Switching between suspension and production in the presence of investment lags and uncertainty

Alfons Balmann*, Karin Kataria*, Lioudmila Moeller*

*Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO), Halle (Saale), Germany

Abstract

A general result in real option theory is that the investment trigger increases with increasing volatility of project returns. However, for irreversible investments with a possibility to reduce losses through temporary production suspension this result does not necessarily hold. In this case, incentives to invest may increase at high volatilities. The reason is that losses can be reduced in bad states while a chance for high profits exists in good states. This paper analyses for the first time how investment triggers are affected by the ratio of variable to fixed production costs and the particular role of time-lags between investment decision and production, given the option to suspend production. Using simulation experiments, it is numerically illustrated that the impact of the suspension option on investment incentives is more pronounced if the ratio of variable to fixed production costs and time-lags are high. It is further shown that this effect exist in both competitive and uncompetitive environments.

Keywords: real options theory, option to suspend, variable to fixed costs, time lags

1. Introduction

The real options approach to investment decisions (e.g. Dixit and Pindyck, 1994) considers investment irreversibility, uncertainty in returns and flexibility in investment timing. A general result of this approach is that the critical value at which it is optimal to invest increases with increasing volatility of the project returns. This is an intuitive result as higher uncertainty increases the value of waiting for additional information which may reduce or resolve uncertainty. However, in the presence of investment lags and convexity of profits in output price it has been shown that this result does not necessarily hold (e.g. Bar-Ilan and Strange, 1996; Aguerrevere, 2003; Maoz, 2008). In this case, the investment trigger may decline at high uncertainties even below the total production costs.

Convexity of profits in output price may be due to different reasons. It may, for example, be due to the option to suspend production. In the case of high uncertainty in investment returns, the option to suspend implies that the size of losses in bad states (low output prices) is limited to the fixed costs as the variable costs can temporarily be avoided by pausing production. Vice versa, continuation of production in good states allows to take the benefits. Thus, there may be an additional effect working in the opposite direction than predicted by Dixit and Pindyck (1994). Accordingly, the net effect of increasing volatility on investment incentives is ambiguous. The option to abandon the investment project leads, for similar reasons, to the same result (see e.g. Bar-Ilan and Strange, 1996). Further factors leading to convexity of profits in output price include the existence of production margins such as shift work or extra hours or a general ability of the firm to adjust the amount produced (Maoz, 2008).

This paper focusses on the case when convexity of profits in output price is due to the option to temporarily suspend production. In particular, our analysis shows for time-lagged irreversible investments with a possibility to temporarily suspend production that an increasing ratio of variable to fixed production costs can positively influence investment incentives and that this effect is especially pronounced in the presence of long lags.

The described effect is analysed by using a real options based investment model in which firms identify their optimal investment triggers using stochastic simulation in combination with genetic-algorithms. Numerical results are obtained which show the net effect of different
parameter settings on investment incentives when production can be temporarily suspended. The analysis is conducted for the cases with and without competition.

The remainder of this article is organized as follows. Section 2, provides an overview of literature dealing with the effect of investment lags on irreversible investments. Section 3 describes the investment model and its assumptions. The simulation results are presented and discussed in section 4, followed by conclusions (section 5).

2. Review of related literature

Real cost-intensive irreversible investments are usually characterized by the fact that their proceeds are realized not immediately after an investment decision is made, but take time. In the economic literature, this has been referred to as time lags, investment lags, time-to-build or ‘gestation period’\(^1\). Authors analyzing the effect of time-to-build on firms’ investment decisions under uncertainty have arrived at different conclusions which can be attributed to differences in their models and assumptions. Majd and Pindyck (1987), for instance, study continuous sequential investments in a single project assuming that the project can be delayed at any stage. The authors find that time lags have a depressing effect on uncertain irreversible investments. This model was revised by Milne and Whalley (2000) by adding the condition of the zero net marginal benefit of investing at the optimal investment threshold. Milne and Whalley show that although the optimal investment threshold is still greater than suggested by a ‘naïve’ net present value (NPV) analysis, the presence of time to build can reduce the effect of increased uncertainty. An increased time-to-build is, however, represented only indirectly through the increased opportunity cost of delay in their model.

