Policy Impact Analysis on Investments and Disinvestments under Competition: A Real Options Approach

Jan-Henning Feil and Oliver Musshoff

Georg-August-Universität Göttingen, Faculty of Agricultural Sciences, Department of Agricultural Economics and Rural Development, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany
(corresponding author; phone: +49(0)551 39-4856; fax: +49(0)551 39-22030;
e-mail address: jan-henning.feil@agr.uni-goettingen.de)

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Abstract

In consequence of changes in general conditions, a higher level of investments and disinvestments in agriculture can be expected. To date, however, there are no policy impact analyses on both investments and disinvestments in competitive agricultural markets in a dynamic-stochastic context. This paper aims to develop a conceptual real options market model, which allows the impact assessment of different political schemes on investment and disinvestment thresholds and the sectoral welfare. Exemplarily, the effects of price floors, investment subsidies and production ceilings are analysed. The results show that the consideration of limited reversibility, that is disinvestments, is of relevance as it can impact the assessment of specific policies.

Keywords

real options, competition, policy impact analysis, genetic algoritms

1. Introduction

The agricultural sector is globally exposed to strong changes in its economic environment. Examples for this are the abolishment of the milk and sugar beet quotas in the EU, the shift from price support systems to different forms of direct subsidies in many developed countries as well as the implementation of guaranteed feed-in prices for renewable energies as it is the case in the German Renewable Energy Sources Act (EEG). In addition, and, at least partially, as a consequence of these aformentioned changes, there have been extreme price fluctuations in the respective agricultural markets, like e.g. in the dairy sector between 2007 and 2009. For this reason, farmers and lobbyists have recently called on their governmental organisations to provide additional market regulation (cf. e.g. European Milk Board, 2009; National Milk Producers Federation, 2009).

In consequence of both the changes in general economic conditions and the increasing price volatility, adjustments in the agricultural sector can be expected, which usually go hand in hand with investment and disinvestment decisions. In the recent literature, there is a range of studies analysing investments in agriculture under simultaneous consideration of political schemes and uncertainty. But although prices in these models are stochastic, price expectations of the firms are mostly assumed to be static. That is why the inter-temporal impact of price risk is not taken into account (cf. e.g. Oude Lansink and Peerlings, 1996; Sckokai and Moro, 2006; Sckokai and Moro, 2009; Serra et al., 2009). Hence, the policy impact analysis on agricultural investments in a dynamic-stochastic context requires more emphasis.

During the past one and a half decades, agricultural economists started to realise that the Real Options Approach (ROA) is more advantageous for analysing investments in agriculture than traditional investment models based on the net present value (NPV) rule. The reason is that investments in agriculture are afflicted by sunk costs, uncertainty of the future cash flows and temporal flexibility in making the investment. The ROA takes into account explicitly these characteristics by analysing investment and disinvestment decisions under dynamic-stochastic conditions and extending the NPV by the value of entrepreneurial flexibility. There have already been many empirical applications of the ROA to agricultural investment decisions (cf. e.g. Carey and Zilberman, 2002; Hill, 2010; Odening et al., 2005; Pietola and Wang, 2000; Purvis et al., 1995; Richards and Patterson, 1998). The majority of these models assume perfect irreversibility of the investments, i.e. disinvestments are not considered. There are only a few studies that deal explicitly with limited reversibility, like it is the case for most investment projects in agriculture (cf. e.g. Isik et al., 2003; Luong and Tauer, 2006).

All of the aforementioned real options applications explicitly or implicitly exploit the finding of Leahy (1993), who state that an investor in a competitive market can act totally myopic and ignore other firms' investment and disinvestment decisions. The underlying reason for assuming myopic planning is that it enables an analytical determination of the optimal investment and disinvestment strategies of the firms. However, it is only applicable if very restrictive and, at least partially, unrealistic conditions are fulfilled. For example, it implicitly excludes any political schemes which affect the price dynamics directly or indirectly. Dixit and Pindyck (1994: ch. 9) relax this constraint by calculating numerically the effects of politically induced price controls on the investment and disinvestment thresholds of the firms by means of stochastic simulation. However, their model addresses just one out of many other relevant policies and is merely limited to one standard stochastic demand process. The same restrictions apply to the model of Price et al. (2005). To the authors' knowledge there has not been any real options model which can be applied sufficiently flexible and, at the same time, allows for a detailed policy impact analysis under consideration of competition.

Against the background of these methodological challenges, the contribution of this paper is twofold. First, it develops a real options market model, which provides the conceptual basis for policy makers to assess the impact of different political schemes on farm investments and disinvestments and the sectoral welfare. Second, it analyses the relevance of limited reversibility for policy impact assessments in competitive agricultural markets underlying real options effects. The model is linked with a combination of Genetic Algorithms (GA), which are a heuristic optimisation technique, and stochastic simulation. Through this, the preconditions of Leahy's theorem can be relaxed and different policies can be handled. This comprises explicitly such policies which according to Leahy cannot be analysed analytically. For demonstration, a comparative analysis of the effects of price floors maintained by governmental purchases of excess supply, subsidies on investments and production ceilings is carried out. These measures cover relevant policies, like e.g. guaranteed feed-in prices for renewable energies or the extension of production ceilings through the abolishment of quota systems, in a simplified way.

The paper has the following structure: Section 2 first explains the fundamentals of the ROA. Afterwards, the real options market model is described (section 3). Section 4 discusses the model's results for the implementation as well as for the abandonment of political schemes by using the example of price floors. Moreover, the effects of price floors, investment subsidies and production ceilings are compared at different irreversibility levels. The paper ends with conclusions concerning the usefulness of political interventions in competitive markets and the relevance of the consideration of limited reversibility for policy impact analyses (section 5).

