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New pesticides regulation: potential economic impacts of the withdrawal of *Pendimethalin* in horticultural crops

Sol Garcia-German*, Isabel Bardaji and Alberto Garrido
Centro de Estudios e Investigación para la Gestión de Riesgos Agrarios y Medioambientales (CEIGRAM). Universidad Politécnica de Madrid. C/ Senda del Rey, 13. 28040 Madrid, Spain

Abstract

The *Thematic Strategy on the Sustainable Use of Pesticides* moves forward towards the sustainability of agriculture fostering the use of Integrated Pest Management (IPM) practices in the European Union (EU). EC Regulation 1107/2009 was adopted in this framework leading to the eventual drop in the Vademecum of authorized substances of some important pesticides which are presently used in EU agriculture. Herbicide *Pendimethalin* will have to renew its registration in 2016 under the new regulation and there is a high probability that it will be removed. In this study we analyze the potential impact of the prohibition of *Pendimethalin* in two export driven horticultural crops grown in Southeastern Spain —lettuce and celery— to provide an illustration of possible consequences of the loss of certain active substances due to the new regulation. To do so, gross margin stochastic models are developed and used to generate Monte-Carlo simulations to look at farms' economic results and their production risks. Econometric models are used to examine consumers' and producers' surplus in export markets of lettuce and celery. The results show that the *Pendimethalin* ban might modify the economic risk profile that the farm faces, affecting the crops' profitability in the short-term. These changes would pass on to markets through shifts in supply and price and finally to European consumers, who would be the major losers.

Additional key words: herbicide regulation; lettuce; celery; economic risk; stochastic models; Monte-Carlo simulations; econometric models.

Introduction

Overall, weeds can produce the highest potential loss (34%), with animal pests and pathogens being less important (losses of 18% and 16%) in the most important world crops (Oerke, 2006). However, societal demands for more sustainable production systems call for the development of more environmentally friendly methods of production. The *Thematic Strategy on the Sustainable Use of Pesticides* (COM (2006) 372 final) aims at the promotion of low pesticide farming and obliges producers to cultivate using the principles of Integrated Pest Management (IPM) from 2014 onwards. The goals are to minimize the risks to health and the environment from the use of pesticides and to reduce the use of potentially dangerous active substances through review processes.

In this framework, EC Regulation 1107/2009 (OJ, 2009), which regulates the approval of active substances and plant protection products (PPP), was adopted and has replaced the previous regulation since June 2011. The main change of this regulation is that it introduces criteria for cut-off approval based on hazard for active substances according to their intrinsic properties.

The implementation of this regulation can lead to an important reduction in the number of active substances, which some authors estimate to be in the range of 20% within the next three years (Hillocks, 2012) after coming into force. A study commissioned by the European Parliament (2008) warned against the

*Corresponding author: sol.garciagerman@upm.es
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Abbreviations used: CV (coefficient of variation); EU (European Union); IPM (Integrated Pest Management); MAGRAMA (Ministry of Agriculture, Food and Environment, Madrid); PBT (persistent, bioaccumulative and toxic); PDF (probability distribution function); PPP (plant protection products).

consequences to European agriculture of the cut-off criteria to approve the use of substances. Impacts on production have serious consequences in some crops, especially in minor horticultural ones, for which there are no clear pesticide substitutes. Minor crops are those for which it is not profitable for firms to undertake the cost of developing and synthesizing new substances, due to their small surface and relative importance. However, the technical requirements for registration of active substances are much stricter now than they were prior to EC Regulation 1107/2009.

The aim of the study is to analyze potential economic impacts of the ban of *Pendimethalin* in lettuce (*Lactuca sativa* L.) and celery (*Apium graveolens* L.) in Southeastern Spain. Its registration expires in July of 2016, and the renewal of its registration will be made under the new regulation. There is a high probability that the active substance will not be approved due to the developments of the new regulation. *Pendimethalin* is a selective active substance which controls broadleaf and grassy weeds of common use in horticultural crops.

The economic analysis is based on in-field trials performed by independent research centres and provided by a firm that markets the herbicide's active substance to establish the effect of weeds control by hand, with *Pendimethalin* and without *Pendimethalin* in both crops in the same production area. This limited approach, though, does not reflect the performance of chemical substitutes to *Pendimethalin*. Thus, the analysis provides an illustration of possible consequences of the loss of certain active substances due to the new pesticides regulation if no chemical alternatives were used, the choice of substances were narrowed significantly and no mitigation strategies apart from hand weeding were used.

The implementation of the new regulation may lead to the withdrawal of *Pendimethalin* when it seeks registration for the next period of approval. *Pendimethalin* is a dinitroaniline herbicide of significant toxicological concern (Wang & Arnold, 2003). According to these authors, the broad use of this herbicide has led to its detection as contaminant in ground and surface water, air and precipitation. This substance could be classified as a persistent, bioaccumulative and toxic (PBT) substance, one of the cut-off criteria included in the review process. If *Pendimethalin* is considered PBT in the review process it will not be re-registered in 2016. If the substance only meets two of the three criteria (persistent, biaccumulative or toxic), it could be classified as an active substance candidate for substitution, which entails registration for a maximum period of seven years with renewable approval for terms that should not exceed another seven years.

This classification as PBT is being questioned by some organizations and firms which, even if they agree that the product is persistent and toxic, they disagree on whether or not it should be considered bioaccumulative under conditions of actual use in field and good agricultural practice. They consider that there are wide margins of safety between hazard criteria — the substance being considered PBT — and its exposure.

The interest of analyzing the effects of the prohibition of *Pendimethalin*, as an example of potential impacts of the new regulation, lies in several facts. Firstly, it is a product which has been widely used in European countries for over thirty years in a wide range of crops and with a significant use though not unique in many horticultural crops. Secondly, it is also one of the first active substances that will have to renew its registration under the new regulation and there is a high probability that it will be removed from the list of permitted substances. Thirdly, even though both lettuce and celery have very low tolerance to weeds, there are few chemical alternatives to *Pendimethalin* in these crops. Alternative substances present advantages and disadvantages over *Pendimethalin* and control a different range of weeds[1]. Lastly, the loss of herbicide active substances can lead to the increase of the risk of resistance buildup. Repeated use of a single herbicide may lead to an increase in herbicide-resistant individuals in a population. To avoid the buildup of resistances, active substances with different modes of action have to be rotated. In this sense, *Pendimethalin* presents an important advantage over other herbicides, because it has a very specific mode of action, and therefore it is less likely to generate resistance. Field work supported the fact that resistance decreased when using *Pendimethalin*.

In the short term the use of alternative herbicides can solve the problem of the loss of *Pendimethalin*. In the medium to long term, due to restricted availability of alternative herbicides, resistance buildup may become a serious concern.

[1] For a list of advantages and disadvantages and the range of weeds each herbicide active substance control in lettuce and celery in Southeastern Spain see Montserrat (2011).

The study of the economic impact of pesticide bans has been addressed by some authors. All previous studies include among the major short-term economic effects the reduction of yields, the rise of variable costs and the rise in prices (Deepak *et al.*, 1996; Knutson, 1999; Carter *et al.*, 2005). The increase in prices depends on the elasticity of demand and mainly harms consumers, providing that the fall in production is not covered by the production of third countries not subject to the ban.