Using a model of uncertain irreversible investments where the project can be abandoned and restarted, Bar-Ilan and Strange (1996) arrive at an opposite conclusion than Majd and Pindyck (1987).\(^2\) They point out the ambiguous effect of increasing uncertainty in the presence of time lags and the option to abandon, which implies a convex profit function regarding the uncertain output price. On the one hand, increasing uncertainty in the presence of time lags means, as in Dixit and Pindyck’s original model, that waiting allows the firm to receive new information which may reduce or resolve uncertainties. On the other side, the opportunity cost of waiting also increases with increasing uncertainty. Due to the option to abandon, firms’ losses are bounded in bad states, while there is no corresponding upward limit in good states. In the presence of longer lags, the opportunity costs of waiting do not depend on the price during the delay, but on the price thereafter. Therefore time lags in combination with the option to abandon increase the likelihood of extreme profits and may not only weaken, but even overcompensate the deterrent effect of uncertainty on investments.

Maoz (2008) modifies the model of Bar-Ilan and Strange (1996) by introducing continuous time and substituting the exit option by the option to vary the output according to market conditions in order to achieve an analytic solution. Like Bar-Ilan and Strange (1996), Maoz considers convexity of profits in output price, although modelled in a different way. In fact, as pointed out by Maoz, convexity of profits in output price may be due to a number of different factors such as the option to abandon the investment project, the option to adjust amount produced or the existence of production margins such as shift work or extra hours (Maoz, 2008). Maoz arrives at a similar conclusion as Bar-Ilan and Strange (1996). In particular, he observ-

---

\(^1\) Kalecki (1937), p. 81. Time lags were first mentioned in economic literature in the 1920th - 30th when it was brought up as a potential explanation of macroeconomic cyclical output fluctuations (Pigou, 1927; Kalecki, 1935). Prior to development of the real options approach, the role of time lag in firms’ investment behaviour was first emphasized by Nerlove (1972). Nickell (1977) analyzed its role for uncertain investment decisions of firms.

\(^2\) As discussed by Bar-Ilan and Strange (1996), this is due to different assumption regarding the opportunity cost of delay. Majd and Pindyck assumed that the opportunity cost of delay is independent of uncertainty.
ers that for short time lags uncertainty affects investments negatively, but sufficiently long lags engender an inverse U-shape relationship between uncertainty and the investment trigger. The author further demonstrates that the longer the time lag (that is the higher the degree of profit convexity), the wider the range of a positive uncertainty-investment relationship and the lower the level of uncertainty from which the critical price decreases. Maoz emphasizes that the condition for the positive effect of volatility on investment is the concurrent presence of time lags and convex profit function of the output price.

Aguerrevere (2003) analyses incremental time-lagged investments in non-storable commodities under conditions of competition and uncertain output price. Like Maoz (2008), Aguerrevere assumes that the output amount can be adjusted according to market conditions which enables firms to limit their losses and causes that the net effect of uncertainty on investments is not always negative as conventional real option models predict. With regard to the effect of competition, Aguerrevere finds that it has no depressing effect on investments (as in Pindyck, 1993), if there is only one production factor or if production factors cannot be substituted. If no substitution is possible, he finds that high uncertainty stimulates investments in capacity even in the presence of free capacity. Optimal capacity under uncertainty may thus be larger than under certainty conditions and increase with longer time lags.

Martins and da Silva (2005) take into account exit and entry options and demonstrate numerically that for time-lagged sequential investments the waiting value may not be very significant, implying that the gap between the NPV and ROA triggers becomes smaller. An increase in uncertainty may even anticipate the decision to invest. The authors also conclude that sequential investments strengthen the effect that time to build has on investments decisions, especially if uncertainty is high. Uncertainty of the investment cost, in turn, has no significant effect on firm’s investment decision.