2. Theoretical Background

Real options models exploit the analogy between a financial option and an investment or disinvestment project (cf. e.g. Abel and Eberly, 1994; Dixit and Pindyck, 1994; McDonald and Siegel, 1986). With an opportunity to invest (disinvest), a firm is holding an "option" analogues to a financial call (put) option; it has the right but not the obligation to buy (sell) an asset at any time in the future. If the firm invests, it exercises the option by giving up the opportunity of waiting for new information to arrive with a potential positive effect on the profitability of the investment. This lost continuation value of the option is an opportunity cost that should be included as part of the investment costs. Furthermore, it is highly sensitive to the uncertainty of the future cash flows. In conclusion, an irreversible investment under uncertainty should only be made, if the present value of its expected returns exceeds the investment costs by an amount equal to the value of waiting for additional information. In comparison to the NPV rule, this means that the critical price at which the firm should invest, in the following referred to as investment trigger price, is shifted upwards because the cash flows do not only have to compensate the investment costs but also the lost value from deferring the investment. By using analogous considerations, it could be rational to tolerate losses to a certain extent after making the investment, before an (irreversible) disinvestment should occur. That is, the disinvestment trigger price is shifted downwards.

The direct transferability of the financial option pricing theory to real investment problems, however, is problematic. Financial options constitute exclusive rights for their owners, whereas real investment opportunities are also open to other market participants in competitive markets. Thus, exceeding (falling below) the (dis)investment trigger price will also cause similar reactions of competitors, which, taken as a whole, will change sectoral supply and, with this, equilibrium prices. In consequence, the price process cannot be considered any longer as exogenous. As the price process determines again the value of the investment and the investment and disinvestment trigger prices, the direct determination of these values is considerably complicated. Leahy (1993), however, demonstrates that under perfect competition, an investor who decides myopically and ignores potential market entries of competitors finds the same trigger prices as a competitive investor.

According to Leahy's model, a perfectly competitive industry is considered, which consists of small homogeneous price-taking firms, producing with the same constant-returns-to-scale technology. The production output of all firms at time t, which equals the market supply X_t, is subject to depreciation as well as investments and disinvestments of the firms. The product price P_t results from the reactions of all firms on the exogenous stochastic demand μ_t. The relationship between the product price on the one hand and the demand and market supply on the other hand is defined by a time-invariant inverse demand function D, that in the following is assumed to be isoelastic (cf. Dixit, 1991):

$$P_t = D(X_t, \mu_t) = \left(\frac{\mu_t}{X_t}\right)^{\Pi} \text{ with } \Pi = -\frac{1}{\eta} \tag{1}$$

η denotes the price elasticity of demand. The demand shock is described by a geometric Brownian Motion (GBM):

$$\mathrm{d}\mu_t = \alpha \cdot \mu_t \cdot \mathrm{d}t + \sigma \cdot \mu_t \cdot \mathrm{d}z \tag{2}$$

α denotes the drift rate and σ the volatility, whereby both parameters are constant. dz stands for the increment of a Wiener process.

As all firms behave in the same way, the price process will be truncated upwards (downwards) as soon as the product price climbs up (falls down) to a specific (dis)investment trigger price level. The investment trigger price hence constitutes an upper reflecting barrier and the disinvestment trigger price a lower reflecting barrier on the price process (Dixit and Pindyck, 1994: ch. 8). A myopic investor, however, ignores this effect and assumes an unregulated exogenous stochastic price process for his investment and disinvestment decisions. Figure 1 illustrates the respective difference between the regulated endogenous price process and the unregulated exogenous price process for the case of a GBM. Although both simulations utilise identical parameters, the sample paths look completely different.

According to Leahy both, the competitive investor and the myopic planner, find identical optimal trigger prices representing the competitive equilibrium. The reason is that the myopic planner commits two errors which completely offset each other (cf. Leahy, 1993): First, he ignores the truncation of the price process and, therefore, overestimates the investment's profitability respectively the risk of incurring losses. Second, he wrongly assumes to have an exclusive option to postpone the make the investment respectively to abandon it. In this respect the value of waiting makes it less attractive to invest or disinvest immediately. In other words, the myopic planner is right for the wrong reasons. The implication of Leahy's result is that the burdensome determination of an endogenous equilibrium price process can be avoided, when dealing with competitive markets. The complicated optimisation problem of a competitive investor can be replaced by the simpler problem of a myopic planner without a loss of precision.

Nevertheless, the restrictive and unrealistic preconditions of using the optimality principle of myopic planning complicate considerably its applicability to competitive markets. Accordingly, next to the aforementioned assumption of perfect competition and constant returns to scale, additional conditions are infinitely divisible investment projects and continuity of demand. Apart from that, the analytical McDonald-Siegel pricing formula can be applied for an analytical solution only if the investment is perfectly irreversible, that is, no disinvestments are considered (cf. McDonald and Siegel, 1986). Furthermore, the uncertain variable has to strictly follow a GBM. This is not the case e.g. in the presence of politically induced price floors. If these conditions are not met, a direct determination of the equilibrium in competitive markets would be necessary, which is commonly assessed in the literature as not practicable (cf. e.g. Leahy, 1993).

In the next section, a real options market model will be developed allowing the direct determination of exactly this equilibrium in competitive markets. Therefore, it does not rely on the preconditions of applying the optimality principle of myopic planning and can be used more flexible than other models, e.g. by allowing for different political schemes.

Note: GBM with $\alpha = 0\%$ and $\sigma = 20\%$, $\eta = -1$

Figure 1. Price dynamics with and without competition

3. The real options market model

For the purpose of studying policy interventions in a market for which the competing firms have to consider the ROA, a numerical model is developed in subsection 3.1. (cf. Balmann and Musshoff, 2002). This model identifies equilibrium strategies of the competing firms by combining stochastic simulations with the heuristic optimization technique GA, which is illustrated in subsection 3.2. Finally, subsection 3.3. shows how the welfare effects of political schemes are quantified.