The effects on producers' overall income are more ambiguous, to the extent that the ban can produce regional shifts or concentration of production. Some producers can experience significant losses due to the substantial reduction on gross margins and other producers may benefit from the price increase (Lichtenberg *et al.*, 1988; Zilberman *et al.*, 1991; Ferguson *et al.*, 1992; Knutson, 1999; Lynch *et al.*, 2005; Sexton *et al.*, 2007).

Wynn (2010) evaluates the impacts of the new European approvals regulation — EC Regulation 1107/2009 — on horticultural crops in the UK, among which lettuce is included. According to the author, reduced weed control can result in the loss of yields and quality of lettuce. In addition, weeds can act as hosts of certain viruses, increasing the risk of diseases. A yield loss of 8.7% is expected due to the appearance of broadleaf weeds when *Pendimethalin* is not used and only *Propyzamide* — the only other herbicide apart from *Pendimethalin* which remains registered for lettuce in the UK — is used, whereas a yield loss of 54.8% due to broadleaf weeds is expected in complete absence of pesticides.

To analyze the effects of the *Pendimethalin* ban we considered two export driven crops, lettuce and celery. Growers from Spain and other EU member states have traditionally used *Pendimethalin* to control weeds in them. The study focuses on their most important growing region, Southeastern Spain.

Spain is the third largest world producer and the leading exporter of lettuce. It is one of the main vegetable crops, with a production of nearly 900,000 tons, which represents 6% of horticultural Spanish production. Lettuce is produced all over Spain and is characterized by its heterogeneity due to the existence of different varieties or cropping or climatic conditions. Intensive lettuce production is concentrated in Southeastern Spain, which is the main exporting area. Celery represents 0.6% of horticultural Spanish production, and although this production is not quantitatively significant, it has great economic importance especially in Southeastern Spain where practically all production is grown. More than 60% of Spanish production of lettuce and more than 80% of Spanish production of celery is exported. Spain is the leading supplier of lettuce and celery in EU, having a market share of nearly 60% and 70% respectively. Although exports of both products are held throughout the year, two export periods are clearly distinguished, as the Spanish winter production supplements the local summer production of consumer countries. Because monthly exporting shipments and prices are country-specific and available from statistical sources, we evaluate consumers' surplus in the main EU importing countries.

Material and methods

This study develops a two-step approach to evaluate, firstly, the impacts of the ban of *Pendimethalin* and the non-use of herbicides on the economic results of representative farms of lettuce and celery, and secondly, the effect on the export markets of both crops. The ban and the non-use of herbicides would modify the economic risk profile that farms face, affecting the crops' profitability in the short-term. It is assumed that these changes in the crops' profitability would pass on to markets through shifts in supply and price and finally to consumers, who would be the major losers.

Due to the large heterogeneity of horticultural crops' production in Spain and the importance of exports in lettuce and celery, the study focuses on the evaluation of the impact of the herbicide ban on the production of lettuce and celery and on the consequences of the ban for export markets of both crops.

Farming without using herbicides would cause a yield loss and a cost increase to producers of lettuce and celery shifting the supply curve upwards. This would interact with demand and determine a new equilibrium in exported quantities and prices. It has been hypothesized that the producer sector can transfer in the short term the variation in average production costs due to not using herbicides to export prices. This is possible because both export sectors can manage export shipments to avoid sudden drops in export prices in the short term. This assumption may not be valid for a long-term perspective.

The farm modelling approach uses the results on yield losses and cost increases to formulate stochastic models which describe the impacts of the ban and the non-use of herbicides on the representative farm.

The study follows a two-step approach, but steps are independent. The only link between them is that the cost increase to producers which shifts the supply curve in the market analysis (second step) was obtained in the farm analysis (first step). The two-step approach is needed because this evaluation not only looks at the consumer markets but also at both the production risks and farms' performance.

The study is based on an exercise which compares two different strategies:

— Baseline scenario: Use of *Pendimethalin* as weeds control strategy.

— Alternative scenario (Scenario 1): Ban of *Pendimethalin*, non-use of herbicides and the use of hand weeding, according to the cultural practices typically used for both crops under different probabilities of occurrence of weed infestation.

There are few registered active substance substitutes to *Pendimethalin* in these crops in Spain. Under the assumption of similar efficacy in control, substitutes might have little effect on the economic results of the farm due to similar yields and costs[2]. In addition, chemical substitutes cover a different range of weeds than *Pendimethalin* and have different modes of action. Though alternatives may be considered substitutes in the short term, they could become complementary in the medium to long term because they could lose efficacy due to the potential development of resistances. For this reasons substitutes were not included in the scenarios. We have not considered potential dynamic adjustments, but they would eventually rise. Pesticide economics literature shows that, when assessing pesticides bans, we must take into account not only current technology but also incentives and capacity to innovate as this can mitigate in the long run the ban's impact (Sexton *et al.,* 2007).

Analysis of economic results of representative farms

The probability of occurrence of weed infestation, their intensity and the impact on yields were obtained from field trials performed by independent research centres and provided by a firm that markets the herbicide active substance and, additionally, from interviews conducted in specific farms whose production is aimed at export markets located in the production area. Infestation, yields and yield losses due to weed infestation were modeled as probability distribution functions (PDFs), which were adjusted statistically with data from 1990 to 2011. When there were series of prices available, these were assumed random and PDFs were statistically adjusted (lettuce). Otherwise prices were considered deterministic (celery). Based on prices, yields and yield losses and production costs obtained in the field, gross margin stochastic models were developed for each crop. Gross margin models were used in the Monte-Carlo simulations. Fig. 1 summarizes the methodological approach to the analysis of economic results of representative farms.

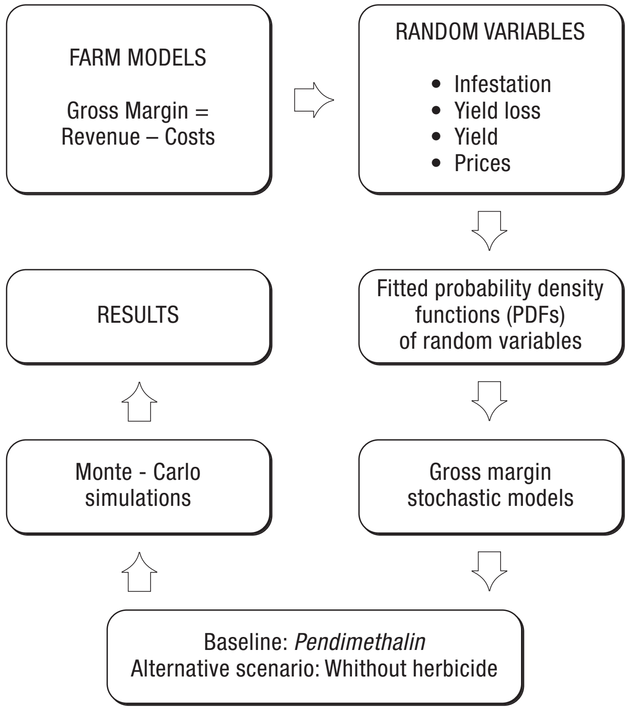

Figure 1. Methodological approach to the economic analysis of representative farms.

