10	Yes American Crystal Sugar Company; Syngenta; Betaseed; Ses Vanderhave NV.	Dillen <i>et al</i> (2013)

Crop	Phenotype class	Year of first field test notification (APHIS)	IP owners (trials in last 5 years)	No. of trials in last 5 years	USDA unregulated status granted (and IP owners)?	Sources used to identify suitability for EU agriculture
Soyabean	HT	1989 Monsanto	Pioneer H-Bred International Inc; M.S. Technologies LLC; Monsanto; Bayer CropScience; University of Georgia; USDA; Iowa State University; University of South Carolina Aiken; BASF Plant Sciences LLC; DAS LLC; Syngenta; Montana State University; OSU-OARDC.	>15	Yes University of Georgia; Upjohn; Northrup King; Pioneer Hi-Bred International Inc; M.S.Technology LLC; Monsanto.	Brookes (2003)
Soya bean	PQ (improved nutritional profile)	1993 Du Pont	Pioneer H-Bred International Inc.; University of Kentucky; USDA; University of Minnesota; Monsanto; University of Missouri; University of Nebraska/Lincoln; University of Kentucky; Montana State University.	>15	Yes Du Pont; Monsanto; Pioneer H-Bred International Inc.	Sowa <i>et al</i> (2014)

Crop	Phenotype class	Year of first field test notification (APHIS)	IP owners (trials in last 5 years)	No. of trials in last 5 years	USDA unregulated status granted (and IP owners)?	Sources used to identify suitability for EU agriculture
OSR /canola	PQ (Lower saturated fat content)	1991 Calgene	None	None	Yes Calgene; Cargyll; InterMountain Canola; Du Pont.	Batista <i>et al</i> (2011)
Wheat	Heat/drought tolerance	1998 (Montana State University)	Syntech Research; Arcadia Biosciences; University of Nebraska; Southern Illinois University; Monsanto; Biogemma USA.	>15	No	Farooq <i>et al</i> (2014) Aschonitis <i>et al</i> (2013) Yadav <i>et al</i> (2015)
OSR /canola	PQ (higher Omega 3 oils)	2014 Nuseed Americas	Nuseed Americas.	1-4	No	Batista <i>et al</i> (2011)
Wheat	PQ (Biologically safe, e.g. for coeliacs)	2011 Washington State University	Washington State University.	1-4	No	Gil-Humanes <i>et al</i> (2010)
Wheat	PQ (improved bread-making quality)	2003 Montana State University	USDA; Murdoch University, Australia.	5-10	No	Graybosch <i>et al</i> (2013)