3.1. Description of the model

Consider a number of N homogenous and risk-neutral competing firms, each having repeatedly the opportunity to undertake an investment up to an exogenously given maximum production capacity X_{cap} either now or at a later point within the period under consideration T. The asset of investment is divisible and, thus, a step-by-step investment is possible as well. Size, investment outlay and production are proportional, i.e., there are no economies of scale. Furthermore, disinvestments are possible as well, that is, the investment is assumed to be partially reversible according to real investments in agriculture. Consequently, the production capacity of a firm n in t, resulting in a production output X_t^n, can be adjusted in two ways: Either via investments once in a period, resulting in an additional production output $Y_{t+\Delta t}^n$ in the following period, or via disinvestments once in a period, resulting in a reduction in production output $Z_{t+\Delta t}^n$ in the following period. In every period the production output declines corresponding to a geometric depreciation rate λ. Then production follows:

$$X_{t+\Delta t}^{n} = X_{t}^{n} \cdot (1-\lambda) + Y_{t+\Delta t}^{n} - Z_{t+\Delta t}^{n} \quad (3)$$

The stochastic demand process μ_t and the price elasticity η are assumed to be known. Prices result from the reactions of *all* market participants on the exogenous stochastic demand process and, hence, need to be determined endogenously within the model. Without loss of generality, the relationship between market supply X_t and price P_t is defined by an isoelastic demand function according to eq. (1). For modeling the demand parameter μ_t any stochastic process can be applied flexibly as needed. However, for this investigation μ_t is assumed to follow a GBM, according to the vast majority of real options applications. Since the GBM according to eq. (2) assumes infinitesimal time step lengths and hence is impractical for simulation purposes, it is transformed into a time-discrete version. This can be done by the use of Ito's Lemma (cf. Hull and White, 1987):

$$\mu_{t+\Delta t} = \mu_t \cdot e^{\left[\left(\alpha - \frac{\sigma^2}{2}\right) \cdot \Delta t + \sigma \cdot \varepsilon_t \cdot \sqrt{\Delta t}\right]} \quad (4)$$

with a standard normally distributed random number ε_t and a time step length Δt. Eq. (4) represents an exact approximation of the time-continuous GBM for any Δt.

Within the model, perfect competition is assumed. Accordingly, the firms are assumed to have rational expectations and complete information regarding the development of demand and the (dis)investment behavior of all competitors. Because of this, it should be expected that in equilibrium all firms have the same investment and disinvestment trigger prices. However, in order to derive this Nash equilibrium by means of the GA approach described in the next subsection, the competing firms need to interact, which they do by defining their at first different investment and disinvestment trigger prices. This interaction of the firms equals a second price sealed bid auction in which each firm can sell its product if it asks less or equal the market price. Furthermore, it is assumed that in a production period all firms first disinvest and then invest, depending on their disinvestment or investment trigger price and the expected market price. Because of this chronological order, the cumulated disinvestments in a period impact the investment decisions of the same period, but not the other way round.

To derive the disinvestment of the firms in the first instance, it is assumed that firms with a higher disinvestment trigger price have a stronger tendency to abandon the investment. Accordingly, all firms can be sorted according to their disinvestment trigger prices, starting with the highest, i.e., $\underline{P}^{m} \geq \underline{P}^{m+1}$. Consequently, firm $m+1$ does not disinvest if firm m is has not already abandoned completely the investment. Likewise, it is obvious that if firm n abandons completely the investment, firm $m-1$ abandons completely the investment, too. Furthermore, in every period t, a marginal (or last) firm exists which disinvests to the extent that its disinvestment trigger price equals the expected product price of the next period. For the size of disinvestment of a firm $\widetilde{m}$ in t, corresponding to its additional production output in $t+\Delta t$, follows:

$$Z_{t+\Delta t}^{\widetilde{m}}\left(\underline{P}^{\widetilde{m}}\right) = \max\left[0, \min\left(\begin{array}{c} X_t^{\widetilde{m}} \cdot (1-\lambda), \\ \left(\sum_{m=1}^{\mathrm{N}} X_t^{m} \cdot (1-\lambda) + \sum_{m=1}^{\widetilde{m}-1} Z_{t+\Delta t}^{m}\left(\underline{P}^{m}\right)\right) - \frac{\hat{\mathrm{E}}(\mu_{t+\Delta t})}{(\underline{P}^{\widetilde{m}})^{-\eta}} \end{array}\right)\right] \quad (5)$$

Eq. (5) implies the following:

1. The "max-query" ensures non-negativity of disinvestments. ($\rightarrow Z_{t+\Delta t}^{\tilde{m}} \leq 0$).
2. The "min-query" ensures that a firm $\tilde{m}$ cannot abandon more production capacity via disinvestments than it has built up in former periods.
3. The "min-query" also ensures that the total quantity of supply is just reduced so far as the disinvestment trigger price of the "last" firm equals the expected product price of the next period.

The investments of a firm are derived analogously, that is, firms with lower investment trigger prices have a stronger tendency to invest. All firms can be sorted according to their investment trigger prices, starting with the lowest, i.e., $\bar{P}^n \leq \bar{P}^{n+1}$. Thus, firm $n+1$ does not invest if firm n is not already completely invested. In every period t, a marginal (or last) firm exists which invests to the extent that its investment trigger price equals the expected product price of the next period. For the size of investment of a firm $\tilde{n}$ in t, corresponding to its additional production output in $t+\Delta t$, follows:

$$Y_{t+\Delta t}^{\tilde{n}}\left(\bar{P}^{\tilde{n}}\right) = \max\left[0, \min\left(\begin{array}{c} X_{cap} - X_t^{\tilde{n}} \cdot (1-\lambda), \\ \dfrac{\hat{\mathrm{E}}(\mu_{t+\Delta t})}{(\bar{P}^{\tilde{n}})^{-\eta}} - \left(\sum_{n=1}^{\mathrm{N}} X_t^n \cdot (1-\lambda) + \sum_{n=1}^{\tilde{n}-1} Y_{t+\Delta t}^n(\bar{P}^n) + \sum_{m=1}^{N} Z_{t+\Delta t}^m\left(\underline{P}^m\right)\right)\end{array}\right)\right] \quad (6)$$

Eq. (6) can be explained as follows:

1. The "max-query" ensures non-negativity of investments. ($\rightarrow Y_{t+\Delta t}^{\tilde{n}} \geq 0$).
2. The "min-query" ensures that a firm $\tilde{n}$ cannot build up more production capacity via investments than it needs to produce its maximum production capacity X_{cap}.
3. The "min-query" also ensures that the total quantity of supply is just expanded so far as the investment trigger price of the "last" invested firm equals the expected product price of the next period.