The field trials were aimed at evaluating the efficacy and selectivity of *Pendimethalin* for lettuce and celery

[2] Although a yield difference with another herbicide (*Propyzamide*) has been stated in the text, this has been obtained from a case study conducted in the UK (Wynn*,* 2010). We consider that we cannot extrapolate the data to our case study in Southeastern Spain for several reasons such as different weed pressures, yield response to weeds or relative activity and use of the different herbicides between countries (see Blake *et al.,* 2011). Field work indicates there was no yield difference when using *Pendimethalin* and when using herbicide alternatives.

in the production area — Southeastern Spain — and to establish the effect of weeds control by hand, with *Pendimethalin* and without *Pendimethalin*. The trials included an assessment of the time spent on hand weeding and a harvest assessment. The trials for lettuce were conducted in 2003, 2008 and 2011 and the trials for celery were conducted in 2011. The economic analysis is based on these in-field results, from which production data and weeds infestation rates were obtained.

As this evaluation of the agro-economic impact of the ban of *Pendimethalin* focuses on export markets, the interviews were conducted in firms located in the production area which aim their production to export markets. Information on the cost structure of production both of lettuce and celery and on the potential yield losses due to weed infestation in case that no other herbicide was used was gathered.

The farm modelling approach was specified by the following function, which defines gross margin, and which was assumed random:

$$\tilde{\pi} = \tilde{I} - C \qquad [1]$$

where $\tilde{\pi}$ is the gross margin obtained for each crop (€ ha^{-1}), $\tilde{I}$ is revenue (€ ha^{-1}) derived from the crops' yield and price, and C represents the costs of production (€ ha^{-1}).

Based on this scheme, different combinations of Equation [1] were used to model the farm´s economic results in the baseline (use of *Pendimethalin*) and in scenario 1 (*Pendimethalin* ban and non-use of herbicides and use of hand weeding), denoted by $\tilde{\pi}_p$ and $\tilde{\pi}_{wp}$, respectively.

Baseline: Use of Pendimethalin

The variables yield and price were considered random. The farm's gross margin ($\tilde{\pi}_p$) was assumed to be random, and was defined by the following function:

$$\tilde{\pi}_p = \tilde{R}\tilde{P} - C \qquad [2]$$

where $\tilde{\pi}_p$ is the crops gross margin (€ ha^{-1}) using *Pendimethalin*, $\tilde{R}$ are annual yields (kg ha^{-1}), $\tilde{P}$ are weekly prices (€ ha^{-1}) and C represents total production costs (€ ha^{-1}).

The following assumption was made. As *Pendimethalin* would be used, there would be no yield loss due to the crops' exposure to weeds, and therefore, crops would be subject to their regular variations of yields. Probability distribution functions were statistically adjusted based on annual average yields for each crop. Data on yields for lettuce were obtained from the Spanish Ministry of Agriculture, Food and Environment (MAGRAMA) Statistical Yearbooks for period 1990-2011 and for celery from Murcia's Agricultural Statistics for period 2005-2010. Data on prices for lettuce for period 2005-2011 were obtained from the MAGRAMA's Origin-Destination Food Price Monitoring Centre and from Murcia's Agricultural Statistics and for celery from field interviews conducted in production areas. Data on costs were obtained from the cost structure of the representative farms interviewed and located in the crops' production areas.

Scenario 1: Pendimethalin ban and non-use of herbicides

The variables infestation level, yield and yield loss and price were considered random. The farm's gross margin ($\tilde{\pi}_{wp}$) was assumed to be random, and was defined by the following function:

$$\tilde{\pi}_{wp} = [\tilde{X}(\tilde{Z})\tilde{R}\tilde{P} + (1 - \tilde{X})(\tilde{Z}')\tilde{R}\tilde{P}] - C \qquad [3]$$

where $\tilde{\pi}_{wp}$ is the gross margin obtained for each crop (€ ha^{-1}) without using *Pendimethalin* or other herbicides, $\tilde{X}$ is a binomial function which takes value 1 when weed infestation is low and value 0 when weed infestation is high, $\tilde{Z}$ is a discrete function of yield loss when infestation is low, $\tilde{Z}'$ is a discrete function of yield loss when infestation is high, $\tilde{R}$ are annual yields (kg ha^{-1}), $\tilde{P}$ are weekly prices (€ ha^{-1}) and C is the total production cost (€ ha^{-1}).

The following assumption was made. As *Pendimethalin* would be banned and no alternative herbicide would be used, there would be weed infestation and therefore a yield loss due to it. Infestation level was assumed to follow a binomial distribution (1, p), denoted by $\tilde{X}$. Thus, two levels of infestation were assumed, a low infestation level ($X = 1$) and a high infestation level ($X = 0$). Each of them was associated to a discrete yield loss function. Field work and trials suggested these low and high infestation rates. For lettuce, three different scenarios of probabilities of weed occurrence were modeled to measure the impact under a wide range of weed pressure. The probability that infestation would be low was assumed to be 0.25, 0.5 or 0.75 (with corresponding probabilities of high infestation rates of 0.75, 0.5 and 0.25). Yield loss when infestation is low was modeled with a discrete random variable {0.5, 0.5; 0.97, 0.92}[3] which associates two probabilities to different levels of yield loss. Similarly, yield loss when infestation is high was modeled with discrete variable $\tilde{Z}$ {0.5, 0.125, 0.125, 0.125, 0.125; 0.93, 0.87, 0.76, 0.84, 0.59}. For celery, yield loss when infestation was high was modeled with discrete variable $\tilde{Z}$ {0.25, 0.25, 0.25, 0.25; 0.8, 0.78, 0.83, 0.92}. Data on yield losses for lettuce and celery were obtained from field trials and from field interviews conducted in production areas.

In scenario 1 the production costs did not include the cost of *Pendimethalin* but included the cost of hand weeding and the labor costs derived from employers' social security contribution per working day for each employee. Data on hand weeding costs were derived from field trials conducted in the production areas.

Short-term analysis of export markets

A model for the demand of exports for each crop was estimated econometrically. The model was estimated by Seemingly Unrelated Regressions[4], including a set of eight demand equations for lettuce and five for celery, one for each of the main EU importers of Spanish lettuce or celery, respectively. The model estimated price elasticities of demand rather than flexibilities because exporters are assumed to manage export shipments to avoid price falls in the European markets. In addition, much of the pesticide economics literature use price elasticities of demand when examining demand markets (Lichtenberg *et al.*, 1988; Ferguson *et al.*, 1992; Carter *et al.*, 2005).

The model for the demand of exports was specified with the following equation:

$$\log(q_{it}) = a_i + b_i \log(p_{it}) + c_i \log(I_{it}) + d_i \, seasonality + \varepsilon_{it}$$
$$E(\varepsilon) = 0 \qquad [4]$$
$$E(\varepsilon\varepsilon^T) = V = \sum \otimes I$$

where I is an identity matrix and Σ is the covariance matrix of the disturbances, with $\sigma_{ij} \neq 0$; and where q_{it} are exported quantities to country i in time t (monthly data between January 1996 and March 2011), p_{it} are average real export prices (monthly data between January 1996 and March 2011), I_{it} is a disposable income indicator (yearly data between 1996 and 2011), *seasonality* is a dummy variable which takes value 1 for months in which Spanish exports concentrate and ε_{it} is the error term in the regression.