In common with many of the studies discussed above, this paper analyses how the presence of investment lags and convexity of profits in output price affects investment incentives in the case of uncertain and irreversible investments. We focus on the case when convexity of profits in output price is due to the option to temporarily suspend production. In particular, our results show that introducing time lags and the possibility to temporary suspend production may not only reduce, but also overcompensate the depressive effect of uncertainty on investments. In this case, higher uncertainty may increase incentives for investment, whereat the effect is stronger for longer time lags. This finding contradicts the conventional result, but is similar to the findings of, e.g., Bar-Ilan and Strange (1996) and Maoz (2008) and can be explained by the fact that for high volatilities the downside risk is limited while a chance for very high profits exists if returns increase by positive shocks. Moreover, we show that this phenomenon exist in both competitive and uncompetitive environments.

A novel contribution of our analysis consists in demonstrating that the ratio of variable to fixed production costs affects investment incentives given the option to suspend production. As in this case convexity of profits in output price is due to the possibility to temporarily avoid variable production cost in periods with low output price, it can be expected that the level of the ratio of variable to fixed production costs determines the magnitude of the effect that the option to suspend has on investment incentives. These effects are analysed using simulation experiments carried out using a version of the investment model in Odening et al. (2007), which will be explained in greater detail in the following section.

3. Model and scenarios

The impact of the ratio of variable to fixed production costs on investment incentives when there is the option to suspend production is analysed numerically using simulation experiments building on Balmann and Müßhoff (2002), Odening et al. (2007), and Feil et al. (2012).
The base scenario reflects a competitive market (i.e. regulated price process) represented by $N$ firms and considers discrete time steps with a time step length of $\Delta t$. In each period $t$ every firm has the opportunity to invest in identical assets or a fraction of them. A time-lagged investment started in $t$, will generate revenues not immediately, but at time $t + \Delta t$, where $l$ is the number of time steps needed for implementation of the investment project, i.e. $\Delta t l$ is the time lag between investment decision and its effectiveness. The maximum asset stock of a firm $n$ is 1 and can be used to produce up to $x_{t,n} \leq 1$ units of output. Constant returns to scale are assumed implying that investment outlay and production are proportional. In every period, the previously installed capital depreciates geometrically with the rate $\lambda$. In order to keep the production capacity constant or to increase it, investments and reinvestments can be made. Letting $I$ denote the maximum initial investment outlay, the maximum investment outlay $M$ of firm $n$ at time $t$ is:

$$M_{t,n}^{max} = \left[1 - (1 - \lambda) \cdot x_{t,n}\right] \cdot I,$$

such that $x_{t+\Delta t,n}^{max} = 1$. Investment outlays are assumed to be irreversible and totally sunk. Investments $M_{t,n}$ are made only if the expected output price $\hat{p}_{t+\Delta t}$ is higher or equal the equilibrium investment price $p^*_n$. When choosing an equilibrium trigger, each firm aims to maximize the expected net present value of future cash flows $\hat{\Pi}_n(p^*_n)$:

$$\max_{p^*_n} \left[ \hat{\Pi}_n(p^*_n) = E\left[ \sum_{t=0}^{\infty} \left( x_{t,n} \cdot (p_t - c) - M_{t,n}(x_{t,n}, p^*_n) \right) \cdot (1 + r)^{-t} \right] \right],$$

where $p_t$ is the output price in period $t$, $c$ the variable production costs per unit of output and period, and $r$ the risk-free interest rate.

The competition among the firms secures that on the aggregated level the expected net present value is zero:

$$E \left[ \sum_{t=0}^{\infty} \sum_{n=1}^{N} \hat{\Pi}_n(p^*_n) \right] \equiv 0.$$

Total supply $X^S_t$ of all firms and the total demand $X^D_t$ for the output in period $t$ are formally defined as

$$X^S_t = \sum_{n=1}^{N} x_{t,n} \quad \text{and}$$

$$X^D_t = \frac{\alpha_t}{(p^*_t)^{-\eta}}$$

with the demand parameter $\alpha$ and the elasticity of demand $\eta$. For the identity of demand and supply, the following holds

$$p_t = \left( \frac{\alpha_t}{X^D_t} \right)^{-\frac{1}{\eta}} = \left( \frac{\alpha_t}{X^D_t} \right)^{-\frac{1}{\eta}}.$$