The goal of the model is to identify the optimal investment and disinvestment trigger prices of the firms, of which each can be expected to be (nearly) identical in equilibrium according to the above assumptions. For this, an objective function needs to be established that determines the (dis)investment behavior of the agents in the model. Each firm's investment and disinvestment decisions aim to maximize the expected NPV of the future cash flows F_0^n, in the real options terminology also called option value, by choosing both its firm specific investment trigger price $\bar{P}^n$ and its firm specific disinvestment trigger price $\underline{P}^n$:

$$\max_{\bar{P}^n, \underline{P}^n}\left\{F_0^n\left(\bar{P}^n, \underline{P}^n\right)\right\} = \max_{\bar{P}^n, \underline{P}^n}\left\{\sum_{t=0}^{T}\left((P_t - k) \cdot X_t^n\left(\bar{P}^n, \underline{P}^n\right) - i \cdot k \cdot \sum_{u=0}^{t} Z_u^n\left(\underline{P}^n\right)\right) \cdot e^{-r \cdot t}\right\} \quad (7)$$

The irreversibility rate i determines what proportion of the investment costs is sunk. k denotes the total costs of investment per output unit and period, which are composed of the capital cost of the initial investment outlay I and all other relevant costs c (e.g. material costs, labor costs):

$$k = I \cdot \{e^{r \cdot t} - (1-\lambda)\} + c \quad (8)$$

In the following, the three political schemes are implemented into the model. In the case of a price floor P_{min} maintained by governmental purchases of excess supply, the determination of the producer's price has to be modified. Considering the product price P_t according to eq. (1), the following applies to the effective producer's price P'_t:

$$P'_t = \max\{P_{min}, P_t\} = \max\left\{P_{min}, \left(\frac{\mu_t}{X_t}\right)^{\Pi}\right\} \tag{9}$$

Consequently, P_t in eq. (7) is replaced by P'_t. As a reference point, P_{min} will be exogenously fixed as a proportion of the total costs of investment k. Following Dixit and Pindyck (1994) on the effects of price controls, it is assumed that governmental purchases are excluded from the market with no future impact on demand and supply.

An investment subsidy s will be paid by the state to any firm undertaking investments in the respective industry. Accordingly, it reduces the initial investment outlay I by a fixed proportion. Thus, k in eq. (7) is replaced by the effective producer's total costs of investment k':

$$k' = I \cdot (1 - s) \cdot \{e^{r \cdot \Delta t} - (1 - \lambda)\} + c \tag{10}$$

Finally, for the implementation of a politically induced production ceiling X_{max}, the formula for the investment size of a firm $\tilde{n}$ according to eq. (6) needs to be supplemented by a further "min-query":

$$Y_{t+\Delta t}^{\tilde{n}}\left(\bar{P}^{\tilde{n}}\right) = \max\left[0, \min\left(\begin{array}{c} X_{cap} - X_t^{\tilde{n}} \cdot (1 - \lambda)\,, \\ X_{max} - \left(\sum_{n=1}^{N} X_t^n \cdot (1 - \lambda) + \sum_{n=1}^{\tilde{n}-1} Y_{t+\Delta t}^n(\bar{P}^n)\right) \\ \frac{\hat{E}(\mu_{t+\Delta t})}{(\bar{P}^{\tilde{n}})^{-\eta}} - \left(\sum_{n=1}^{N} X_t^n \cdot (1 - \lambda) + \sum_{n=1}^{\tilde{n}-1} Y_{t+\Delta t}^n(\bar{P}^n) + \sum_{m=1}^{N} Z_{t+\Delta t}^m\left(\underline{P}^m\right)\right) \end{array}\right)\right] \tag{11}$$

As explained in section 2, the analytical deviation of the trigger prices within the model described above is not possible because political schemes are considered and the use of any stochastic demand processes (except a GBM) shall be feasible. To identify the individual optimal trigger prices and respectively the equilibrium trigger price for both investments and disinvestments despite of these new features, the stochastic model is repeatedly simulated and linked to a GA. This combined solution procedure is described in the following subsection.

3.2. Solving the model by means of genetic algorithms and stochastic simulation

GA are heuristic search methods for the optimisation or identification of equilibria in strategic settings, which have been used in many disciplines during the last two decades including agriculture in particular (cf. e.g. Cacho and Simmons, 1999; Graubner et al., 2011; Mayer et al., 1996). GA apply the evolutionary concepts of natural selection, crossover and mutation on a population of behavioural strategies (cf. e.g. Goldberg, 1998). In this analysis the GA is used to analyse the effects of specific policies on long-term equilibrium investment strategies of the firms, that is, the equilibrium investment trigger price (cf. e.g. Arifovic, 1994; Dawid, 1999).

Even though GA vary from each other in some detail, at least three attributes are considered as standard: a population of genomes, a fitness function, and GA operators. A population of genomes generally describes a collection of candidate solutions to a given problem. In this case, each genome of a population represents a pair of trigger prices, that is, the investment and the disinvestment trigger price of a firm n. The population size chosen here is $N = 50$, which at the same time corresponds with the number of firms. The fitness function generally serves as the evaluation criterion for the quality of a solution. Here, the fitness function is represented by the objective function of the model, that is, the option value of a firm n subject to its investment and disinvestment trigger price according to eq. (7). Finally, the GA operators are applied to the population of genomes. Usually, and also in this case, the GA operators consist of selection, mutation and crossover. Through this procedure, good solutions are identified and new, probably superior solutions are incorporated. The result is a new generation of the population of genomes on which the GA operators are repeatedly applied until no better solution can be found, that is, until the optimal trigger price prices respectively the equilibrium trigger prices are determined.

In the following, the steps of the GA are explained in detail and it is shown, how the GA is combined with stochastic simulation. Programming of the GA can directly be done in MS EXCEL.

Step 1: Initialization

The first generation of genomes is initialised by drawing random values each for the investment and the disinvestment trigger prices out of a pragmatically defined range, which results in $N = 50$ heterogeneous trigger price pairs of the firms. This heterogeneity of genomes is a requirement for an efficient optimisation procedure of the GA (Mitchell, 1996). In the model, it is technically ensured that $\underline{P}^n \leq \bar{P}^n$ for all n.