The data on monthly export quantities and export values from Spain to the main importing countries from January 1996 to March 2011 were obtained from EUROSTAT. Average export prices were estimated from export values and export quantities and were deflated with the vegetable consumer price index to consider real prices, as the dependant variable is real. The vegetable consumer price index and the disposable income indicator for each of the importing countries were also obtained from EUROSTAT.

The panel for the demand of lettuce consists of the main importers of Spanish lettuce, which include Germany, the UK, France, The Netherlands, Italy, Sweden and Denmark. These countries account for more than 80% of total Spanish exports of lettuce. A group comprising the rest of the importing countries was also included (Rest). The panel for the demand of Spanish celery consists of the major importing countries of Spanish celery — the UK, The Netherlands, Germany and France — which account for more than 80% of total Spanish exports. A group which comprises the rest of importing countries was included (Rest).

Using the estimated price elasticities of demand and the expected increases in export prices, the variations in export flows and consumer and producer surpluses were calculated. The expected increases in export prices are due to the rise in production costs caused by the use of hand weeding.

Assuming the simplest case of parallel shifts in the supply curve, changes in consumer surplus were given by the following function:

$$\Delta CS = (P_2 - P_1)X_2 + \frac{1}{2}(P_2 - P_1)(X_2 - X_1) \qquad [5]$$

Changes in producer surplus (quasi-rents) were given by the following function:

$$\Delta PS = (P_2 X_2 - P_1 X_1) - (C_2 X_2 - C_1 X_1) \qquad [6]$$

where P_1, X_1 and C_1 represent export prices, exported quantities and production costs respectively in the baseline and P_2, X_2 and C_2 represent export prices, exported quantities and production costs respectively in scenario 1.

[3] Notation goes as follows $\tilde{Z}\{p1, p2, ..., pn; r1, r2, ..., rn\}$ where *p*i are probabilities and *r*i reductions of yields percentage.
[4] For seminal work see Zellner (1962).

Average production costs for each scenario are defined as the ratio of total production costs to average yields, both calculated in the farm approach. The average yields considered in the previous step were the means of the PDFs of yields for each crop estimated in the farm analysis. Average production costs are used to estimate production costs.

Results

Analysis of economic results of representative farms

Table 1 reports the distribution functions which best fitted the series of data on yields and prices provided. For lettuce there were series of prices available, therefore a probability function was adjusted. For celery, prices were considered deterministic at € 0.15 unit^{-1}.

Fig. 2 and Table 2 present the economic results of the representative farm of lettuce. Fig. 2 shows the

Table 1. Statistical information on fitted distribution functions

	Distribution function	Test	*p*-value
Lettuce			
Yield	Weibull	Chi-squared	0.8232
Price	Weibull	Chi-squared	0.00
Celery			
Yield	Uniform	Chi-squared	0.6340

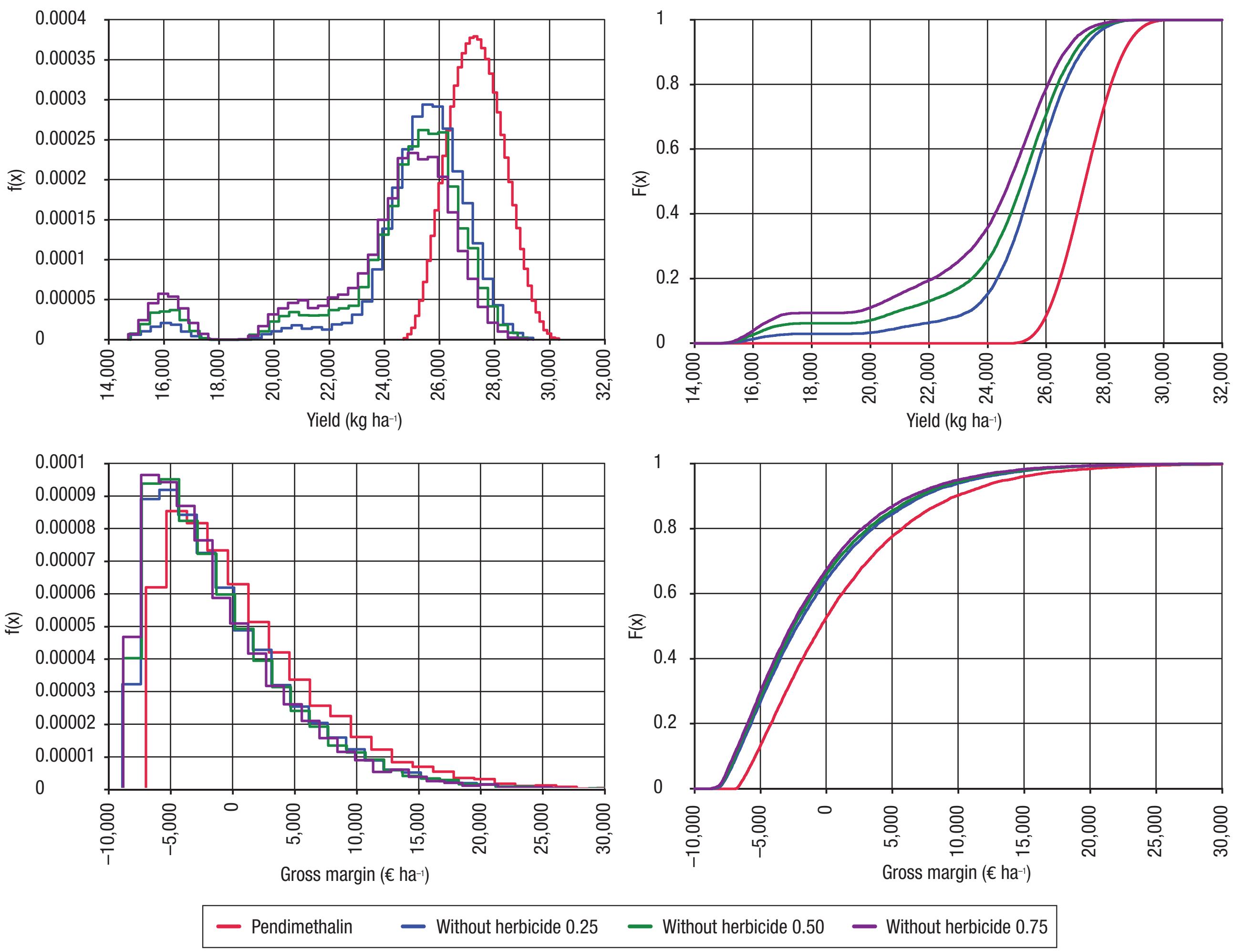

Figure 2. Probability distribution functions (PDF) of yields and gross margins obtained in the baseline (*Pendimethalin*) and in scenario 1 (without herbicide) under three different probabilities of weed occurrence in lettuce (to the left presented as a density function and to the right as a cumulative distribution function).