The demand parameter in the next period $\alpha_t$ is assumed to follow a time-discrete version of the geometric Brownian motion

$$a_t = \alpha_{t-\Delta t} \cdot \exp \left( \left( \mu_{\alpha} - \frac{\sigma_{\alpha}^2}{2} \right) \cdot \Delta t + \sigma_{\alpha} \cdot \varepsilon_{\alpha,t} \cdot \sqrt{\Delta t} \right),$$

where $\mu_{\alpha}$ and $\sigma_{\alpha}$ are the expected return and volatility of $\alpha$, $\varepsilon_{\alpha,t}$ is a standard normal random variable, and $\Delta t$ is the time step length.
where $\sigma$ denotes demand volatility, $\mu$ its drift rate, and $\varepsilon_t$ a normally distributed random number. Equations (6) and (7) show that after the investment decision has been made, output price will depend on the relation of $\alpha_t$ and $\alpha_{t-\Delta t}$.

Taking into account the identity of demand and supply (Equations (4) and (5)), for the expected output price holds

$$
\hat{p}_{t+\Delta t} = \left( \frac{\hat{\alpha}_{t+\Delta t}}{\hat{\lambda}_{t+\Delta t}} \right)^{-\frac{1}{\eta}}
$$

with

$$
\hat{\lambda}_{t+\Delta t} = \sum_{n=1}^{N_n} \hat{x}_{t+\Delta t,n}
$$

where

$$
\hat{x}_{t+\Delta t,n} = \begin{cases} 
1 & \text{if } n \text{ invests } M_{t,n}^\text{max} \\
(1-\lambda) \cdot x_{t,n} + \frac{M_{t,n}}{n} & \text{if } n \text{ invests } 0 < M_{t,n} < M_{t,n}^\text{max} \\
(1-\lambda) \cdot x_{t,n} & \text{if } n \text{ invests } M_{t,n} = 0.
\end{cases}
$$

The environment of a firm $n$ consists therefore not only of the uncertain demand for output, but also of the behaviour of other firms. In order to capture competitive interaction between the firms, an agent-based setting is used where firms acting as agents can respond to changing environment individually and autonomously\(^3\). It is further assumed that firms with lower trigger prices $p_{n}^*\text{'}$ have a stronger tendency to invest, so that all firms can be sorted according to their trigger prices $p_{n}^* \leq p_{n+1}^*$. It then holds that: i) if firm $n$ does not invest in $t$, then firm $n + 1$ will also not invest in $t$, ii) if firm $n$ invests in $t$, then firm $n - 1$ will invest $M_{t,n-1}$ in $t$, and iii) in every period $t$, a marginal firm $n_t^0$ exists which invests $M_{t,n_t^0}$ such that the expected price for the next period is equal to the investment trigger of firm $n_t^0$\(^4\).

The investment of firm $n_t^0$ is calculated as follows:

$$
p_{n_t^0} = \hat{p}_{t+\Delta t} = \left( \frac{\hat{\alpha}_{t+\Delta t} \cdot \hat{x}_{t+\Delta t,n_t^0} \cdot (n_t^0 - 1) \cdot \sum_{n=n_t+1}^{N} \hat{x}_{t,n} \cdot (1-\lambda)}{\hat{x}_{t+\Delta t,n_t^0} \cdot (n_t^0 - 1)} \right)^{-\frac{1}{\eta}},
$$

implying that

$$
x_{t+\Delta t,n_t^0} \cdot (p_{n_t^0}^*)^{-\eta} = \left[ (n_t^0 - 1) + (1-\lambda) \cdot \sum_{n=n_t+1}^{N} \hat{x}_{t,n} \right],
$$

and

$$
M_{t,n_t^0} = \frac{\hat{\alpha}_{t+\Delta t} \cdot \hat{x}_{t+\Delta t,n_t^0} \cdot (n_t^0 - 1) \cdot \sum_{n=n_t+1}^{N} \hat{x}_{t,n}}{(p_{n_t^0}^*)^{-\eta}} = \left[ (n_t^0 - 1) + (1-\lambda) \cdot \sum_{n=n_t+1}^{N} \hat{x}_{t,n} \right].
$$

Equation (13) is an equilibrium condition; all firms fully investing and, hence, producing at maximum capacity have trigger prices which are less than or equal to the trigger price of the firm $n_t^0 + 1$. This price is also equal to the expected price of the next period. All firms which do not invest have trigger prices higher or equal the expected price of the next period. The last


\(^4\)Notice, $n_t^0$ is zero, if there is no investor in period $t$. 

