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Analysing investment and disinvestment decisions under uncertainty, firm heterogeneity and tradable output permits

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Abstract

This paper develops an agent-based real options model, which is capable of analyzing the investment and disinvestment decisions of heterogeneous competing firms under consideration of tradable output permits. A permit market is integrated into the model in which the firms can trade permits with each other according to their investment or disinvestment behavior for production capacity. The empirical application of the model to the EU dairy sector shows that (changes in) tradable output permit systems can have considerable effects on investments and disinvestments, in particular in markets with a high degree of firm heterogeneity. Amongst others, they can ceteris paribus increase both the willingness to invest and to disinvest especially of the less efficient firms in a market. The results shed new lights on the ongoing public debate about the potential effects of tradable output permit systems on structural change in a sector.

Keywords

Investment and disinvestment, real options, firm heterogeneity, tradable output permits

1. Introduction

Tradable output permits have become an accepted instrument of market regulation in agriculture and natural resource industries. Examples of this are milk production quotas, fishing quotas, public cattle-grazing permits, manure production rights and the more recent topic of carbon emission allowances. Currently, efforts are being made by politicians to either abolish existing tradable output permit systems with the aim of a further market liberalization (e.g. the EU milk and sugar beet quotas) or to implement new systems in order to limit production externalities (e.g. carbon emission allowances in intensive livestock farming).

Output permits constitute a (usually) scarce production factor, causing strong interdependence of firms' investment and disinvestment decisions: Firms usually cannot grow in size, that is invest, unless other firms shrink or exit the market, that is disinvest, since new factor supply can only hereby be provided (e.g. Balmann et al., 2006). In consequence of the implementation, intensified use or abolishment of output permit systems, changes in firms' investment and disinvestment strategies can be expected. Therefore, the analysis of investment and disinvestment decisions of competing firms and their respective interactions under tradable output permit systems is of particular interest.

Many investigations have shown that the real options approach (ROA), which exploits the analogy between a financial option and a real investment opportunity, is generally better suited to explain agricultural investments than traditional investment models based on the net present value (NPV) rule (e.g. Odening et al., 2005; Purvis et al., 1995; Richards and Patterson, 1998). This is due to agricultural investments commonly being afflicted by the uncertainty of future cash flows, irreversibility of investment costs and temporal flexibility in conducting investments. The ROA explicitly takes these characteristics into account by analysing investment decisions under dynamic-stochastic conditions and extending the NPV by the value of entrepreneurial flexibility, which is also referred to as the value of waiting (e.g. Dixit and Pindyck, 1994; Trigeorgis, 1996).

However, the simultaneous analysis of investment and disinvestment decisions in the real options context in a competitive environment is complex (e.g. Dixit and Pindyck, 1994: ch. 8 and 9). The reason for this is that, in contrast to financial options, real investment opportunities are rarely exclusive. Due to this non-exclusiveness, similar competitor responses can be expected when they are faced with aggregated uncertainty, such as demand uncertainty for instance. The joint reactions of competitors change sectoral supply and hence equilibrium prices. Consequently, the dynamics of the investment returns, for instance the stochastic process for the product price, which determine the value of an investment as well as the optimal investment and disinvestment threshold, cannot be considered as exogenous.

To avoid a difficult iterative derivation of the endogenous equilibrium price process, all existing real options applications explicitly or implicitly exploit Leahy's optimality property of myopic planning (Leahy, 1993). In this approach, he shows that an investor in a perfectly competitive market finds the same optimal investment and disinvestment threshold as a myopic planner who behaves like a price taker and ignores other firms' investment and disinvestment decisions. The implication of this result is that the firms' optimal investment and disinvestment thresholds can be determined in a straightforward and analytical manner by assuming an exogenous price process and hence ignoring competitive effects.

By assuming Leahy's optimality property of myopic planning, however, the applicability of the ROA to real investments is considerably complicated. Through merely focusing on the myopic planner, the assumption of homogeneous firms is implicitly made for which the determined investment and disinvestment threshold equally apply. Yet, there exists a relatively high degree of firm heterogeneity in many agricultural markets, which may result in different levels of efficiency (e.g. Alvarez and Arias, 2004; Claassen and Just, 2011). From these variations in efficiency arise different levels of the production costs and, with this, different optimal investment and disinvestment thresholds of the competing firms. This again leads to an interdependence of investment and disinvestment decisions; for instance, the investments of relatively efficient firms could lead to intensified disinvestments of less efficient firms. These interdependencies cannot be analyzed by models which assume myopic planning is optimal. For this, a direct determination of the endogenous equilibrium price process in markets with firm heterogeneity would be required, an endeavor which has not yet been conducted.

Moreover, the limitation of focusing only on the myopic planner further complicates the applicability of the ROA to markets with tradable output permits since permit trade relies on simultaneous investment and disinvestment decisions of heterogeneous firms. For instance, if several efficient firms intend to expand production and therefore need to buy additional permits, a necessary condition could be that less efficient firms exit the market and release their permits (e.g. Turvey et al., 2003). Thus, tradable output permits can be expected to have considerable effects on the investment and disinvestment decisions of heterogeneous firms. However, as it has not yet been possible to determine the latter within the real options context, the respective effects of tradable output cannot be analyzed either.

In the agricultural economics literature, only few studies have addressed investment and disinvestment decisions in the real options context in connection with output permits thus far. Weninger and Just (2002) analyze the effects of firm-level uncertainty on firms exit thresholds and output permit prices in the real options context. Zhao (2003) uses the ROA and derives a general equilibrium model which is capable of determining firms' optimal investment thresholds in irreversible abatement technologies under tradable emission permits. Wossink and Gardebroek (2006) develop a real options model that determines the impact of policy uncertainty on investments in tradable output permits. Kersting et al. (2016) determine firms' optimal entry and exit decisions under firm-level uncertainty, as well as given capacity constraints at the sectoral level by means of a dynamic-stochastic equilibrium modeling approach. However, neither of these models considers heterogeneity of the firms when determining their optimal investment and disinvestment decisions. Additionally, and partially as a consequence, neither of them can directly model output permit trade caused by the investment and disinvestment decisions of (heterogeneous) competing firms.

Hence, the objective of this paper is to analyze investment and disinvestment decisions of heterogeneous competing firms under uncertainty and tradable output permits. In order to achieve this, an agent-based real options market model is developed which determines the optimal investment and disinvestment thresholds of heterogeneous competing firms in production capacity for a homogeneous commodity. Additionally, a permit market is integrated into the model; through this integration, the firms either act as demanders or suppliers for the permits according to their investment or disinvestment behavior. The model is solved numerically by linking genetic algorithms (GAs) and stochastic simulation. Hereby, the endogenous equilibrium price processes for both the commodity and the permits can be simultaneously derived and, based on this, the firms' optimal investment and disinvestment thresholds can be determined. The model is exemplarily applied to the EU dairy sector.

Amongst others, the results indicate that, in markets with relatively homogeneous firms, tradable output permits can ceteris paribus foster structural change, in other words, the firms generally invest earlier and are less slow in abandoning production, depending on the specific design of the permit system. In markets with a more pronounced firm heterogeneity, this effect of decreasing investment thresholds and decreasing disinvestment thresholds is weakened for the more efficient firms, while it is even intensified for the less efficient firms. Both results are in contrast to the current public debate on the effects of tradable output permits on structural change, for instance the debate surrounding the recent abolishment of the EU milk production quota. Thus, the model can provide improved decision support for politicians, for instance with regard to the potential introduction of tradable carbon emission allowances.

The following section develops an agent-based real options market model with an integrated tradable output permit market. The numerical solution procedure is subsequently explained. Following this, the assumptions and model parameters for the application to the EU dairy sector are presented. The results section is split into two parts: First, the model is validated for the base scenario of homogeneous firms and no output permit system. Second, the model results for the introduction of firm heterogeneity and tradable output permits are presented and discussed. The paper ends with a summary of the main findings and the derivation of some policy implications.