Table 2. Statistics for yields and gross margins obtained in the baseline (*Pendimethalin*) and in scenario 1 (without herbicide) under three different probabilities of weed occurrence in lettuce [probability of 25% (1), 50% (2) and 75% (3) of high weed infestation occurrence]

	Mean	Std. deviation	Percentile 05	Percentile 25	Coeff Variation (%)	Prob <0 (%)
Yields (kg ha^{-1})						
Pendimethalin	27,340.68	971.31	25,773.89	26,630.38	3.55	0
Without herbicide + Hand weeding [1]	25,184.44	2,196.97	21,044.04	24,598.21	8.72	0
Without herbicide + Hand weeding [2]	24,504.60	2,735.32	16,697.40	23,931.40	11.16	0
Without herbicide + Hand weeding [3]	23,857.41	3,049.88	16,131.19	22,954.89	12.78	0
Yield change of [1] over *Pendimethalin* (%)	–7.89	—	–18.35	–7.63	—	—
Yield change of [2] over *Pendimethalin* (%)	–10.37	—	–35.22	–10.13	—	—
Yield change of [3] over *Pendimethalin* (%)	–12.74	—	–37.41	–13.80	—	—
Gross margins (€ ha^{-1})						
Pendimethalin	1,153.97	6,387.89	–6,026.51	–3,633.35	—	53
Without herbicide + Hand weeding [1]	–749.86	5,939.07	–7,386.69	–5,198.23	—	64
Without herbicide + Hand weeding [2]	–996.92	5,834.19	–7,526.25	–5,365.55	—	66
Without herbicide + Hand weeding [3]	–1,247.50	5,732.26	–7,588.96	–5,468.26	—	68
Gross margin change of [1] over *Pendimethalin* (%)	–164.98	—	–22.57	–43.07	—	—
Gross margin change of [2] over *Pendimethalin* (%)	–186.39	—	–24.89	–47.68	—	—
Gross margin change of [3] over *Pendimethalin* (%)	–208.11	—	–25.93	–50.50	—	—

PDFs of yields and gross margins obtained in the baseline (use of *Pendimethalin*) and in scenario 1 (without herbicide) and Table 2 shows summary statistics for yields and gross margins.

In the absence of herbicide applications, the average yield risks increased significantly, since the variability of yields of lettuce was lower in the *Pendimethalin* scenario than in the hand weeding scenario under the three different probabilities of weed infestation modeled — the coefficient of variation (CV) for yields in the *Pendimethalin* scenario was lower (3.55%) than the CV in scenario 1 (8.72%, 11.16% and 12.78% when the probability of high weed infestation is 25%, 50% and 75% respectively). Yields decrease by 7.89%, 10.37% and 12.74% when the probability of high weed infestation is 25%, 50% and 75% respectively. Fig. 2 illustrates that the yield functions in scenario 1 present a bimodal form, where the yields obtained when the probability of weed occurrence is low and high in the three different probability schemes modeled can be clearly distinguished. This distinction was more marked as the probability of high weed infestation increased. It has been evaluated that there was a non negligible probability of obtaining lower yields when the infestation level is high (probabilities of 3.1%, 6.1% and 9.4% when the probability of high occurrence of weed infestation is 25%, 50% and 75% respectively).

Gross margin becomes negative and both the percentile 05 and percentile 25 decrease by 22.57%, 24.89% and 25.93% (perc05) and 43.07%, 47.68% and 50.50% (perc25) in the three probabilities of occurrence of high weed infestation considered respectively. The risk of obtaining more adverse economic results was higher in scenario 1 (probability of obtaining a negative gross margin in the range of 64-68%) than in the baseline (53%). Once again, this risk of obtaining negative results increases in 2% and 4% as the probability of higher weed occurrence rises (from probability of 25% to 50% of high weed infestation occurrence and from 25% to 75% of high weed infestation occurrence respectively). The lower gross margins obtained in scenario 1 were caused by the yield loss due to the non-use of herbicides and to the higher production costs. Due to the fact that only extreme scenarios have been considered, these results are only illustrative of the potential impact of the ban. The global impact of the *Pendimethalin* ban in the short term would have to take into account the performance of the alternative herbicides to *Pendimethalin* which are registered for lettuce or of other mitigation strategies apart from hand weeding.

Table 3. Statistics for yields and gross margins obtained with *Pendimethalin* and without herbicide in celery

	Mean	Std. deviation	Percentile 05	Percentile 25	Coeff. variation (%)	Prob < 0 (%)
Yields (kg ha^{-1})						
Pendimethalin	64,000.00	3,233.32	58,959.92	61,199.52	5.05	0
Without herbicide + Hand weeding	53,277.54	4,330.29	47,048.48	49,885.94	8.13	0
Yield change (%)	–16.75	—	–20.20	–18.49	—	—
Gross margin (€ ha^{-1})						
Pendimethalin	11,029.47	1,212.50	9,139.45	9,979.30	—	0
Without herbicide + Hand weeding	5,963.81	1,623.86	3,627.91	4,691.96	—	0
Gross margin change (%)	–45.93	—	–60.30	–52.98	—	—

Fig. 3 and Table 3 show the economic results of the representative farm of celery. Fig. 3 shows the PDFs of yields and gross margins obtained in the baseline (use of *Pendimethalin*) and in scenario 1 (Without herbicide) and Table 3 shows yield and gross margin statistics.

In the case of celery, the use of hand weeding decreased both average yields and gross margins by 16.75% and 45.93% respectively. The probability of obtaining higher yields in the baseline (use of *Pendimethalin*) was greater than in scenario 1 (without herbicide). The variability in yields was lower in the baseline than in scenario 1 — the CV in the *Pendimethalin* scenario was 5.05%, whereas in the non-herbicide scenario the CV was 8.13% — and therefore there was a lower risk of obtaining reduced yields in the baseline. The higher gross margin obtained in the baseline when compared to scenario 1 (decrease of 45.93% in scenario 1 when compared to the baseline) was, as in the case of lettuce, also due to the yield loss and to higher production costs. In addition, the risk of obtaining economic negative results increased when an herbicide was not used, as the mean is lower and the standard deviation is higher in the non-herbicide scenario.

In conclusion, the increase of the exposure to weeds caused changes in the risk profiles faced by farms of lettuce and celery, which decreased the expected physical and economic results and increased the probability of obtaining negative economic results. The immediate consequence of this impact would be a reduction in crop production, causing a reduction in supply. This conclusion would depend on the potential of using alternative ingredients and, in the long-term, in the built-in resistance that would result from a narrower choice of herbicides.

Short term analysis of export markets

Table 4 shows the parameter estimates of the models of the demand for exports of both crops, along with their standard deviations in brackets. The level of significance of the explanatory variables provided generally good results.

The parameter estimates of the demand of exports of lettuce show that the variables are statistically significant in all equations, and the coefficient estimates of export prices (p_{it}) and disposable income (I_{it}) are of the correct sign. Regarding the estimated price elasticity of demand for exports of lettuce, the case of the UK demands special attention. It is much more inelastic (–0.329) than the demand for exports of the other countries (in a range between –0.72 and –1.29), probably due to the scarcer possibilities of substitutability between suppliers of lettuce in the British market. As a result, the revenues of exporters of lettuce to the UK are expected to increase, in the face of an increase of lettuce export prices, whereas the revenues of exporters to other countries are expected to remain the same or decrease.