5
firm with a positive investment \( n_i^* \) can be identified by iteratively testing all firms for \( p_{n_i^*} = \hat{p}_{n_i^*} \). Due to the competitive environment and identical production technologies, the expected profitability of a rational investment strategy (as presented in Equation (2)) will fulfill the zero-profit condition given all other strategies are also rational.

Within this model all firms compete via defining their trigger prices. The interaction of the firms (or agents) equals a second price sealed bid auction in which each agent can sell his/her product if he/she asks less or equal the equilibrium price. Because all agents have identical production costs and because they have no market power, it should be expected that in equilibrium all agents have the same trigger price. According to the Leahy model and its assumptions (Leahy, 1993), this equilibrium trigger price equals the trigger price of the myopic planner (cf. Odening et al., 2007). If all agents apply the equilibrium price, the resulting price process equals (cp. Balmann and Mußhoff, 2002):

\[
p_t = \begin{cases} 
  p^* \cdot s_t^{-\frac{1}{\eta}} & \text{if } p_{t-\Delta t} \geq (1 - \lambda)^{\Delta t} \cdot p^* \\
  p_{t-\Delta t} \cdot \left(\frac{s_t}{(1-\lambda)^{\Delta t}}\right)^{-\frac{1}{\eta}} & \text{otherwise,}
\end{cases} \quad (14)
\]

where

\[
s_t = \exp \left[ \left( \mu_{\alpha} - \frac{\sigma_{\alpha}^2}{2} \right) \cdot \Delta t + \sigma_{\alpha} \cdot \epsilon_{\alpha, t} \cdot \sqrt{\Delta t} \right]. \quad (15)
\]

For identical trigger prices and parameters of the stochastic process the agent-based model and the direct simulation of the regulated price process lead to identical price processes (which, thus, validates the agent-based model; cf. Balmann and Mußhoff (2002), figure 5).

An important extension for our analysis is that when output price falls below total production costs, firms can suspend production and restart it when business conditions improve. This option is assumed to incur no additional costs and can be understood as firms’ operating flexibility which allows varying the output amount according to market conditions. This implies that there is a lower limit for the price equal to the level of variable unit costs.

In a second scenario, we consider the case of no competition (i.e. unregulated price process). The above described endogenous regulated price process is then replaced by an exogenous price process:

\[
p_t = p_{t-\Delta t} \cdot \exp \left[ \left( \mu_{\delta} - \frac{\sigma_{\delta}^2}{2} \right) \cdot \Delta t + \sigma_{\delta} \cdot \epsilon_{\delta, t} \cdot \sqrt{\Delta t} \right] \quad (16)
\]

where \( \sigma_{\delta} \) denotes output price volatility, \( \mu_{\delta} \) its drift rate, and \( \epsilon_{\delta, t} \) a normally distributed random number. Thus, in the unregulated scenario, the price process is assumed to directly follow a time-discrete version of the GBM.

The model is solved using stochastic simulation in combination with a genetic algorithm\(^5\) as approximation technique to identify an equilibrium investment trigger.\(^6\) The calculations are

---

\(^5\) Genetic algorithm (GA) is a heuristic optimization and search technique developed in analogy to the processes of natural evolution, making use of concepts such as selection, crossover and mutation (cf. Goldberg, 1998). Within the economic discipline it has been used as a tool for optimisation but also for determining equilibriums (e.g. Arifovic, 1994; Balmann and Happe, 2002; Feil et al., 2012).