Step 2: Stochastic simulation of the option values of the firms

The stochastic demand parameter μ_t according to eq. (4) is simulated over the period under consideration of $T = 100$ years in $S = 50{,}000$ simulation runs. For each simulation run, the demand parameter μ_t is used to calculate in any period the disinvestments and investments subject to the firms' trigger prices according to eq. (5) and (6) and the already given production capacity. Following the model assumptions in the previous section, the disinvestments are determined in the first instance. For this, the firms are sorted according to the disinvestment trigger price level starting with the highest. The firm with the highest disinvestment trigger price abandons as much production as it has built up via investments in former periods, followed by the firm with the second highest disinvestment trigger price, etc., until a last firm disinvests whose trigger price is equal to the expected price of the next period. The model ensures that there always is one firm out of the $N = 50$ firms which disinvests last. By using analogous considerations, the investments are subsequently determined by sorting the firms according to the investment trigger price level starting with the lowest. The firm with the lowest investment trigger price invests to the extent of its maximum output capacity, followed by the firm with the second lowest trigger price, etc. Both the investment and the disinvestment size of a firm n yields the total production output corresponding to eq. (3) and subsequently the product price following the demand function defined by eq. (1). Finally, the option value per firm according to eq. (7) is calculated for the respective simulation run. The determination of the option value per firm is carried out as arithmetic mean of the option values of the repeated simulation runs with a given population of trigger price pairs and random demand parameters.

Step 3: Determination of the fitness of the investment strategies

The option values determined in step 2 give information about the “quality” of the respective genomes to solve the problem at hand: The higher the option value of a trigger price pair, the higher the fitness of the genome. Thus, the trigger price pairs are sorted according to their respective option values starting with the highest.

Step 4: Application of the GA operators

On the basis of the genomes of the current generation and their fitness, now the operators of the GA are applied to define the population of genomes of the next generation. It should be noted that the following specification only represents one of many possibilities. However, if selected and applied properly, the expected outcome is identical; only differences in the computational efficiency may occur.

Step 4.1: Selection and Replication

Selection identifies the genomes (i.e. the set of trigger price pairs) to be reproduced in the next generation. The common feature is selection proportional to the fitness value of the genome. The higher the fitness of a genome, the more likely it is to be selected for replication. Here the five most successful strategies are quadruplicated, the next five are triplicated, the next five are doubled, and the next five survive but are not multiplied. Hence, the other 30 genomes of the current generation are not selcted for the next generation, i.e. deleted.

By duplicating the fittest strategies, it is ensured, that the population converges toward the equilibrium trigger price throughout the optimisation process. By this, however, the variability of the population decreases. Moreover, the initial population consists of random values for the trigger price pairs whereby it is unlikely that a good or even close to optimal solution is contained. In order to extend the search space during the process and to avoid the lock-in of the process in a suboptimal state, new strategies are to be generated. This happens in the next two steps *Crossover* and *Mutation*.

Step 4.2: Crossover

Crossover recombines the information of two parent genomes to create one or two offspring with a given probability, the crossover rate. In this case, for every investment trigger price from *Selection and Replication* starting with the ninth fittest, the arithmetic mean from itself and its foregoing neighbour is calculated to produce an offspring with a crossover rate of 5 %. The related disinvestment trigger price is adjusted analogously. By leaving the first eight trigger price pairs unchanged, it is ensured that potential optimal solutions of the current population do not get lost and that the GA arrives at a stable result.

Step 4.3: Mutation

Mutation is a random manipulation of a solution with a given probability, the mutation rate, and thus also creates new genetic varieties. Furthermore, it serves as a reminder or insurance operator against an early fixation on an inferior solution as it allows to recover lost genetic material from previous generations. Here, every (dis)investment trigger price from *Crossover* starting with the ninth fittest is modified with a mutation rate of 20 %. In specific, the (dis)investment trigger price is either increased or decreased by a factor which is determined by drawing a random number out of the range of 0.1 % and 2 %.

Step 5: Next Generation

Step 4 results in a new population of trigger price pairs, on which the steps 2 and 3 are applied again. This process is repeated until the population of trigger price pairs converges toward an equilibrium and both the equilibrium investment and disinvestment trigger price of the firms are hence determined. Accordingly, the GA can be stopped when the obtained strategies are both homogenous, i.e. very similar to each other within one generation, and stable, i.e. very similar from one generation to the next. In this case, both stop criterions are achieved if the arithmetic mean of the (dis)investment trigger prices of the ten fittest firms has not changed up to the second decimal place for at least 100 generations.

It should be noted that, due to the nature of the GA, there still exists a low risk of a suboptimal solution. To solve this issue, the GA is run for a specific scenario more than ones. Only if the resulting equilibrium investment and disinvestment trigger prices are very similar to each other over several GA runs, i.e. merely differ from the second decimal place, the global optimum is found.

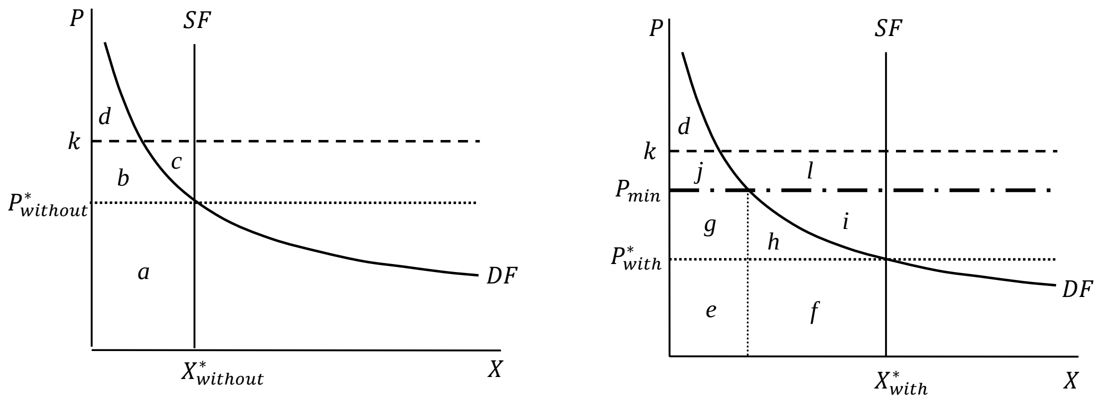
3.3. Determination of the economic efficiency of political schemes

To quantify the welfare effects of different political schemes, the concept of consumer and producer surplus is applied (cf. e.g. Just et al., 2004: ch. 8). Accordingly, figure 3 shows the welfare without (left half) and with (right half) political schemes using the example of price floors maintained by governmental purchases of excess supply. In the figure, a comparative-static view for a random production period is taken for the sake of illustration. As a consequence, the supply function is fully price-inelastic.