The parameter estimates of the demand for exports of celery show that the variable export prices (p_{it}) is statistically significant in all equations, and its coefficient estimates are of the correct sign. Disposable income is significant for the UK, Germany and the group which comprises the rest of importing countries. Seasonality is significant in all equations. Similarly to the case of lettuce, the elasticity of demand for exports of the UK is also more inelastic (–0.43) than that of the rest of the countries (in a range between –0.74 and –1.42). This fact leads to the expectation that the revenues of exporters of lettuce to the UK may increase too, if export

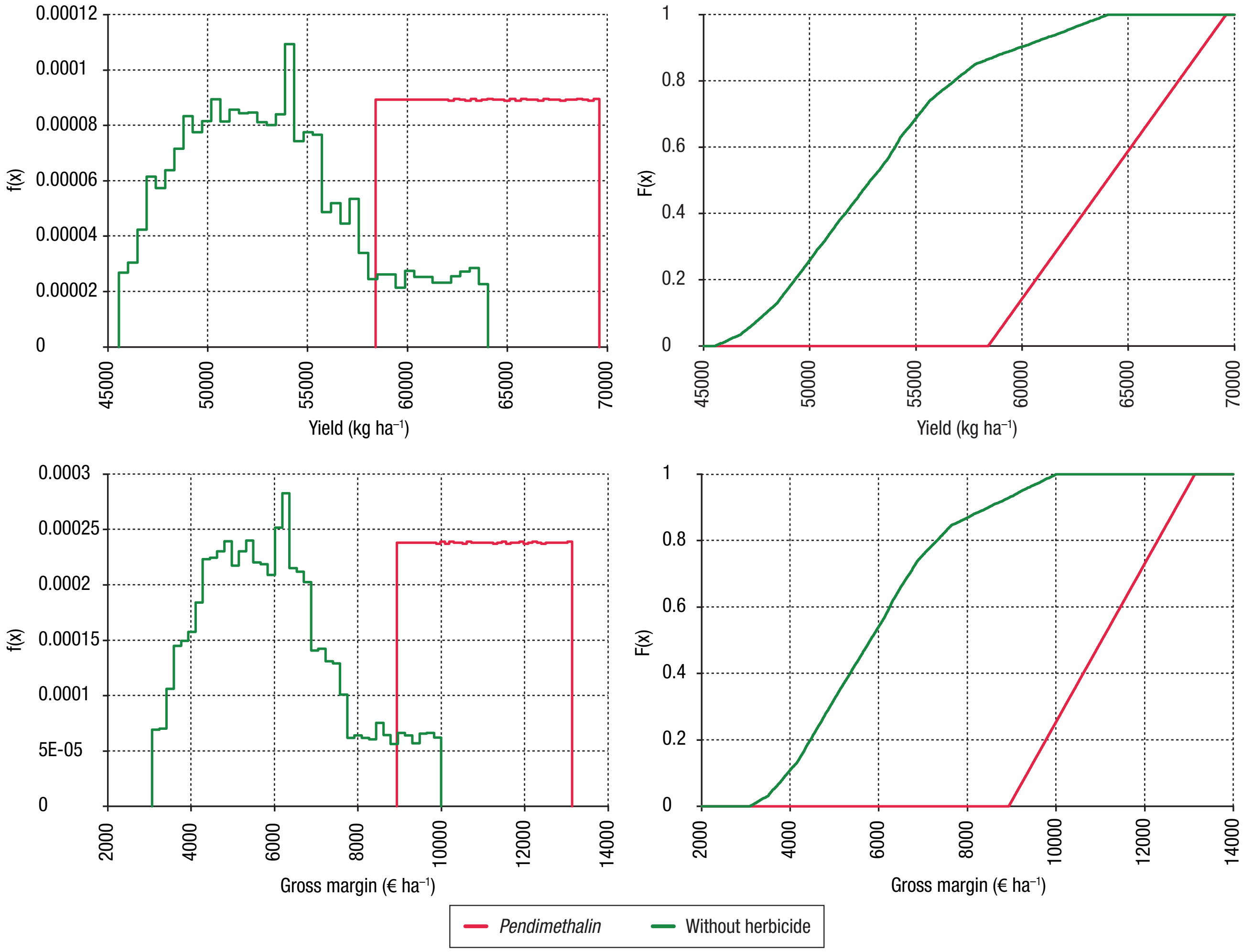

Figure 3. Probability distribution functions (PDFs) of yields and gross margins obtained in the baseline (*Pendimethalin*) and in scenario 1 (without herbicide) in celery (to the left presented as a density function and to the right as a cumulative distribution function).

prices increase, as might also occur in the case of lettuce.

Table 5 shows the impact of the non-use of herbicides on export markets of lettuce. Export prices are assumed to increase gradually until the producer sector is able to transfer the total variation in average production costs to them (from 2 to 27%). The inelasticity of the demand for exports of the main importers of lettuce (Germany and especially the UK) would probably cause a reduction on exports and a rise in prices which would benefit producers in the short term. This benefit to the producer sector increases as export prices rise.

On the other hand, the higher elasticity of demand for exports of the smaller importers (France, The Netherlands, Italy, Sweden, Denmark and the group which comprises the rest of importers) would cause losses to the producer sector. The loss to the producer sector is smaller as export prices rise. Denmark is an exception, where the loss to producers increases as export prices rise. This is due to the very elastic demand for exports of the country.

Overall, the impact on exports to the main and the smaller importing countries would be offset, at the expense of a major redistribution of income among producers. Some farms would likely abandon the activity, due to growing production costs, reduced demand and the rise in the risk of experiencing losses, but the most efficient farms would maintain production.

Table 6 shows the impact of the non-use of herbicides on export markets of celery. As in the case of lettuce, export prices increase gradually until they

Table 4. Regression results of the estimated demand for exports functions. Models are estimated by seemingly unrelated regressions in logarithms

	P_{it}	I_{it}	Seasonality	Constant	R^2	Nº observations
Lettuce						
Germany	–0.72**	7.81**	3.51**	–25.76**	0.63	152
	(0.13)	(1.30)	(0.21)	(5.98)		
UK	–0.329*	4.07**	2.59**	–9.85**	0.59	152
	(0.16)	(0.62)	(0.19)	(3.10)		
France	–0.88**	11.61**	0.67**	–39.83**	0.57	152
	(0.20)	(0.93)	(0.18)	(4.49)		
Netherlands	–0.80**	7.47**	4.16**	–25.14**	0.68	152
	(0.15)	(0.95)	(0.24)	(4.53)		
Italy	–0.94**	14.72**	2.63**	–56.59**	0.67	152
	(0.13)	(1.37)	(0.17)	(6.36)		
Sweden	–0.93**	8.38**	4.04**	–28.79**	0.65	152
	(0.18)	(0.84)	(0.26)	(3.80)		
Denmark	–1.29**	18.03**	3.42**	–70.89**	0.63	152
	(0.17)	(1.56)	(0.26)	(7.15)		
Rest	–0.78**	9.49**	2.52**	–32.47**	0.72	152
	(0.10)	(0.61)	(0.15)	(2.75)		
Celery						
UK	–0.43**	1.12*	3.86**		0.79	142
	(0.15)	(0.52)	(0.16)			
Netherlands	–0.74**		3.19**	11.34**	0.65	142
	(0.17)		(0.21)	(3.72)		
Germany	–0.91**	10.80**	3.84**	–42.01**	0.66	142
	(0.17)	(1.54)	(0.27)	(7.17)		
France	–1.02**		2.08**	12.52**	0.60	142
	(0.18)		(0.16)	(3.35)		
Rest	–1.42**	3.07**	2.73**		0.59	142
	(0.20)	(0.73)	(0.19)			

** $p < 0.01$; * $p < 0.05$.

reach the total variation which takes place in farms production costs (from 5% to 30%).