\(^6\) The number of iterations considered here is 2,000.
based on an interest rate \( r = 6\% \), a depreciation rate \( \lambda = 5\% \), demand elasticity \( \eta = -1 \), a drift rate \( \mu = 0 \), and discrete time steps \( \Delta t = 0.25 \). The considered time horizon \( T \) is 100 years. An investment cost \( I_{A=5\%} \) of 36.0112 € is assumed, which corresponds to a periodical fixed production cost of 1 per unit. The stochastic demand and price processes in Equations (6) and (15) assume drift rates \( \mu = 0 \), whereas the volatilities are assumed to vary from 5% to 40%. The variable cost respectively the ratio of variable-to-fixed cost per unit, is varied between 0, 1, 2, 4, 8, 16 and 32. The time lag lengths between the investment decision and its effectiveness is varied between 0, 0.25, 0.5, 0.75 and 1 periods (corresponding to 0, 1, 2, 3 and 4 time steps).

4. Simulation results

Although the real options theory as presented in Dixit and Pindyck (1994) does not explicitly consider the effect of time lags on the investment rule, it nevertheless allows to conclude that a smaller time lag would reduce the likelihood of extreme prices in the presence of high volatility leading to a lower expected product price or marginal return. This would induce a higher trigger value able to compensate the investment outlays. A longer time lag, vice versa, would lead to a lower trigger. As evident from Figure 1, our simulation results support this intuition.

Figure 1: The effect of time lags and variable to fixed cost ratios on the investment rule in the case of competition (regulated case).
However, our results also show that increasing volatility does not necessarily lead to increasing investment triggers if investments are characterized by long time lags and high ratio of variable to fixed costs. The values of the equilibrium investment triggers for volatilities 10%, 15% and 20% are reported in Tables 1 and 2.

As Figure 1 shows, for small ratios of variable to fixed costs, the impact of increasing volatility on investment trigger is not affected by the length of investment lags. For significant fractions of variable costs in the total costs (VC/FC=16), in contrast, the positive correlation between volatility and investment trigger does not hold for longer time lags. Similar results were obtained for scenario with no competition (Figure 2), in which the decline in trigger was observed already for a smaller fraction of operating cost (VC/FC=8).

Table 1: Equilibrium investment triggers for different volatilities σ, ratios of variable to fixed costs and time lags in the regulated case

<table>
<thead>
<tr>
<th>σ</th>
<th>VC/FC</th>
<th>no time lag</th>
<th>time lag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10%</td>
<td>0</td>
<td>1.060</td>
<td>1.060</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.122</td>
<td>1.121</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.183</td>
<td>1.180</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.292</td>
<td>1.291</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.476</td>
<td>1.458</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1.721</td>
<td>1.641</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>2.004</td>
<td>1.694</td>
</tr>
<tr>
<td>15%</td>
<td>0</td>
<td>1.138</td>
<td>1.139</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.275</td>
<td>1.273</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.399</td>
<td>1.395</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.599</td>
<td>1.590</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.899</td>
<td>1.838</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2.260</td>
<td>2.084</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>2.666</td>
<td>2.043</td>
</tr>
<tr>
<td>20%</td>
<td>0</td>
<td>1.236</td>
<td>1.236</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.457</td>
<td>1.461</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.646</td>
<td>1.637</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.922</td>
<td>1.898</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2.302</td>
<td>2.215</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2.744</td>
<td>2.444</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>3.243</td>
<td>2.317</td>
</tr>
</tbody>
</table>
Table 2: Equilibrium investment trigger for different volatilities $\sigma$, ratios of variable to fixed costs in the unregulated case