The welfare is composed of three components (cf. figure 3): The consumer surplus *CS*, the producer surplus *PS* and the state budget *BG*. The latter must be paid for by taxes, and hence it is ultimately a cost to consumers. Analytically, the consumer surplus corresponds with the integral below the demand function up to the quantity demanded, less the expenditures. As the demand function according to eq. (1) tends to infinity for $X \rightarrow 0$ and a negative elasticity of demand, the willingness to pay would also be infinite. To avoid this, the minimum quantity demanded is assumed to be 1. Thus, the results for the below efficiency measures can only be interpreted as ordinal numbers. The three welfare components for the basis scenario of the absence of political schemes, for price floors maintained by governmental purchases of excess supply, for investment subsidies and for production ceilings are determined according to table 1. The total welfare for the whole period under consideration is calculated as the present value of the welfare of all T production periods (cf. e.g. Just et al., 2004: ch. 14):

$$WF = \sum_{t=1}^{T} WF_t \cdot e^{-r \cdot t} = \sum_{t=1}^{T} (CS_t + PS_t + BG_t) \cdot e^{-r \cdot t} \tag{12}$$

Wefare without price floor	Welfare with price floor ($P_{min} > P^*$)



CS	=	willingness to pay - expenditures		*CS*	=	willingness to pay - expenditures
	=	*a+b+d* - *a*			=	*e+g+j+d* - (*e+g*)
PS	=	revenues - costs		*PS*	=	revenues - costs
	=	*a* - (*a+b+c*)			=	*e+f+h+g+i* - (*e+f+h+g+i+j+l*)
BG	=	0		*BG*	=	- (*f+h+i*)
WF	=	*CS* + *PR* + *BG*		*WF*	=	*CS* + *PR* + *BG*
	=	*b+d* + (-*b-c*) + 0			=	*j+d* + (-*j-l*) + (-*f-h-i*)
	=	*d-c*			=	*d-l-f-h-i*

CS	consumer surplus	*PS*	producer surplus	*BG*	state budget	*WF*	welfare
DF	demand function	*SF*	supply function				

Note: Comparative-static view for a random production period

Figure 2. Welfare with and without price floor

For the determination of the effects of policy interventions on the economic efficiency, the welfare with the respective political scheme WF_{with} is finally set in relationship to the welfare without political schemes $WF_{without}$, resulting in the economic efficiency measure R:

$$R = \frac{WF_{with}}{WF_{without}} \tag{13}$$

In order to correctly consider the volume dynamics when determining R, it is essential to use two different sets of genomes: The optimal trigger prices in case of the existence of a political scheme are taken for the calculation of WF_{with}, and the optimal trigger prices in case of the absence of a political scheme are taken for the calculation of $WF_{without}$. In the course of the stochastic simulation, R is calculated S times and, consequently, the expected economic efficiency results from the arithmetic mean of R over all simulation runs S.

Table 1. Calculation of consumer surplus, producer surplus and state budget

	Consumer surplus	Producer surplus	State budget
Basis scenario (no political scheme)	$CS_t = \int_1^{X_t} \frac{\mu_t}{X_t} dX_t - \mu_t$	$PS_t = X_t \cdot P_t - X_t \cdot k$	$BG_t = 0$
Price floor	See basis scenario, replace X_t by X_t': $X_t' = \begin{cases} X_t, & if\ P_t > P_{min} \\ \frac{\mu_t}{(P_{min})^{-\eta}}, & otherwise \end{cases}$	See basis scenario, replace P_t by P_t': $P_t' = \max\{P_{min}, P_t\}$	$BG_t = \max[0, (P_{min} - P_t) \cdot \left(X_t - \frac{\mu_t}{(P_{min})^{-\eta}}\right)]$
Investment subsidy	See basis scenario	See basis scenario, replace k by k': $k' = I \cdot (1-s) \cdot \{e^{r \cdot \Delta t} - (1-\lambda)\} + c$	$BG_t = \sum_{n=1}^{N} \Delta X_t^n \cdot I \cdot s$
Production ceiling	See basis scenario	See basis scenario	See basis scenario

4. Results

The model's results discussion is split into two parts: In subsection 4.1., the effects of political schemes on investment and disinvestment trigger prices and the sectoral welfare are analysed for the basis scenario of perfect irreversibility according to most real options applications in the literature. This is done by using the example of price floors maintained by governmental purchases of excess supply. Subsequently, the effects of price floors, investment subsidies and production ceilings are compared. This is carried out at different irreversibility levels to investigate the relevance of limited reversibility for policy impact assessments (subsection 4.2.).

4.1. Effects of price floors on trigger prices and economic efficiencies

In table 2, the effects of the implementation respectively the abolishment of price floors on investment and disinvestment trigger prices, consumer surpluses, producer surpluses, state budgets and economic efficiencies are quoted. For this, the price floors are fixed at $P_{min} = 0$ %, 80 % and 95 % of the total costs of investment k. These are standardised at $k = 1$ for all firms and, without loss of generality, are assumed to only consist of the capital costs of investment, that is, $c = 0$. For the presented scenario, the irreversibility rate is $i = 0$, that is, perfect irreversibility is assumed. Furthermore, a drift rate of $\alpha = 0$ %, a volatility of $\sigma = 20$ %, a depreciation rate of $\lambda = 0$ % and a price elasticity of $\eta =$ -1 are chosen. The risk-free interest rate is fixed at $r = 5.83$ % (which corresponds to a time-discrete interest rate of 6 % p.a.).