2. Model

The model which will be detailed in this section uses the model put forth by Feil and Musshoff (2013) as a basis. Their real options market model is capable of simultaneously analysing the investment and disinvestment thresholds, specifically the investment and disinvestment trigger prices, of competing firms in a market. This is achieved by directly deriving the endogenous equilibrium price process and thus overcoming some restrictive preconditions for applying Leahy's optimality principle of myopic planning. Due to complexity circumstances, however, their model does still assumes the homogeneity of firms, whereby the realistic interactions between the firms' investment and disinvestment decisions caused by their heterogeneity cannot be depicted. Therefore, the model developed in this article additionally considers two important aspects: First, it allows for firm heterogeneity. Second, a market for tradable output permits is integrated in which the firms act simultaneously either as demanders or as suppliers according to their investment or disinvestment behavior for production capacity.

Basic model structure

Within the model, a market consisting of I risk-neutral firms is considered, all of which compete to satisfy the same exogenous stochastic demand μ_t for a homogeneous commodity. The firms can be split into groups, so that every firm i can always be uniquely assigned to a group j. Within a group, the firms are homogeneous regarding their production and investment possibilities. However, across the groups the firms may be heterogeneous from each other, for instance with regard to their efficiency levels. The firms plan in discrete time, which is a necessary assumption for numerical options valuation procedures. Each firm has the option to repeatedly invest in its production capacity within the period of consideration T, until an exogenously given maximum output capacity X_{cap} is reached. Investment outlay and production output are proportional, which means that there are no economies of scale. The investment project has an unlimited useful lifetime and is subject to depreciation with geometric rate λ. After implementation, the investment can be abandoned and its costs partially recovered, that is, investment and disinvestment options are simultaneously considered. Consequently, the production capacity of a firm i belonging to a group j in period t, resulting in a production output $X_{i,t}^{j}$, can be adjusted in two ways: Either through investments once per period to the extent of $Y_{i,t}^{j}$, resulting in an additional production output in the following period, or via disinvestments once per period to the extent of $Z_{i,t}^{j}$, resulting in a reduction in production output in the following period. Production thus follows:

$$X_{i,t+\Delta t}^{j} = X_{i,t}^{j} \cdot (1-\lambda) + Y_{i,t}^{j} - Z_{i,t}^{j}. \tag{1}$$

The aggregated production output of all firms represents the market supply for the homogeneous commodity. Prices result from the reactions of all market participants on the exogenous stochastic demand parameter μ_t and hence, need to be endogenously determined within the model. Without loss of generality, the relationship between market quantity X_t and price P_t is defined by an isoelastic demand function (e.g. Dixit, 1991):

$$P_t = D(X_t, \mu_t) = \left(\frac{\mu_t}{X_t}\right)^{\Pi} \qquad \text{with} \qquad \Pi = -\frac{1}{\eta} \tag{2}$$

where η is the price elasticity of demand.

To be entitled to produce in a specific period, the firms have to own tradable output permits prior to investment. In a certain period $\tilde{t}$ the government issues permits to the overall amount of $U_{\tilde{t}}$. In the model, the permits can be distributed among the firms as flexibly as needed, for instance even among all $I = 100$ firms in $\tilde{t} = 0$ or to the extent of the production capacity of every invested firm at a later point. In the issue period and all subsequent periods, the permits can be traded between the firms on a separate market according to their investment and disinvestment behavior. Equilibrium permit prices Q_t result from the interplay of supply and demand and, thus, need to be determined endogenously within the model. Consequently, the output permit stock of a firm can either be increased by additional purchases $V_{i,t}^j$ or decreased by sales $W_{i,t}^j$. The calculation of the permit stock is as follows:

$$U_{i,t+\Delta t}^j = U_{i,t}^j + V_{i,t}^j - W_{i,t}^j \qquad \text{with} \qquad \sum_{i=1}^{I} U_{i,t+\Delta t}^j = U_{\tilde{t}} \;\; \forall \;\; t \geq \tilde{t} \tag{3}$$

According to the model of homo economicus, all firms maximize their expected NPV. Furthermore, all firms have complete information regarding the stochastic demand process as well as the investment and disinvestment behavior, along with the output permit trading behavior of all competitors. Based on this, firms build price expectations for the respective following period. Consequently, all firms within a homogeneous firm group *j* should have the same optimal investment and disinvestment trigger price as well as the same optimal permit purchase and sales price in equilibrium. To derive this Nash equilibrium in the model, all competing firms across all groups interact by gradually adjusting their (initially different) investment and disinvestment trigger prices ($\overline{P}_i^j$, $\underline{P}_i^j$) as well as their (initially different) permit purchase and sales trigger prices ($\overline{Q}_i^j$, $\underline{Q}_i^j$), which is explained further in the next section. Within a period, it is assumed that all firms first make a disinvestment decision and then an investment decision. In this context, it is technically ensured that $\overline{P}_i^j \geq \underline{P}_i^j$ for all firms; in other words, a firm i in group *j* will not make the decision to invest if it has decided to disinvest immediately before. Due to this system of chronological order, the disinvestments accumulated in a period impact the investment decisions of the same period, but not vice versa.

Investment, disinvestment and permit trading decisions

To derive the disinvestment volume 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 are sorted according to their disinvestment trigger prices, starting with the highest, i.e. $\underline{P}_i^j \geq \underline{P}_{i+1}^j$. Consequently, firm $i + 1$ does not disinvest if firm i has not already completely abandoned the investment. Likewise, it is obvious that if firm $i + 1$ abandons the investment completely, firm i completely abandons 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. The disinvestment volume of a firm i^* in t, corresponding to its additional production output in $t + \Delta t$ is as follows:

$$Z^j_{i^*,t+\Delta t}\left(\underline{P}^j_{i^*}\right) = \max\left[0, \min\left(\begin{array}{c} X^j_{i^*,t} \cdot (1-\lambda)\,, \\ \left(\sum_{i=1}^{I} X^j_{i,t} \cdot (1-\lambda) + \sum_{i=1}^{i^*-1} Z^j_{i,t+\Delta t}\left(\underline{P}^j_i\right)\right) - \dfrac{\hat{\mathrm{E}}(\mu_{t+\Delta t})}{(\underline{P}^j_{i^*})^{-\eta}} \end{array}\right)\right] \tag{4}$$

The “max-query” of equation (4) ensures non-negativity of the disinvestment volume. Furthermore, the “min-query” ensures that a firm cannot abandon more production capacity via disinvestments than it has built up in former periods. The “min-query” also guarantees that the total supply quantity is just reduced as long as the disinvestment trigger price of the “last” firm equals the expected product price of the next period.

In contrast to the disinvestment volume, the actual investment volume is determined in three steps: First, the intended investment volume is determined as it is unclear at this point whether the firm owns sufficient output permits to be entitled to produce additional output. The intended investment volume is similarly derived to the disinvestment volume, i.e., firms with lower investment trigger prices have a stronger tendency to invest. All firms are sorted according to their investment trigger prices, starting with the lowest, i.e. $\overline{P}^j_i \leq \overline{P}^j_{i+1}$. Thus, firm $i + 1$ may not invest if firm i has not already potentially invested in production capacity up to X_{cap}. In every period t, it is technically ensured that de facto a marginal (or last) firm exists which may invest to the extent that its investment trigger price would equal the expected product price of the next period. As a result of this and the relatively large number of firms ($I = 100$), the market within the model can be seen as an approximation of an atomistic market. The calculation of the intended investment volume of a firm i^* in t is as follows

$$\tilde{Y}^j_{i^*,t+\Delta t}\left(\overline{P}^j_{i^*}\right) = \max\left[0, \min\left(\begin{array}{c} X_{cap} - X^j_{i^*,t} \cdot (1-\lambda)\,, \\ \dfrac{\hat{\mathrm{E}}(\mu_{t+\Delta t})}{(\overline{P}^j_{i^*})^{-\eta}} - \left(\sum_{i=1}^{I} X^j_{i,t} \cdot (1-\lambda) + \sum_{i=1}^{i^*-1} Y^j_{i,t+\Delta t}\left(\overline{P}^j_i\right) + \sum_{i=1}^{I} Z^j_{i,t+\Delta t}\left(\underline{P}^j_i\right)\right) \end{array}\right)\right] \tag{5}$$

Similar to equation (4), the “max-query” of equation (5) ensures non-negativity of the intended investment volume. The “min-query” ensures that a firm cannot build-up more production capacity via investments than it needs in order to produce its maximum production capacity X_{cap}.