<table>
<thead>
<tr>
<th>$\sigma$</th>
<th>VC/FC</th>
<th>no time lag</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.197</td>
<td>1.198</td>
<td>1.198</td>
<td>1.198</td>
<td>1.198</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.398</td>
<td>1.390</td>
<td>1.389</td>
<td>1.406</td>
<td>1.374</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.557</td>
<td>1.567</td>
<td>1.570</td>
<td>1.569</td>
<td>1.571</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.829</td>
<td>1.807</td>
<td>1.808</td>
<td>1.770</td>
<td>1.827</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2.241</td>
<td>2.240</td>
<td>2.203</td>
<td>2.196</td>
<td>2.216</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2.681</td>
<td>2.678</td>
<td>2.593</td>
<td>2.547</td>
<td>2.462</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>3.403</td>
<td>3.101</td>
<td>2.874</td>
<td>2.686</td>
<td>2.554</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.311</td>
<td>1.312</td>
<td>1.312</td>
<td>1.312</td>
<td>1.312</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.607</td>
<td>1.600</td>
<td>1.575</td>
<td>1.591</td>
<td>1.603</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.840</td>
<td>1.826</td>
<td>1.825</td>
<td>1.793</td>
<td>1.789</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.154</td>
<td>2.162</td>
<td>2.163</td>
<td>2.138</td>
<td>2.121</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2.654</td>
<td>2.519</td>
<td>2.589</td>
<td>2.437</td>
<td>2.477</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2.979</td>
<td>2.878</td>
<td>2.845</td>
<td>2.900</td>
<td>2.563</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>3.816</td>
<td>2.801</td>
<td>2.674</td>
<td>2.247</td>
<td>1.920</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.428</td>
<td>1.438</td>
<td>1.438</td>
<td>1.438</td>
<td>1.438</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.804</td>
<td>1.753</td>
<td>1.789</td>
<td>1.814</td>
<td>1.781</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.068</td>
<td>2.021</td>
<td>2.023</td>
<td>2.128</td>
<td>2.098</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.470</td>
<td>2.489</td>
<td>2.457</td>
<td>2.409</td>
<td>2.383</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>3.059</td>
<td>3.018</td>
<td>2.850</td>
<td>2.680</td>
<td>2.687</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>3.669</td>
<td>3.380</td>
<td>3.128</td>
<td>3.021</td>
<td>2.572</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>4.093</td>
<td>3.537</td>
<td>2.683</td>
<td>2.453</td>
<td>1.215</td>
<td></td>
</tr>
</tbody>
</table>

The decreasing critical prices are however owed not only to the disproportionately high variable costs, but to the simultaneous possibility to temporarily suspend the investment project in the case of unfavourable prices. As the results display, the investment triggers decrease at the high volatility ends, i.e. with increasing likelihood of very high prices. Given the possibility of the temporary project suspension, the downside risk and losses can be limited, while a chance for very high profits exists after positive shocks. These opportunities compensate for fixed costs during suspension. This effect is the stronger the longer the investment proceeds are lagged. In competitive environment (Figure 1) with sufficiently long time lags and very high fractions of operating costs, the equilibrium investment trigger may even decline below the production cost (and hence, below the trigger under certainty) even in the presence of small volatilities.

Competition between the firms not only lowers the product price leading to low profit margins and, consequently, to a lower investment trigger than in the case of no competition (Figure 2). In the case of no competition (Figure 2), a longer time lag (in our model 3 or 4 periods) induces a more ambiguous relationship between investment trigger and volatility, similar to a sigmoid or an inverse U-shape; and the longer the time lag the wider is the range of the negative uncertainty-trigger relationship.
Figure 2: The effect of time lags and variable to fixed cost ratios on the investment rule in the case of no competition (unregulated case).

Similar observations have been made by Maoz (2007). However, in contrast to Maoz, our results demonstrate that such inverse U-shape relationships exists only in the presence of high variable to fixed cost ratio. Bar–Ilan and Strange (1996) argue that longer time lags offset uncertainty, because in the presence of time lags the opportunity costs of waiting depend not on the prices during the delay, but on the future prices. That is, the higher the volatility and the higher the time lag, the lower is the correlation between the current and the future price. Our simulations additionally point out the combined importance of time lags, option to suspend and cost structure for the positive uncertainty-investment relationship.