The inelasticity of demand, especially of the UK but also of The Netherlands, which are the major importers of Spanish celery, would cause a reduction on exports and a rise in prices, benefitting producers in the short term. Similarly to the case of lettuce, the gains for producers will be greater as export prices increase.

The higher elasticity of demand of the smaller importers (Germany, France and the group which comprises the rest of importers) would cause losses to the producer sector, offsetting the global impact and bearing the same potential consequences as in the case of lettuce.

In the short to medium term, the biggest losers of the non-use of herbicides both in lettuce and celery would be consumers of EU countries, the main destination of Spanish production, with overall losses exceeding 35% in lettuce and nearly 40% in celery of consumers' welfare once the producer sector has transferred the total increase in producer costs to export prices (Tables 5 and 6). Generally, consumers' surplus decreases as export prices rise. However, reduced welfare from lower consumption may be compensated by welfare gains resulting from increased environmental and health protection, should this be a result of the ban of *Pendimethalin*.

Table 5. Impact of non-use of herbicides on export markets of lettuce

	Demand elasticity	Δ Export price (%)	Exports 2010 (×1000 t)	Δ Exports (%)	Δ Consumer Surplus (million €)	Δ Consumer Surplus (%)	Δ Producer Surplus (million €)	Δ Producer Surplus (%)
Germany	–0.72**	27	164.31	–19.44	–37.49	–35.10	2.18	2.19
		22		–15.84	–31.16	–29.17	0.26	0.26
		17		–12.24	–24.55	–22.98	–2.22	–2.23
		12		–8.64	–17.66	–16.53	–5.25	–5.27
		7		–5.04	–10.49	–9.83	–8.84	–8.88
		2		–1.44	–3.07	–2.86	–13.06	–13.03
UK	–0.329*	27	101.39	–8.88	–26.79	–16.98	10.98	15.60
		22		–7.24	–22.02	–13.95	7.63	10.84
		17		–5.59	–17.16	–10.87	4.12	5.85
		12		–3.95	–12.22	–7.74	0.43	0.61
		7		–2.30	–7.19	–4.55	–3.43	–4.88
		2		–0.66	–2.09	–1.31	–7.54	–10.6
France	–0.877**	27	83.98	–23.68	–19.09	–41.75	–1.67	–3.18
		22		–19.29	–15.94	–34.87	–1.99	–3.79
		17		–14.91	–12.62	–27.59	–2.66	–5.06
		12		–10.52	–9.12	–19.94	–3.68	–7.00
		7		–6.14	–5.44	–11.90	–5.05	–9.61
		2		–1.75	–1.59	–3.48	–6.77	–12.90
Netherlands	–0.802**	27	55.57	–21.65	–12.95	–38.62	–0.22	–0.61
		22		–17.64	–10.99	–32.17	–0.64	–1.77
		17		–13.63	–8.83	–25.41	–1.30	–3.54
		12		–9.62	–6.48	–18.32	–2.21	–5.91
		7		–5.61	–3.92	–10.91	–3.38	–8.9
		2		–1.60	–1.16	–3.18	–4.83	–12.49
Italy	–0.937**	27	34.85	–25.30	–7.11	–44.20	–0.98	–5.26
		22		–20.61	–5.95	–36.98	–1.07	–5.73
		17		–15.93	–4.72	–29.32	–1.30	–6.96
		12		–11.24	–3.42	–21.22	–1.67	–8.95
		7		–6.56	–2.04	–12.69	–2.18	–11.70
		2		–1.87	–0.60	–3.71	–2.84	–15.20
Sweden	–0.933**	27	29.16	–25.19	–6.19	–44.04	–0.85	–5.11
		22		–20.53	–5.17	–36.84	–0.91	–5.47
		17		–15.86	–4.10	–29.21	–1.09	–6.57
		12		–11.20	–2.97	–21.14	–1.39	–8.41
		7		–6.53	–1.77	–12.64	–1.82	–10.98
		2		–1.87	–0.52	–3.70	–2.37	–14.29
Denmark	–1.29**	27	12.85	–34.94	–2.94	–57.67	–1.56	–17.46
		22		–28.47	–2.49	–48.83	–1.30	–14.52
		17		–22.00	–1.99	–39.16	–1.12	–12.54
		12		–15.53	–1.46	–28.64	–1.03	–11.51
		7		–9.06	–0.88	–17.30	–1.02	–11.44
		2		–2.59	–0.26	–5.11	–1.10	–12.32
Rest	–0.777**	27	85.41	–20.98	–21.19	–37.56	0.15	0.25
		22		–17.09	–17.64	–31.27	–0.55	–0.93
		17		–13.21	–13.92	–24.67	–1.59	–2.68
		12		–9.32	–10.03	–17.78	–2.98	–5.01
		7		–5.44	–5.97	–10.58	–4.70	–7.90
		2		–1.55	–1.74	–3.08	–6.77	–11.38

Table 5 (cont.). Impact of non-use of herbicides on export markets of lettuce

	Demand elasticity	Δ Export price (%)	Exports 2010 (×1000 t)	Δ Exports (%)	Δ Consumer Surplus		Δ Producer Surplus	
					(million €)	(%)	(million €)	(%)
Total		27			–133.75	–35.09[1]	8.04	1.95[1]
		22			–111.36	–29.22[1]	1.44	0.18[1]
		17			–87.89	–23.07[1]	–7.16	–2.15[1]
		12			–63.34	–16.63[1]	–17.78	–5.03[1]
		7			–37.71	–9.90[1]	–30.43	–8.47[1]
		2			–11.03	–2.89[1]	–45.27	–12.46[1]

** $p < 0.01$; * $p < 0.05$. [1] Weighted average.

Discussion

More likely decreases in farm yields and gross margins stand out among the short term impacts identified in the study. This could lead also to an increase of the probability of obtaining negative economic results. The immediate consequence of this impact would be a reduction in planting area and crop production, causing a reduction in supply of lettuce and celery.

These results would affect not only farms. Given the importance of horticultural crops in foreign trade and in related upstream and downstream industries, labour markets in the Spanish production regions would also be negatively affected.

The impact on the producer sector would be offset, due to benefits from exports to the main importing countries and losses to the smaller importing countries. This would result in a major redistribution of income among producers. From an economic perspective, the major losers of the non-use of herbicides are the consumers of EU countries, with overall losses reaching up to nearly 40% of consumers' welfare in the case of celery. In the long term, if the herbicide ban is not applied in third countries, it can stimulate production in other areas thus reducing the impact on consumers. In this case, the biggest losers would be the Spanish and other European producers who would see their market share reduced.

In conclusion, currently the use of herbicides is essential to maintain the production and profitability of farms, especially in minor crops, such as celery. Due to the fact that only extreme scenarios have been considered, these results are just indicative of the potential impact of the ban of *Pendimethalin*. The global impact of the ban of *Pendimethalin* would depend on the potential use of the alternative registered active substances or other non-chemical weed mitigation strategies, and in the long term, on resistance buildup due to the narrower choice of herbicides.