Additionally, the “min-query” ensures that the total quantity of supply is only expanded as far as the investment trigger price of the “last” invested firm equals the expected product price of the next period.

Second, based on its disinvestment and intended investment decision, a firm may become active on the permit market to adjust its permit stock. It may either be the case that the firm has to buy additional permits to be entitled to produce additional output caused by the investment decision according to equation (5). Or the firm may be in a position to sell excess permits caused by the disinvestment decision according to equation (4) and/or by depreciations in the current and previous periods. Hence, the firms can act as either suppliers or demanders for output permits. The permit demand of a firm i in t is determined as follows:

$$\tilde{V}_{i,t}^{j} = \max\left[0; X_{i,t}^{j} \cdot (1-\lambda) + \tilde{Y}_{i,t+\Delta t}^{j} - Z_{i,t+\Delta t}^{j} - U_{i,t}^{j}\right] \tag{6}$$

Similarly, the permit supply of a firm i in t is derived as follows:

$$\widetilde{W}_{i,t}^{j} = \max\left[0; U_{i,t}^{j} - X_{i,t}^{j} \cdot (1-\lambda) - \tilde{Y}_{i,t+\Delta t}^{j} + Z_{i,t+\Delta t}^{j}\right] \tag{7}$$

The equilibrium permit price in each period is settled on a permit exchange on a bid-ask basis: The firms with an individual permit demand place bids according to equation (6), that is, permit purchase trigger prices $\overline{Q}_{i}^{j}$, while those with an individual supply according to equation (7) set ask prices, that is, permit sales trigger prices $\underline{Q}_{i}^{j}$ The model then ranks and accumulates the quantity and price of the firms’ permit demands as well as the quantity and price of the firms’ permit supplies. The equilibrium permit price Q_t, which is the market-clearing price, thus it is the price at which the accumulated demand equals the accumulated supply. Since demand equals supply, all offers to purchase at or above Q_t and all offers to sell at or below Q_t are satisfied. The actual permit purchases and sales of the firms are as follows:

$$V_{i,t}^{j}\left(\overline{Q}_{i}^{j}\right) = \begin{cases} \tilde{V}_{i,t}^{j}\left(\overline{Q}_{i}^{j}\right) & \text{if } \overline{Q}_{i}^{j} \geq Q_t \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

and

$$W_{i,t}^{j}\left(\underline{Q}_{i}^{j}\right) = \begin{cases} \widetilde{W}_{i,t}^{j}\left(\underline{Q}_{i}^{j}\right) & \text{if } \underline{Q}_{i}^{j} \leq Q_t \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

Based on this, a firm i in group j can derive its actual investment volume as a third and final step:

$$Y_{i,t+\Delta t}^{j}\left(\overline{P}_i^j,\overline{Q}_i^j,\underline{Q}_i^j\right)=\max\left[0,\min\begin{pmatrix}\tilde{Y}_{i,t+\Delta t}^{j}\left(\overline{P}_i^j\right),\\ U_{i,t+\Delta t}^{j}\left(\overline{Q}_i^j,\underline{Q}_i^j\right)-X_{i,t}^{j}\cdot(1-\lambda)\end{pmatrix}\right] \tag{10}$$

The "max-query" of equation (10) guarantees non-negativity of the actual investment volume. The "min-query" ensures that the actual investment volume of firm i does not exceed the intended investment volume according to equation (5). Furthermore, it ensures that firm i cannot build up more production capacity via investments than it is entitled to produce through its adjusted output permit stock for the next period.

Option value

Finally, an objective function needs to be established in order to determine the optimal investment, disinvestment and permit trading decisions of the firms. According to the aforementioned assumptions, each firm aims to maximize its expected NPV of the future cash flows $F_{i,0}^j$, in the real options terminology also referred to as option value, by choosing its firm-specific investment trigger price $\overline{P}_i^j$, its disinvestment trigger price $\underline{P}_i^j$, its output permit purchase trigger price $\overline{Q}_i^j$ and its output permit sales trigger prices $\underline{Q}_i^j$:

$$\max_{\overline{P}_i^j,\underline{P}_i^j,\overline{Q}_i^j,\underline{Q}_i^j}\left\{F_{i,0}^j\right\}=\max_{\overline{P}_i^j,\underline{P}_i^j,\overline{Q}_i^j,\underline{Q}_i^j}\left\{\sum_{t=0}^{\infty}\left(\left(P_t-C^j-K^j\right)\cdot X_{i,t}^j\left(\overline{P}_i^j,\underline{P}_i^j\right)-s\cdot C^j\cdot\sum_{u=0}^{t}Z_{i,u}^j\left(\underline{P}_i^j\right)\right.\right.$$
$$\left.\left.-L_{i,t}^j\left(\overline{Q}_i^j,\underline{Q}_i^j\right)\right)\cdot e^{-r\cdot t}\right\}$$

(11)

The discount factor r in equation (11) is time-continuous. C^j represents the constant capital costs of the investment outlay per output unit, which can have different levels for every firm group j due to different efficiency levels. The sunk cost rate s determines what proportion of C^j cannot be recovered upon abandonment. All other operational costs to be paid by a firm group j (e.g. for material and labour) are also assumed to be constant and depicted by K^j. Furthermore, $L_{i,t}^j$ denotes the total permit costs of a firm i in t:

$$L_{i,t}^j\left(\overline{Q}_i^j,\underline{Q}_i^j\right)=L_{i,t-\Delta t}^j+Q_t^p\cdot\left(U_{i,t}^j\left(\overline{Q}_i^j,\underline{Q}_i^j\right)-U_{i,t-\Delta t}^j\left(\overline{Q}_i^j,\underline{Q}_i^j\right)\right) \tag{12}$$

with Q_t^p being the perpetuity of the equilibrium permit price in t:

$$Q_t^p = Q_t \cdot (e^{r \cdot \Delta t} - 1) \tag{13}$$

To validate the plausibility of the endogenously derived equilibrium permit price Q_t, one can refer to welfare economic considerations. Accordingly, the value and, with this, the price of the tradable output permits should equal the incremental producer surplus caused by the output permit system (e.g. Veeman, 1982). To make the producer surplus comparable to the permit price, the present value of the producer surplus per output unit of all T production periods is calculated in the model:

$$PS = \sum_{t=1}^{T} PS_t \cdot e^{-r \cdot t} = \sum_{t=1}^{T} \left(\left(\sum_{i=1}^{I} X_{i,t}^{j} \cdot \left(P_t - C^j - K^j\right) \right) / X_t \right) \cdot e^{-r \cdot t} \tag{14}$$

For the determination of the incremental producer surplus caused by the output permit system, the producer surplus without output permits is deducted from the producer surplus with output permits:

$$\Delta PS = PS^{with} - PS^{without} \tag{15}$$

3. Solution procedure

As no analytical solution exists for the optimization problem described in the previous section, the model is solved numerically by combining GAs with stochastic simulation. GAs are a heuristic search method which apply the evolutionary concepts of natural selection, crossover and mutation on a population of behavioral strategies (e.g. Goldberg, 1998). In the field of economics, they are mostly used for solving optimization problems and the identification of equilibria in strategic settings, respectively (e.g. Allen and Karjalainen, 1999; Altiparmak et al., 2006; Graubner et al., 2011).