Table 2. Effects of price floors

Price floor (% of k)	Investment trigger price (€)	Disinvestment trigger price (€)	Consumer surplus (€)	Producer surplus (€)	State budget (€)	Economic efficiency (%)
0.0	1.5819	0.0000	276.49	-0.27	0.00	100.00
80.0	1.3202	0.0000	295.13	-0.02	-32.76	81.07
95.0	1.0841	0.0000	302.61	0.09	-76.16	65.35

Note: GBM with $\alpha = 0$ % and $\sigma = 20$ %, $\eta =$ -1, $\lambda = 0$ %, $r =$ 5.83 %, $N =$ 50, $X_{cap} =$ 10, $T =$ 100, $I =$ 16.67 €, $k = 1$ €

The results presented in table 2 can be summarised as follows:

1. The increase of a price floor induces a decline in the investment trigger price. This is due to the fact that, analogously to the disinvestment trigger price, the price floor represents a lower reflecting barrier for the firms, whereby the expected product price rises. Consequently, a lower investment trigger price can already ensure a compensation of the total costs of investment by the expected present value of the future cash flows.
2. The disinvestment trigger price is zero for both the absence and the presence of a price floor. The reason lies in the assumption of perfect irreversibility. Because of this, the firms do not achieve a liquidation value and thus are not able to reduce their capital costs by abandoning the investment. Accordingly, it is not rational to disinvest at any expected product price level.
3. The consumer surplus increases with the implementation as well as the increase of a price floor. This is due to the fact that the firms are investing earlier (cf. 1.) and thus the supply function is shifted to the left. As a result, the sum of the areas *d* and *j* on the right side of figure 2 is larger than the sum of the areas *b* and *d* on the left side.
4. The producer surpluses amount to (nearly) zero for all scenarios, which can be confirmed by a simple comparison of means at a 5% significance level. This means that the firms do not make any profits despite of a price floor, i.e. the zero-profit-condition is still met. To the extent that the expected product price increases through implementation of a price floor (cf. 1.), the firms cause a decline of the upper reflecting barrier by investing earlier. Therefore, even though price stabilisation policies induce less risk for the producers, they do not offer any sustainable financial benefits.
5. The burden of the state budget increases with an increasing price floor. This follows directly from figure 2. The reason is that the government needs to intervene more often through purchases of excess supply.
6. The economic efficiency decreases with implementation and increase of a price floor because the negative welfare effect of burdening the state budget (cf. 5.) overcompensates the positive welfare effect of the increasing consumer surplus (cf. 6.).

4.2. Comparison of the effects of price floors, investment subsidies and production ceilings at different irreversibility levels

By implementing investment subsidies and production ceilings at different levels into the model, the same general effects as in the case of price floors can be observed (cf. subsection 4.1.). It is yet to clarify, how the economic efficiencies of the three political schemes compare for a given stimulation of the willingness to invest and how the introduction of reversibility affects these results. For this purpose, in table 3 the effects of price floors, investment subsidies and production ceilings on the investment and disinvestment trigger prices and the economic efficiencies are compared. By iterative searching, the investment subsidies and the production ceilings are fixed such that the resulting investment trigger prices (nearly) equal the trigger prices of the price floors at $P_{min} = 80$ % and 95 %. These calculations are carried out for irreversibility rates of $i = 100$ % and 50 %. Moreover, a drift rate of $\alpha = 0$ %, a volatility of $\sigma = 20$ %, a price elasticity of $\eta =$ -1 and a depreciation rate of $\lambda = 0$ % are assumed.

The discussion of the results of table 3 is split into two parts. First, the three policies are compared for the assumption of perfect irreversibility, that is, $i = 100$ %. For this scenario, the economic efficiencies of an investment subsidy and a production ceiling are nearly the same at both levels of investment trigger prices. Furthermore, the economic efficiency of a price floor is significantly lower. This is due to the following reasons:

1. The consumer surplus in case of an investment subsidy is considerably higher than in case of a price floor. This can be illustrated by the following: As the trigger prices for both political schemes are the same, the market supply of the firms is the same as well. Therefore, the consumer surplus resulting from an investment subsidy is higher to the extent of the areas g and h on the right side of figure 2, compared to the consumer surplus resulting from a price floor. The consumer surplus in case of a production ceiling again is slightly lower than in case of a price floor. The reason is that limiting the market supply through a production ceiling in periods of high demand obviously reduces the consumer surplus stronger than maintaining the price floor through governmental purchases of excess supply in periods of low demand.
2. The producer surplus amounts to (nearly) zero for all three political schemes, which can be confirmed by a comparison of means at a 5% significance level. This follows directly from the aforementioned validity of the zero-profit-condition, that is, the competing firms do not make any profit despite of political support.
3. The burden of the state budget is zero in case of a production ceiling (cf. table 1) and positive to nearly the same extend for both a price floor and an investment subsidy. The latter is due to the fact that both measures reduce the investment trigger price to the same level by paying the farmers a financial compensation for investing correspondingly earlier. As the stochastic demand process is the same in both cases, this compensation has to be the same as well.
4. The economic efficiency of an investment subsidy is higher than the economic efficiency of a price floor. As the producer surplus and the state budget are the same for both measures (cf. 2. and 3.), this follows directly from the higher consumer surplus in case of an investment subsidy (cf. 1.). Furthermore, the economic efficiencies of both an investment subsidy and a production ceiling are nearly at the same level. Although the consumer surplus of an investment subsidy is significantly higher (cf. 1), this is obviously fully compensated by the negative welfare effect through burdening the state budget, which again is zero for a production ceiling (cf. 3). Under the given stimulation of the willingness to invest, investment subsidies and production ceilings, therefore, are more advantageous than price floors.