Other alternative treatments to chemical substances include IPM systems which have specific regulation for both crops in the production area, ecological production systems, or cultural practices such as mulching, mechanical weeding, hand weeding, rotations or localized applications. Although hardly used presently, these methods have a significant interest, but need further development and adjustment.

Resistance buildup in the medium to long term could seriously hinder the control of weeds. It is therefore necessary to have a minimum number of active substances with different modes of action to prevent resistance buildup and to develop possible risk mitigation strategies. Unless economically viable solutions are developed and reach the market place, reducing the number of permitted active substances could threaten farms' viability.

Even though understanding the economic impact is crucial to assessing the impact of the ban, ours is a very limited approach and does not reflect other costs to society, such as environmental and health impacts and the development of resistance. These are also welfare-increasing, a fact we acknowledge but do not get into in this paper. Further research should be carried out to check if improved health and environmental effects, which are the aims of the regulation, are enough to offset the economic impacts.

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Table 6. Impact of non-use of herbicides on export markets of celery

	Demand elasticity	Δ Export price (%)	Exports 2010 (×1000 t)	Δ Exports (%)	Δ Consumer Surplus		Δ Producer Surplus	
					(million €)	(%)	(million €)	(%)
UK	–0.43**	30	33.17	–12.90	–7.44	–24.14	2.63	13.23
		25		–10.75	–6.27	–20.34	2.00	10.07
		20		–8.60	–5.07	–16.46	1.32	6.63
		15		–6.45	–3.85	–12.48	0.58	2.90
		10		–4.30	–2.59	–8.42	–0.22	–1.12
		5		–2.15	–1.31	–4.25	–1.08	–5.43
Netherlands	–0.74**	30	11.38	–22.20	–1.85	–39.47	0.05	1.14
		25		–18.50	–1.58	–33.57	–0.005	–0.11
		20		–14.80	–1.29	–27.41	–0.089	–1.91
		15		–11.10	–0.98	–20.97	–0.199	–4.26
		10		–7.40	–0.67	–14.26	–0.334	–7.16
		5		–3.70	–0.34	–7.26	–0.496	–10.61
Germany	–0.91**	30	6.88	–27.30	–1.18	–47.14	–0.17	–5.49
		25		–22.75	–1.01	–40.33	–0.16	–5.11
		20		–18.20	–0.83	–33.09	–0.17	–5.38
		15		–13.65	–0.64	–25.44	–0.20	–6.30
		10		–9.10	–0.43	–17.37	–0.25	–7.87
		5		–4.55	–0.22	–8.89	–0.32	–10.09
France	–1.02**	30	4.49	–30.60	–0.76	–51.83	–0.21	–9.78
		25		–25.50	–0.66	–44.50	–0.18	–8.46
		20		–20.40	–0.54	–36.64	–0.17	–7.86
		15		–15.30	–0.42	–28.26	–0.17	–8.00
		10		–10.20	–0.29	–19.36	–0.19	–8.85
		5		–5.10	–0.15	–9.93	–0.22	–10.44
Rest	–1.42**	30	11.84	–42.60	–1.82	–67.05	–1.35	–25.38
		25		–35.50	–1.58	–58.40	–1.11	–20.81
		20		–28.40	–1.32	–48.73	–0.92	–17.26
		15		–21.30	–1.03	–38.06	–0.79	–14.74
		10		–14.20	–0.72	–26.38	–0.71	–13.24
		5		–7.10	–0.37	–13.69	–0.68	–12.77
Total		30			–13.05	–38.38[1]	0.95	1.03[1]
		25			–11.10	–32.84[1]	0.55	0.20[1]
		20			–9.05	–26.96[1]	–0.03	–1.16[1]
		15			–6.92	–20.74[1]	–0.78	–3.04[1]
		10			–4.70	–14.17[1]	–1.70	–5.45[1]
		5			–2.39	–7.25[1]	–2.79	–8.39[1]

** $p < 0.01$; * $p < 0.05$. [1] Weighted average.

References

Blake J, Wynn S, Maumene C, Jørgensen LN, 2011. Evaluation of the benefits provided by the azole class of compounds in wheat, and the effect of losing all azoles on wheat and potato production in Denmark, France and the UK. Report 1-Impact of the loss of all azoles. Available in http://www.ecpa.eu/files/attachments/Microsoft%20Word%20-%20ADAS-ECPA%20report%201%20-%20Azoles%20-%2030%20Sep%2011.pdf [October 2013].

Carter CA, Chalfant JA, Goodhue RE, Han FM, DeSantis M, 2005. The methyl bromide ban: economic impacts on the California strawberry industry. Rev Agr Econ 27(2): 181-197.

Deepak MS, Spreen TH, VanSickle JJ, 1996. An analysis of the impact of a ban of methyl bromide on the US winter fresh vegetable market. J Agr Appl Econ 28 (2): 433-443.

European Parliament, 2008. The consequences of the "cut off" criteria for pesticides: agronomic and financial aspects. IP/B/AGRI/IC/2008_166. Brussels.

Ferguson WL, Moffit LJ, Davis RM, 1992. Short-run welfare implications of restricting fungicide use in vegetable production. J Agribusiness 10(10): 41-50.

Hillocks RJ, 2012. Farming with fewer pesticides: EU pesticide review and resulting challenges for UK agriculture. Crop Prot 31: 85-93.

Knutson RD, 1999. Economic impacts of reduced pesticide use in the United States: measurement of costs and benefits. AFPC Policy Issues Paper 99-2. Agr Food Policy Cent, Dept Agr Econ. Texas A&M Univ, TX, USA.

Lichtenberg E, Parker DD, Zilberman D, 1988. Marginal analysis of welfare costs of environmental policies: the case of pesticide regulation. Am J Agr Econ 70: 867-874.

Lynch L, Malcolm S, Zilberman D, 2005. Effect of a differentially applied environmental regulation on agricultural trade patterns and production location: the case of methyl bromide. Agr Resour Econ Rev 34(1): 54-74.

Montserrat A, 2011. Manejo de la flora en cultivos hortícolas. Agrícola Vergel 345: 89-100.

Oerke EC, 2006. Crop losses to pests. J Agr Sci 144: 31-43.

OJ, 2009. Regulation (EC) No 1107/2009 of the European Parliament and the Council of October 21. Official Journal of the European Union L309 24/11/2009. p: 1.

Sexton SE, Lei Z, Zilberman D, 2007. The economics of pesticides and pest control. Int Rev Environ Resour Econ 1: 271-326.

Wang S, Arnold WA, 2003. Abiotic reduction of dinitroaniline herbicides. Water Res 37: 4191-4201.

Wynn S, 2010. Impact on changing pesticide availability on horticulture. DEFRA. Available in http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17126&FromSearch=Y&Publisher=1&SearchText=if01100&SortString=ProjectCode&SortOrder=As. [December 2011].

Zellner A, 1962. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. J Am Stat Assoc 57: 348-368.

Zilberman D, Schmitz A, Casterline G, Lichtenberg E, Siebert B, 1991. The economics of pesticide use and regulation. Science 253: 518-522.