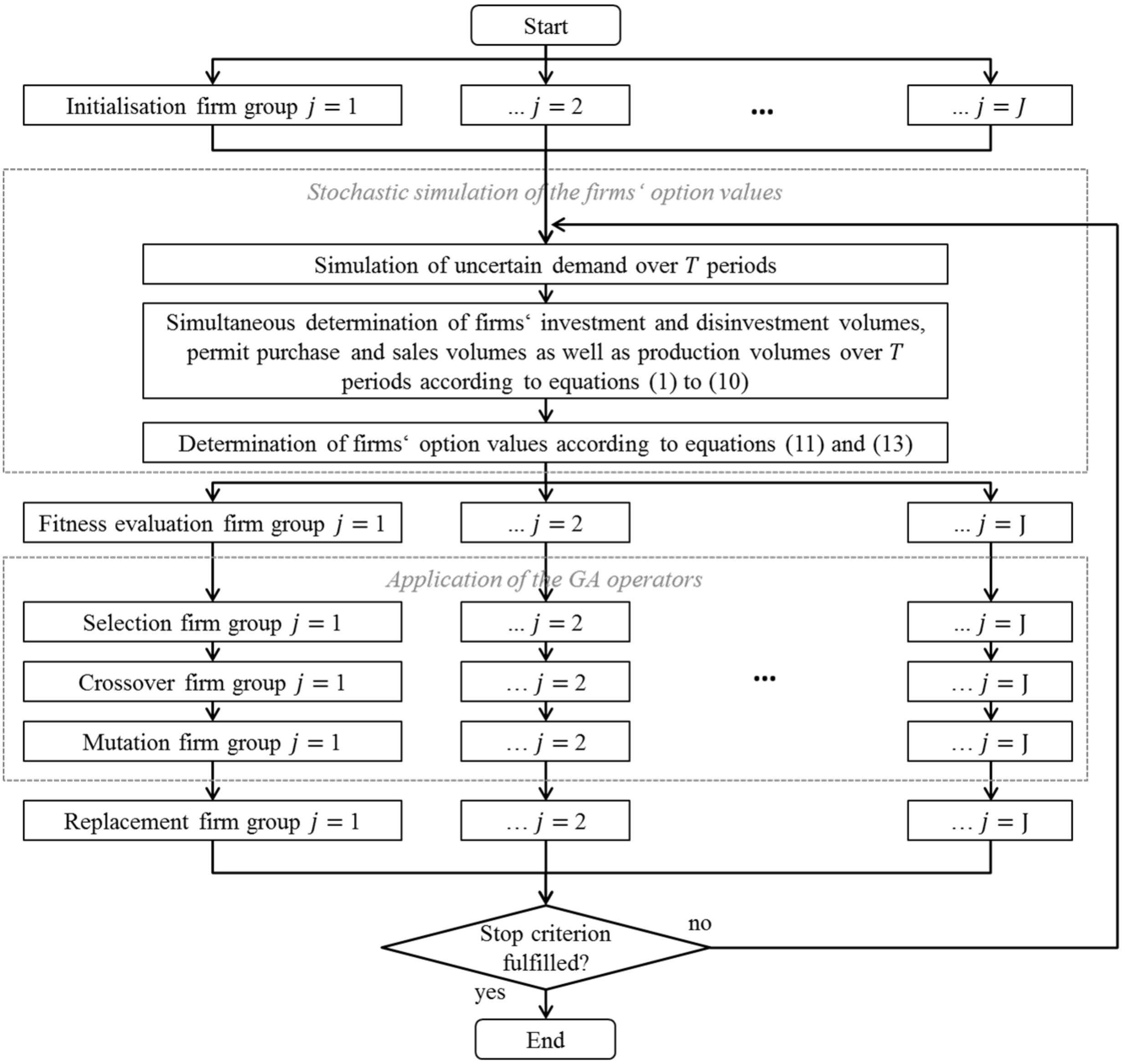
In the present analysis, GAs are used to examine optimal investment and disinvestment strategies of the competing firms under explicit consideration of related output permits trade between these firms. In doing so, the GA approach of Feil and Musshoff (2013) and Feil et al. (2013) is expanded in two ways: First, a firms' strategy is not just represented by one value, for instance merely its investment trigger price, but by a combination of four values, that is, its investment and disinvestment trigger price as well as its permit purchase and sales trigger price. This combination of four values is optimised simultaneously throughout the GA procedure. Second, not just one, but several, GAs have to be implemented. This is due to the fact that there are heterogeneous firm groups in the model which can have different combinations of optimal trigger prices. Since the outcome of a GA in general is an equilibrium strategy, in other words, one combination of optimal trigger prices, which equally applies to all firms considered in the GA, one GA is implemented for each firm group j. However, the GAs are linked with each other in a way that, in every period, all N firms in the model across the groups compete to satisfy the same exogenous stochastic demand.

In general, GAs have three standard features in common: a population of genomes, a fitness function and GA operators. A population of genomes generally describes a collection of contender solutions to a given problem. In this case, each genome of a population represents a strategy, i.e., a combination of the four trigger prices. The fitness function serves as the evaluation measure for the quality of a solution. Here, the fitness function is represented by the objective function of the model, which is the option value of a firm i in group j according to equation (11). These option values are determined by means of stochastic simulation. Finally, the GA operators are applied to the population of genomes. Usually, as well as in this case, the GA operators consist of selection, mutation and crossover. Through the utilization of this procedure, solutions with a high fitness function value are identified and new, possibly superior solutions are incorporated.

Figure 1, illustrates the solution procedure. The first generation of genomes is initialized by drawing random values for the four trigger prices of every firm i in a group j out of a pragmatically defined range, overall resulting in I heterogeneous combinations of four trigger prices. For an efficient optimisation procedure of the GA, this heterogeneity of genomes is a prerequisite (Mitchell, 1996). In the model, it is technically ensured that $\underline{P}_i^j \leq \overline{P}_i^j$ for all i.

Following this, the option values of the firms are determined by means of stochastic simulation. The stochastic demand parameter μ_t is simulated in $S = 10{,}000$ simulation runs over the infinite period under consideration, which is approximated by $T = 100$ years. In response to μ_t and on the basis of the trigger prices of the previous step, the disinvestment and investment volumes, permit purchase and sales volumes as well as production outputs of all I firms across all J firm groups are simultaneously determined according to equations (1) to (10) for each simulation run. This endogenously yields the market equilibrium prices for both the commodity and the permit. With these values, the option value per firm for the respective simulation run is calculated according to equation (11), (12) and (13) is calculated. The determination of the option value per firm further used in the optimization procedure is carried out as an arithmetic mean of the option values of the repeated simulation runs S with a given population of trigger price combinations and random demand parameters.

Figure 1. Illustration of the models' solution procedure.



Subsequently, the firms and their respective combinations of four trigger prices are again separately arranged into the initial firm groups. Within each group, the fitness of the firms' strategies is determined. The option values determined in the previous step give information about the "quality" of the respective genomes and their ability to solve the problem at hand: The higher the option value of a strategy, the higher the fitness of the genome. As a result, the strategies (combinations of four trigger prices) within each group 1re sorted according to their respective option values, starting with the highest.

As illustrated in Figure 1, the GA operators are now applied separately to each group to define the population of genomes for the next generation within the group. The detailed technical implementation of the GA operators is conducted analogous to Feil et al. (2013). It should be noted that the GA operators' specification does not affect the results itself, but merely the computational efficiency of the solution procedure.