Table 3. Comparison of the effects of price floors, investment subsidies and production ceilings with different irreversibility levels

	Price floor				Investment subsidy				Production ceiling			
Irreversibility (%)	Level (% of k)	Investment trigger price (€)	Disinvestment trigger price (€)	Economic efficiency (%)	Level (% of k)	Investment trigger price (€)	Disinvestment trigger price (€)	Economic efficiency (%)	Level (units)	Investment trigger price (€)	Disinvestment trigger price (€)	Economic efficiency (%)
	0	1.5819	0.0000	100.00	0.0	1.5819	0.0000	100.00	n.a.	1.5819	0.0000	100.00
100	80	1.3202	0.0000	81.07	16.0	1.3210	0.0000	93.48	246	1.3194	0.0000	93.62
	95	1.0841	0.0000	65.35	31.5	1.0865	0.0000	84.90	199	1.0836	0.0000	85.08
	0	1.5163	0.3659	100.00	0	1.5163	0.3659	100.00	n.a.	1.5163	0.3659	100.00
50	80	1.3201	0.0000	80.68	11.2	1.3192	0.3116	94.75	275	1.3211	0.3818	95.96
	95	1.0863	0.0000	64.91	27.5	1.0854	0.2766	89.20	208	1.0849	0.4216	87.86

Note: GBM with $\alpha = 0$ % and $\sigma = 20$ %, $\eta =$ -1, $\lambda = 0$%, $r = 5.83$ %, $N = 50$, $X_{cap} = 10$, $T = 100$, $I = 16.67$ €, $k = 1$ €

To investigate how the consideration of reversibility affects the results of the policy impact analysis, the results are discussed for an irreversibility rate of $i = 50$ %. For this scenario, the following effects can be observed:

5. The introduction of reversibility induces an increase in the disinvestment trigger price for the case of no political scheme (from $\underline{P} = 0.000$ to 0.3659). The firms achieve a liquidation value and hence are able to reduce their capital costs through abandoning the investment. Therefore, it is worthwhile for them to disinvest (earlier). The resulting increase of the lower reflecting barrier implies a reduction of the so-called range of action, i.e. the price volatility decreases. Through this, the firms invest correspondingly earlier and the investment trigger price again decreases (from $\overline{P} = 1.5819$ to 1.5163). In consequence of both effects, it can be stated that through not considering reversibility, the (dis)investment hysteresis is generally overestimated in competitive markets with real options effects.
6. Depending on the political scheme, the consideration of reversibility has different effects on the disinvestment trigger of the firms. For the implementation of a price floor at both levels chosen ($P_{min} = 80$ % and 95 %), the disinvestment trigger price falls back to $\underline{P} = 0.000$. The reason is that at these guaranteed price floor levels, it is not worthwhile for the firms to abandon the investment at any expected product price level. In case of the implementation as well as the increase of an investment subsidy, the disinvestment trigger price decreases. This can be explained as follows: Besides the investment outlay, the subsidy also reduces the liquidation value (cf. eq. (10)), whereby the capital costs are reduced less and it is advantageous for the firms to abandon the investment later. This decreasing effect on the disinvestment trigger price obviously overcompensates the increasing effect from reducing the range of action through actively decreasing the investment trigger price. Finally, the introduction of a production ceiling has an increasing effect on the disinvestment trigger price. Again, this can be explained by decreasing the investment trigger price and, through this, reducing the range of action.
7. In case of a price floor, the level of political intervention and hence the economic efficiency remains (nearly) the same under consideration of reversibility, when assuming the same decrease of the investment trigger price. This follows directly from the fact that the disinvestment trigger price is zero (cf. 6.). Thus the conditions are ceteris paribus the same as under the assumption of perfect irreversibility. For the implementation of investment subsidies and production ceilings, the policy needs to intervene less strong and hence the economic efficiencies are reduced less. The reason is that the disinvestment trigger price stays positive in both cases (cf. 6), which ceteris paribus has already a decreasing effect on the investment trigger price (cf. 5). However, as the economic efficiencies of these two measures still are nearly the same with reversibility, the ranking of the three investigated political schemes does not change compared to the scenario of perfect irreversibility (cf. 4).

5. Concluding remarks

The policy impact analysis in competitive markets in which real options effects exist is challenging. Investment thresholds in such markets can only be determined analytically under very restrictive assumptions. This in particular refers to the absence disinvestment options, like e.g. the sale of a cow barn, or price affecting policies, such as price floor or production ceilings. Therefore, a wide range of relevant policy shifts with effects on both investments and disinvestments cannot be analysed in a straightforward analytical way. The objective of this paper was hence to develop the conceptual basis of the assessment the effects of different political schemes on investments, disinvestments and the welfare in competitive markets with real options effects. This was achieved by developing a real options market model and linking it with a combination of GA and stochastic simulation. By means of the model, investment and disinvestment triggers can be calculated numerically and through this, the unrealistic preconditions for deriving a solution in an analytical way are relaxed. The model can analyse the effects of the implementation as well as of the abolishment of different political schemes as needed. By allowing for disinvestments, the relevance of limited reversibility for the assessment of policies can be quantified.

The results of this analysis underline the relevance of the presented model with regard to the assessment of current and (potential) future policy changes in agriculture, like e.g. the implementation of guaranteed feed-in prices for renewable energies in Germany or the abolishment of the quota systems for milk and sugar beets in the EU. Accordingly, it is shown that the implementation or the extension of political schemes generally decrease the investment trigger, but either increase or decrease the disinvestment trigger depending on the investigated measure. At the same time, these effects also apply in the opposite direction, i.e. the abolishment or the lowering of policies. Moreover, it is proven that under consideration of political schemes the zero-profit-condition is still met in competitive markets underlying real options effects, i.e. the producers mutually “marginalise” the additional financial assistance they receive from the government in the long run. This is particularly worth mentioning, as “helping the producers” is the most commonly used argument by farmers and lobbyists when calling for additional political support like e.g. in the dairy sector in recent years. Finally, the results state that the consideration of limited reversibility can be of relevance for policy impact analyses. In the present case, production ceilings and investment subsidies become even more advantageous against price floors with regard to their economic efficiency, assuming the same stimulation of the willingness to invest.

However, it should be noted that the results of the present study are still based on some simplifying assumptions: While the use of a GBM for the stochastic demand process allows the validation of the model in the first instance, its application to specific markets like e.g. the dairy or the bio-energy sector, would need further adjustments. In addition, further sensitivity analyses would be necessary before applying the model empirically. Moreover, the fact that, in reality farmers have just limited possibilities to expand their production capacities, because they are bounded to their respective locations, has not been considered explicitely. Likewise, the assumption of homogenous agents represents a simplification from reality. It should also be noted that by means of the model good but not necessarily the best policies are determined for the respective market because these need to be given exogenously. This basket of political schemes selected ex ante by policy makers could potentially exclude the most superior one.

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