The result is a new population of genomes, consisting of a combination of four trigger prices each, which replaces the old population and on which the above procedure is applied again. This process is repeated until the population converges towards an equilibrium and the equilibrium combination of optimal trigger prices is determined. Accordingly, the GA can be stopped when the obtained strategies are both homogenous, that is, very similar to each other within one generation, and stable, i.e. very similar from one generation to the next. The specific design of the stop criterion of a GA depends on the complexity of the planning problem at hand. For instance, Graubner et al. (2011) stop after a total of 2,500 generations. In the present case, the GA is stopped if the arithmetic mean of each of the four trigger prices of the ten fittest firms has not changed up to the third decimal place for at least 100 generations.

Due to the nature of the GA, there still exists a low risk of a suboptimal solution. To resolve this issue, the procedure is run more than once for a specific scenario. The global optimum is found only if the resulting combinations of four trigger prices are very similar to each other over several GA runs (i.e. differ from the second decimal place).

4. Application to the European dairy sector

To realistically and practically illustrate the developed model, it is applied to the EU dairy sector. This can be justified by the following reasons: First, many applications of the ROA have already shown that investments in this sector are afflicted by uncertainty, irreversibility of investment costs and temporal flexibility in conducting investments (e.g. Engel and Hyde, 2003; Purvis et al., 1995; Tauer, 2006). Second, the EU dairy sector is highly competitive, comprising 708,170 producers in 2013 that are either classified as specialized dairy farms, or as dairying, rearing and fattening combination farms (European Commission, 2016). Third, dairy farms across the EU are characterised by a high degree of heterogeneity, especially with regards to their levels of efficiency (e.g. Abdulai and Tietje, 2007; Heshmati and Kumbhakar, 1994; Alvarez and Arias, 2004). These aspects support, or at least do not contradict, the applicability of the described model framework. Moreover, until recently the EU dairy sector was characterized by a tradable output permit system, the EU milk production quota scheme. The effects of the abolishment of the latter on the investment and disinvestment decisions of the firms and thus on structural change can be exemplarily analyzed by means of the model. The utilized model parameters are summarized in Table 1 and in details explained in the following.

Mainly due to issues regarding data availability, it is practically impossible to directly estimate the stochastic demand process μ_t and its parameters empirically. Instead, following many other real options applications to agriculture in general and to the dairy sector in specific (cf. e.g. Engel and Hyde, 2003; Purvis et al., 1995; Tauer, 2006), the stochastic price process and its

Table 1. Model parameters for the application to the EU dairy sector.

Number of firms in total I and in groups I	$I = 100$, $I^1 = 50$, $I^2 = 50$
Milk yield	Group 1: 10,000 kg per cow and year (resp. 7,000)
	Group 2: 7,000 kg per cow and year
Period under consideration T	Infinite, approximated by 100 years
Capital costs for the investment outlay C^j	$C^1 = 0.0328$ € per kg and year
(excluding costs for output permits)	$C^2 = 0.0469$ € per kg and year
Sunk cost rate s	50 %
Useful lifetime of investment	Infinite
Geometric depreciation rate λ	4.25 %
Operational costs K^j (after deducting sales	$K^1 = 0.2136$ € per kg and year
revenues for old cows and calves)	$K^2 = 0.3052$ € per kg and year
Risk-free time-continuous interest rate r	3.38 %
Stochastic process of the demand parameter μ_t	Geometric Brownian motion (GBM)
Drift rate α	-2.97 %
Volatility σ	19.59 %
Time step length Δt	1.00 (i.e. one planning period equals one year)
Price elasticity of demand η	-0.99
Simulation runs S	10,000

parameters are estimated from available historic price data. Subsequently, the parameters of the stochastic price process can be re-transformed into the parameters of the stochastic demand process μ_t (e.g. Odening et al., 2007).

For the empirical estimation of the stochastic price process, it is crucial to use historical prices that have not, or have only to a minor extent, been affected by any market interventions. Hence, historical EU milk prices do not seem to be appropriate because of the EU milk price intervention system that was in place through 2007 and the EU milk quota production system that was just recently abolished. In contrast, the dairy sector in New Zealand is not characterised by any significant political interventions and, therefore, the inflation-adjusted average prices for milksolid in New Zealand from 1973 to 2014 are taken as a basis (LIC, 2014). Applying a unit root test to this time series, it is shown that the null hypothesis of non-stationarity cannot be rejected at a 95 % significance level. Following common practice of other real options applications, this test result can be seen as an indication that a geometric Brownian Motion (GBM) represents an adequate model for the price process.

In general, a GBM represents the solution of the stochastic differential equation (e.g. Leahy, 1993):

$$\mathrm{d}\mu_t = \alpha \cdot \mu_t \cdot \mathrm{d}t + \sigma \cdot \mu_t \cdot \mathrm{d}z \tag{16}$$

where α denotes the drift rate and σ the volatility of the stochastic demand. Both parameters are assumed to be constant. $\mathrm{d}z$ is the increment of a Wiener process. If $\mathrm{d}\mu_t$ describes a demand shock, the stochastic demand process according to equation (16) can be translated into a stochastic price process (Odening et al., 2007):

$$\mathrm{d}P_t = \hat{\delta}(P_t, X_t) \cdot \mathrm{d}X_t + \hat{\alpha} \cdot P_t \cdot \mathrm{d}t + \hat{\sigma} \cdot P_t \cdot \mathrm{d}z \tag{17}$$

with

$$\hat{\delta}(P_t, X_t) = -\Pi \cdot X_t^{-1} \cdot P_t, \qquad \hat{\alpha} = \Pi \cdot \alpha + \frac{1}{2} \cdot \sigma^2 \cdot (\Pi^2 - \Pi) + \lambda \cdot \Pi, \qquad \hat{\sigma} = \Pi \cdot \sigma$$

By using the available historic price data from New Zealand, the estimation of the parameters of the stochastic price process yields a drift rate of $\hat{\alpha} = 1.31$ % and a volatility of $\hat{\sigma} = 19.39$ %. To re-transform these into the parameters of the stochastic demand process α and σ by means of equation (17), the price elasticity of demand η and the geometric depreciation rate λ are needed: Thiele (2008) reports a price elasticity for dairy products in Germany of $\eta =$ -0.99. Furthermore, according to the German Association for Technology and Structures in Agriculture, a depreciation rate of $\lambda = 4.25$ % p.a. for milk production capacity in Germany can be assumed (KTBL, 2014). With this information, the parameters of the stochastic price process $\hat{\alpha}$ and $\hat{\sigma}$ can be re-transformed into the parameters of the stochastic demand process α and σ, following equation (17), which yields $\alpha =$ -2.97 % and $\sigma = 19.59$ %.

Since the GBM as stochastic demand process assumes infinitesimal time length steps and is hence impractical for simulation purposes, it is transformed into a time-discrete version. This can be done through the use of Ito's Lemma (cf. Hull and White, 1987):

$$\mu_{t+\Delta t} = \mu_t \cdot e^{\left[\left(\alpha - \frac{\sigma^2}{2}\right) \cdot \Delta t + \sigma \cdot \varepsilon_t \cdot \sqrt{\Delta t}\right]} \tag{18}$$

with a standard normally distributed random number ε_t and a time step length Δt. Equation (18) represents an exact approximation of the time-continuous GBM for any Δt. For the risk-free discount rate, the arithmetic mean of the inflation-adjusted monthly average yields of listed federal securities with 15 to 30 years residual maturity for the period from 1989 to 2013 is calculated at 3.44 % per year (Bundesbank, 2014), which corresponds to a time-continuous interest rate of 3.38 %.

With regard to investment costs, a typical investment to build up milk production capacity in Germany with an initial investment outlay of 4,371 € per cow or 0.62 € per kg milk is considered (KTBL, 2014). Considering the firms' efficiency levels, milk yields of 7,000 and 10,000 kg per cow per year are considered to model the effects of firm heterogeneity. In this respect, the milk yield of 7,000 kg represents the average milk yield across Germany (KTBL, 2014), whereas 10,000 kg could for instance refer to firms with higher management capabilities and which are no rarity in Germany. If 10,000 kg represents the milk yield of the firms in group $j = 1$ and 7,000 kg the milk yield of the firms in group $j = 2$, then the resulting capital costs for the investment outlay are $C^1 = 0.0328$ € and $C^2 = 0.0469$ € per kg per year. Furthermore, the operational costs (e.g. for heifer, fodder, labour and veterinarian), after deducting the sales revenues for old cows and calves, are $K^1 = 0.2136$ € and $K^2 = 0.3052$ € per kg per year.

Regarding the output permit market, it is assumed that the government issues output permits in period $\tilde{t} = 0$ to the amount of the actual aggregated market quantity of milk. The initial allocation of the permits to the firms is conducted in an auction: The firm with the highest bid, i.e., the highest permit purchase trigger price $\overline{Q}_i^j$, purchases permits to the amount of its maximum output capacity X_{cap}, followed by the firm with the second highest trigger price, until all permits are sold. It should be noted that the permits can be initially allocated to the firms as flexibly as needed with regard to the point in time of the allocation and the modality; this represents just one of many possibilities. Immediately afterwards and in all 100 consecutive periods, the firms can trade permits between each other according to their investment and disinvestment behavior, as explained in the model section.

5. Results and discussion

The presentation and discussion of the results is split into two parts. First, the numerical model results are validated for the base scenario of homogeneous firms and no tradable output permits with using the model parameters for the EU dairy sector as described in Table 1. Second, the model is simulated for the case of heterogeneous firms with regard to their milk yield and tradable output permits.

Model validation for the base scenario of homogeneous firms and no tradable output permits

To validate the numerical model results, Leahy's optimality property of myopic planning (Leahy, 1993) can be applied. Accordingly, an investor in a perfectly competitive market finds the same optimal investment and disinvestment trigger price as a myopic planner, which can both be determined in a straightforward and analytical manner. To establish the conditions for applying the optimality property of myopic planning in the model, all firms are assumed to be homogeneous, that is, the two firm groups have the same milk yield of 7.000 kg. Furthermore, no market interventions, such as tradable output permits, are considered in the model. Considering that it is technically ensured within the model that there is always one firm which invests last (cf. model section), the zero-profit-condition holds for all firms in this scenario. The result is an optimal investment trigger price for all firms of $\overline{P} = 0.4133$ € per kg and an optimal disinvestment trigger price of $\underline{P} = 0.2784$ € per kg, as depicted in the first line of Table 2. It should be noted here that there are only negligible differences in the optimal investment and disinvestment trigger prices between both firm groups according to Table 2, which is an unavoidable consequence of the numerical solution procedure of the model.

Table 2. Investment and disinvestment trigger prices at different reversibility levels of the investment costs for different time step lengths.

		Firm group 1 (milk yield of 7,000 kg/year)		Firm group 2 (milk yield of 7,000 kg/year)	
	Time step length	Investment trigger price	Disinvestment trigger price	Investment trigger price	Disinvestment trigger price
Model results	1.00	0.4133	0.2784	0.4133	0.2785
	0.50	0.4261	0.2693	0.4260	0.2694
	0.10	0.4431	0.2572	0.4431	0.2571
Result follwing Dixit/Pindyck[a]	→ 0	0.4928	0.2213	0.4928	0.2213

Note: GBM with $\alpha =$ -2.97% and $\sigma =$ 19.20%, $\eta =$ -0.99, $T =$ 100, $I =$ 100 with $I^1 = 50$ and $I^2 = 50$, $C^1 = C^2 = 0.0469$ €/kg, $K^1 = K^2 = 0.3052$ €/kg, $\lambda = 4.25\%$, $s = 50\%$, $r = 3.38\%$.

[a] Solving the analytical system of equations of Dixit and Pindyck (1994: 216ff.) by means of iterative approximation.

These results illustrate the pronounced real options effect, which has already been observed in other real options applications in the dairy sector, which implicitly or explicitly exploit the optimality property of myopic planning (e.g. Engel and Hyde, 2003; Purvis et al., 1995; Tauer, 2006). Accordingly, the investment trigger price in the model is considerably higher than the investment trigger price according to the classical NPV rule (the sum of the capital costs and operational costs, hence 0.3521 € per kg). Similarly, the disinvestment trigger price of the model is considerably lower than that of the classical NPV rule (the reversible share of the capital costs plus the operational costs, hence 0.3287 € per kg).

The validation of the above model results can be carried out by means of the analytical system of equations following Dixit and Pindyck (1994: 216ff.), according to which the optimal investment trigger price is $\overline{P} = 0.4928$ and the disinvestment trigger price is $\underline{P} = 0.2213$ € per kg. Through comparison with the aforementioned model results, it is obvious that the model underestimates the investment trigger price and overestimates the disinvestment trigger price. This is due to the discretisation of time, which is an unavoidable assumption of numerical evaluation methods in contrast to (time-continuous) analytical procedures. At the same time, this time-discrete procedure represents an advantage of numerical models with regard to their application, since, in many sectors and especially agriculture, investments can often be made just once a year due to long implementation times, climate restrictions or other reasons. Nevertheless, the results following Dixit and Pindyck (1994) can be approximated through increasingly smaller time step lengths as illustrated in Table 2.

Accordingly, the firms' optimal investment trigger price increases and their optimal disinvestment trigger price decreases with smaller time step lengths. This is due to the fact that the likelihood of prices (strongly) overshooting the optimal investment trigger price, which acts like an "upper reflecting barrier" (Dixit and Pindyck, 1994), is reduced as a consequence of the smaller time lag in production. As a result, the expected commodity price is ceteris paribus lower and hence induces a higher investment trigger price to compensate the investment costs. Similarly, the risk of prices falling (strongly) below the optimal disinvestment trigger price, which acts like a "lower reflecting barrier", is reduced. Thus, the firms accept a lower disinvestment trigger price before abandoning the investment.

Effects of firm heterogeneity and tradable output permits

Table 3 presents the model results for four different scenarios to illustrate the ceteris paribus effects of both firm heterogeneity and tradable output permits on the firms' optimal investment and disinvestment decisions.

Table 3. Impact analysis of firm heterogeneity and tradable output permits on the firms' investment and disinvestment decisions.

Scenario	Tradable output permits	Firm group	Milk yield (kg/year)	Investment trigger price (€/kg)	Disinvestment trigger price (€/kg)	Output permit trigger price (€/kg)	Incremental producer surplus (€/kg)
A	No	1	7000	0.4133	0.2784	n.a.	n.a.
		2	7000	0.4133	0.2785	n.a.	
B	No	1	10000	0.2895	0.1947	n.a.	n.a.
		2	7000	0.4377	0.2859	n.a.	
C	Yes	1	7000	0.3650	0.2946	0.4791	0.4785
		2	7000	0.3649	0.2952	0.4792	
D	Yes	1	10000	0.2760	0.1984	0.4804	0.4809
		2	7000	0.3456	0.3132	0.4801	

Note: GBM with $\alpha =$ -2.97% and $\sigma =$ 19.20%, $\eta =$ -0.99, $T = 100$, $I = 100$ with $I^1 = 50$ and $I^2 = 50$, $C^1 = 0.0328$ €/kg, $C^2 = 0.0469$ €/kg, $K^1 = 0.2136$ €/kg, $K^2 = 0.3052$ €/kg, $\lambda =$ 4.25%, $s =$ 50 %, $r =$ 3.38 %, $\Delta t = 1$ year.

In scenario A, the base scenario of homogeneous firms with a milk yield of 7,000 kg and no tradable output permits is presented (cf. Table 2). In scenario B, heterogeneity between both firm groups is introduced in such a way that the firms in group 1 become more efficient with a milk yield of 10,000 kg, while the efficiency of the firms in group 2 stays constant with a milk yield of 7,000 kg per cow per year. Scenario C again considers homogeneous firms with a milk yield of 7,000 kg, but introduces a tradable output permit system. In scenario D, the effects of both firm heterogeneity and tradable output permits are depicted.

The ceteris paribus effects of heterogeneity on the firms' investment and disinvestment decisions in markets without tradable output permits (comparison of scenario A and B): Through the improvement of the efficiency level of the firms in group 1 from 7,000 to 10,000 kg milk yield, their optimal investment as well as their disinvestment trigger price decreases considerably, so that they invest earlier and a have a higher inertia to abandon the investment once implemented. This is due to the associated reduction of the capital and operational costs per output unit of the firms in group 1, which can be compensated by a lower investment trigger price. Furthermore, the optimal investment trigger price of the firms in group 2 increases, so that these firms' willingness to invest decreases, although this group's efficiency level remains stable at 7,000 kg. This again can be explained by the positive market quantity effect, which is induced by the higher willingness to invest for the firms in group 1 in the first instance (see above). Hereby, expected milk prices decrease ceteris paribus, therefore leading to a lower expected profitability of the investment project for the firms in group 2. The investment trigger price at present, which needs to compensate for the unchanged capital and operational costs per output unit of the firms in group 2, hence needs to increase. In conclusion, it can be stated that efficiency changes of certain firms do not only affect their own investment and disinvestment decisions, but also the ones of firms with unchanged efficiency levels in the respective market.

The ceteris paribus effects of tradable output permits on the investment and disinvestment decisions of homogeneous firms (comparison of scenario A and C): Through the introduction of tradable output permits, the homogeneous firms' optimal investment trigger price decreases, leading to them investing earlier. There are two opposing effects that need to be considered here: On one hand, the firms additionally have to take into account the capital costs for the output permits to be entitled to produce. This has an increasing effect on the investment trigger price, as the overall investment costs increase. On the other hand, the aggregated quantity of milk supply is restricted in periods of high demand. Hereby, expected milk prices increase ceteris paribus and, with this, the expected profitability of the investment project. Hence, a lower investment trigger price at present can compensate for the capital and operational costs of the firms. In the present case, obviously the latter decreasing effect clearly over-compensates for the former increasing effect. Furthermore, the optimal disinvestment trigger price of the firms slightly increases through the introduction of tradable output permits. This can be explained by the fact that the permit price can be recovered on the permit market if needed and is thus perfectly reversible. In doing so, the firms are able to monetize a higher share of their investment costs straight away upon abandonment, which obviously represents an incentive for them to disinvest earlier. Consequently, this means that in markets with relatively homogeneous firms (or a low degree of firm heterogeneity), the introduction of tradable output permits ceteris paribus can foster structural change.

The ceteris paribus effects of tradable output permits on the investment and disinvestment decisions of heterogeneous firms (comparison of scenario B and D): Under firm heterogeneity, the decreasing effect of tradable output permits on investment trigger prices as well as the increasing effect on disinvestment trigger prices, which both could be observed in the case of homogeneous firms (comparison of scenario A and C), is weakened for the more efficient firms in group 1, while it is even intensified for the less efficient firms in group 2. Through the introduction of the output permit system, the associated restriction of the overall available market quantity especially affects the less efficient firms in group 2, because the more efficient firms in group 1 already invest earlier due to their lower disposable costs per output unit. This obviously forces the less efficient firms in group 2 to decrease the investment trigger price stronger. On the contrary, the disinvestment trigger price of the firms in group 2 would decrease by abolishing the tradable output permit system (going from Scenario D back to Scenario B), so that the firms would be more reluctant to abandon the investment project. This indicates that the recent abolishment of the EU milk production quota will ceteris paribus not lead to an accelerated exit of less efficient farms, which is consistent with the widespread opinion of politicians and lobbyists in the current public debate, but ultimately have quite the opposite effect.

The ceteris paribus effects of heterogeneity on the firms' investment and disinvestment decisions in markets with tradable output permits (comparison of scenario C and D): Through the improvement of the efficiency level of the firms in group 1 in a market, the optimal investment trigger price of the firms in group 1 decreases, because their unit costs decrease as well, as already described in the case of no tradable output permits (comparison of scenario A and B). However, this decreasing effect on the investment trigger price is less pronounced, because the market supply quantity is already restricted by the output permits in the reference scenario (scenario C). This has an increasing effect on the expected commodity price level, whereby the firms in group 1 can already afford to invest at a lower trigger price in the first place. In contrast to the effect of firm heterogeneity without tradable output permits (comparison of scenario A and B), the optimal investment trigger of the remaining firms in group 2, whose efficiency level stays as is, also decreases. This again can be explained by the restriction of the market supply quantity through the permits in the first place. As the firms in group 1 invest earlier (see above), the remaining market quantity available for the firms in group 2, until the overall market permit quantity is exhausted, decreases. This pressure forces them to decrease their investment trigger price to enter the market. This decreasing effect on the optimal investment trigger price of group 2 obviously over-compensates the increasing effect caused by the intensified investments of group 1 (comparison of scenario A and B). In result, the consideration of existing tradable output permits is important when analysing the ceteris paribus effects of different heterogeneity levels on structural change.

Plausibility check of the output permit price level (output permit trigger prices and incremental producer surplus in scenario C and D): According to the model results, the optimal output purchase and sales trigger price within a firm group correspond with each other for both scenarios C and D, in Table 3 depicted as output permit trigger price in the second-last column. This seems reasonable in consideration of the fact that the permit price is perfectly reversible and can immediately be recovered upon exiting the permit market if needed. Furthermore, by comparing the two permit trigger prices of both firm groups within a scenario, it gets obvious that these are (almost) identical. This can be explained by the fact that all firms in the model are assumed to have complete information with regard to their competitors' trading behavior. In market equilibrium, the permit trigger prices of all firms should hence converge against the same level, which is confirmed by the model. The plausibility of the determined permit trigger prices can be checked by comparing them to the incremental producer surplus per output unit (last column of Table 3), which is determined according to equation (14) and (15). Accordingly, both values are (almost) the same for both scenarios, which can be seen as a confirmation that the permits are valued in the model in accordance with common welfare economic theory.

6. Conclusion

In light of the implementation, intensified use or abolishment of tradable output permit systems in agriculture and natural resource industries, changes in firms' investment and disinvestment strategies can be expected. Therefore, the analysis of heterogeneous firms' investment and disinvestment decisions and their respective interactions under tradable output permit systems is of particular interest. In this article, an agent-based real options model is developed which is capable of determining the optimal investment and disinvestment thresholds of heterogeneous competing firms. In the model, a permit market is integrated, wherer the firms either act as demanders or as suppliers according to their investment or disinvestment behavior for production capacity. Through a numerical solution procedure consisting of a combination of GAs and stochastic simulation, the endogenous equilibrium price processes for both the product and the permits can be simultaneously derived, along with the firms' optimal investment and disinvestment thresholds for production capacity.

The results of the model reveal new insights into the effects of tradable output permits on investments and disinvestments at firm level and on structural change at sectoral level. Therefore, the model can serve as an improved decision support for both entrepreneurs and politicians especially in agriculture and natural resource industries, where the abolishment or the introduction of tradable output permit system are currently being conducted or discussed. Amongst others, the results indicate that in markets with relatively homogeneous firms, which show relatively similar levels of efficiency, tradable output permits ceteris paribus can even foster structural change: The firms' investment thresholds decrease, leading them to invest earlier, while the disinvestment thresholds increase, leading to the earlier abandonment of production capacity. In markets with relatively heterogeneous firms, which therefore show greater differences in their levels of efficiency, this effect of decreasing investment thresholds and decreasing disinvestment thresholds is weakened for the more efficient firms, while it is even intensified for the less efficient firms. Interestingly, this finding clearly contrasts with the widespread opinion of the public debate that the recent abolishment of the EU milk production quota leads to an accelerated exit of smaller and, thus, less efficient farms. Therefore, it counters the main argument of politicians and lobbyist who call for the introduction of new support measures due to the milk production quota abolishment. The model simultaneously provides politicians with an understanding of the potential effects of the introduction of tradable carbon emission allowances on structural change. In this respect, the vast modeling flexibility of the model should also be underlined, for instance with regard to the specific design of the carbon emission allowance system.

Although the model addresses some crucial aspects for analyzing investment and disinvestment decisions in competitive environments in reality, it still provides room for further extensions, which are out of scope for this article, but can be the basis for future research. Due to complexity reasons, the present model assumes a constant returns-to-scale technology of the firms, as all other existing real options models in the literature do. Although it can be expected that more complex input-output relationships will not qualitatively change the investigated effects of tradable output permits, their additional consideration could nevertheless lead to further improved forecasts of firms' adaption behaviors. Furthermore, no transaction costs are assumed for the firms with regard to output permit trade, which, however, are existent in reality (e.g. Stavins, 1995). Finally, heterogeneity could not only be manifested in the efficiency levels of the firms, but also in the risk preferences of their managers. To assess the respective impacts on the firms' investment and disinvestment decisions, future research could be beneficial.

References

Abdulai, A. and H. Tietje (2007): Estimating technical efficiency under unobserved heterogeneity with stochastic frontier models: application to northern German dairy farms. In: *European Review of Agricultural Economics* 34(3): 393-416.

Abel, A.B. and J.C. Eberly (1994): A Unified Model of Investment under Uncertainty. In: *American Economic Review* 84: 1369-1384.

Allen, F. and R. Karjalainen (1999): Using genetic algorithms to find technical trading rules. In: *Journal of financial Economics* 51: 245-271.

Altiparmak, F., M. Gen, L. Lin, and T. Paksoy (2006): A genetic algorithm approach for multi-objective optimization of supply chain networks. In: *Computers & Industrial Engineering* 51: 196-215.

Alvarez, A. and C. Arias (2014): Technical efficiency and farm size: a conditional analysis. In: *Agricultural Economics* 30: 241-250.

Arifovic, J. (1994): Genetic algorithm learning in the cobweb model. *Journal of Economic Dynamics and Control* 18: 3-28.

Baldursson, F. M. and I. Karatzas (1997): Irreversible Investment and Industry Equilibrium. *Finance and Stochastics* 1: 69-89.

Balmann, A., K. Dautzenberg, K. Happe and K. Kellermann (2006): On the dynamics of structural change in agriculture: Internal frictions, policy threats and vertical integration. In: *Outlook on Agriculture* 35: 115-121.

Bundesbank (2014). *Time series of monthly average yields on debt securities outstanding issued by residents with residual maturity of more than 15 and up to 30 years.* http://www.bundesbank.de/statistik/ statistik_zeitreihen.en.php?func=row&tr=WU3975. Accessed 2 November 2014.

Claassen, R. and R.E. Just (2011): Heterogeneity and distributional form of farm-level yields. In: *American Journal of Agricultural Economics* 93: 144-160.

Dawid, H. (1999). *Adaptive Learning by Genetic Algorithms: Analytical Results and Applications to Economic Models*. Second Edition. Heidelberg, Germany: Springer-Verlag Berlin.

Dixit, A. (1991). Irreversible imvestments with price ceilings. In: *Journal of Political Economy* 99: 541-557.

Dixit, A. and R.S. Pindyck (1994): *Investment under Uncertainty*. Princeton, US: Princeton University Press.

Engel, P.D. and J. Hyde (2003). A Real Options Analysis of Automatic Milking Systems. In: *Agricultural and Resource Economics Review* 32: 282-294.

European Commission (2016). *EUROSTAT data*. http://ec.europa.eu/eurostat/data/database. Accessed 6 February 2016.

Feil, J.H. and O. Musshoff (2013): Modelling investment and disinvestment decisions under competition, uncertainty and different market interventions. In: *Economic Modelling* 35: 443-452.

Goldberg, D.E. (1989). *Genetic Algorithms in Search, Optimization and Machine Learning*. Reading, MA: Addison-Wesley.

Graubner, M., A. Balmann, R.H. Sexton (2011): Spatial price discrimination in agricultural product procurement markets: a computational economics approach. In: *American Journal of Agricultural Economics* 93: 949-967.

Heshmati, A. and S.C. Kumbhakar (1994): Farm heterogeneity and technical efficiency: some results from Swedish dairy farms. In: *Journal of Productivity Analysis* 5(1): 45-61.

Hull, J.C. and A. White (1987): The Pricing of Options on Assets with Stochastic Volatilities. In: *Journal of Finance* 42: 281-300.

KTBL (2014): Association for Technology and Structures in Agriculture (Ed.): *Betriebsplanung Landwirtschaft 2013/2014*. Darmstadt, Germany.

Kersting, S., S. Hüttel, and M. Odening (2016): Industry dynamics under production constraints—The case of the EU dairy sector. In: *Economic Modelling* 55: 135-151.

Leahy, J.V. (1993): Investment in Competitive Equilibrium: The Optimality of Myopic Behavior. In: *Quarterly Journal of Economics 108*: 1105-1133.

LIC (2014): *Livestock Improvement Corporation: New Zealand Dairy Statistics Publications*. http://www.lic.co.nz/lic_Publications.cfm. Accessed 2 November 2014.

Mitchell, M. (1996): An introduction to genetic algorithms. MIT Press, Cambridge.

Odening, M., O. Musshoff and A. Balmann (2005): Investment Decisions in Hog Finishing: An Application of the Real Options Approach. In: *Agricultural Economics* 32: 47-60.

Odening, M., O. Musshoff, N. Hirschauer and A. Balmann (2007): Investment under Uncertainty – Does Competition Matter? In: *Journal of Economic Dynamics and Control* 31: 994-1014.

Purvis, A., W.G. Boggess, C.B. Moss and J. Holt (1995): Technology Adoption Decisions Under Irreversibility and Uncertainty: An Ex Ante Approach. In: *American Journal of Agricultural Economics* 77: 541-551.

Richards, T.J. and P.M. Patterson (1998): Hysteresis and the Shortage of Agricultural Labor. In: *American Journal of Agricultural Economics* 80: 683-695.

Stavins, R.N. (1995): Transaction costs and tradeable permits. In*: Journal of environmental economics and management* 29(2): 133-148.

Tauer, L.W. (2006): When to get in and out of dairy farming: A real option analysis. In: *Agricultural and Resource Economics Review* 35: 339-347.

Thiele, S. (2008): Food demand elasticities: An AIDS using German cross sectional date. In: *German Journal of Agricultural Economics* 57: 258-268.

Trigeorgis, L. (1996): *Real options: Managerial flexibility and strategy in resource allocation*. MIT press, 1996.

Turvey, C., A. Weersink and C. Martin (2003): The value of dairy quota under a commercial export milk program. In: *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 51: 69-83.

Veeman, M.M. (1982): Social costs of supply-restricting marketing boards. In: *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 30 (1): 21-36.

Weninger, Q. and R.E. Just (2002): Firm dynamics with tradable output permits. In: *American Journal of Agricultural Economics* 84(3): 572-584.

Wossink, A. and C. Gardebroek (2006): Environmental policy uncertainty and marketable permit systems: The Dutch phosphate quota program. In: *American Journal of Agricultural Economics* 88(1): 16-27.

Zhao, J. (2003): Irreversible abatement investment under cost uncertainties: tradable emission permits and emissions charges. In: *Journal of Public Economics* 87: 2765-2789.

Diskussionspapiere

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Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
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- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

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