As Figure 1 and 2 further show, if time lags are small (no lag or only 1 period), uncertainty affects investments negatively in both scenarios. This finding is in line with the general investment rule for uncertain irreversible investment (cf. e.g. Dixit and Pindyck, 1994; Majd and Pindyck, 1987). Long time lags, in turn, can engender an inverse U-shape relationship also between the trigger and sufficiently high operating costs, as seen in Figures 3 and 4.
Figure 3: The effect of variable to fixed cost ratio and competition on the investment rule for $\sigma=10\%$ and $\sigma=20\%$ (regulated case).

Figure 4: The effect of variable to fixed cost ratio and no competition on the investment rule for $\sigma=10\%$ and $\sigma=20\%$ (unregulated case).

Figure 5 exemplifies this case for time lag equal to 4 periods in a competitive environment. The presented relationship is inconsistent to the general prediction of the real option literature on the negative uncertainty-investment relationship, and can be attached to the combined effect of the cost structure, possibility of loss limitation and projects’ time to build. Figure 5 also demonstrates that the higher the uncertainty, the lower the variable to fixed cost ratio can be at which the depressive effect of uncertainty on investments is overcompensated.
Figure 5: The effect of variable to fixed cost ratios and competition on the investment trigger for time lag=4 periods (regulated case).

As a part of the model robustness analysis (along with the examination of the non-negativity of the profit function) the effect of the time lags and operating cost on the investment trigger was studied also for different depreciation rates. In particular, we compared depreciation rates equal and higher than the degree of uncertainty. As presented in Figure 6, depreciation rates approaching or exceeding the volatility lead to a convergence of the critical investment price to that under certainty.

Figure 6: The effect of depreciation rate and competition on the investment rule for σ=10% (regulated case).
The comparison of Figure 6 with Figure 3 (for $\sigma=10\%$) makes this effect even more evident. However, the depressing effect of the increasing operating costs and the option to suspend on the investment trigger still holds and is the stronger the more the investment is time-lagged. As discussed above, in the presence of high operating costs the effect of the option to suspend on investment incentives is especially pronounced as it means that a larger share of total production costs can be avoided in times with low product prices. A higher depreciation rate reduces losses in times of negative demand shocks as it enables prices to recover faster and therefore reinforces this effect.

5. Summary and conclusions

Previous studies have shown that the conventional result of the real option theory, i.e. that the investment trigger increases with increasing volatility of project returns, may not necessarily hold for irreversible time-lagged investments when profit is a convex function of product price. The convexity of profits in output price may for example stem from the option of suspending production which enables producers to temporarily avoid variable production cost in periods with low product prices (i.e. a price lower than variable production costs). In this case, investment triggers may instead decline if uncertainties increase.

This paper showed for the first time that, if there is the option to suspend production, investment incentives depend on the ratio of variable to fixed production costs. Specifically, it is argued that a higher ratio of variable to fixed production costs implies a greater effect of the option to suspend on investment incentives as it means that a larger share of total production costs can be avoided in times with low product price. This effect was confirmed numerically using simulation experiments. Our analysis shows that a higher ratio of variable to fixed costs implies lower investment triggers and, thus, higher investment incentives. In fact, for very high volatilities, the investment trigger may be even lower than predicted by the classical NPV investment trigger. The same is true for very high ratios of variable to total production costs. This result can be explained by the fact that high price volatilities induce a chance for very high profits whereas losses are limited to the fixed costs through the option to suspend. One may argue that in such cases existing production capacities at a given time provide a (European) option to produce. An increasing ratio of variable to fixed production costs similarly means that the asymmetry in absolute levels of potential gains and losses increases as a larger share of the losses can be avoided when the share of variable costs is higher. Our results further show that this effect exists in both competitive and uncompetitive environments, but is more pronounced in competitive settings.

The findings of this study show that the conventional conclusion of the real option theory may lead to highly incorrect predictions about investment behaviour in industries characterized by a high share of variable production costs (e.g. building and construction industry, heavy equipment industry) and longer times to build. For these industries, the accuracy of applying the real options approach strongly depends on a proper specification of the investment model as well as that of the returns in order to capture the degree of the flexibility the producer has in adjusting output levels during times with low product prices.

It should finally be noted that since our conclusions are based on numerical simulation experiments, further research that analytically show the impact of the option to suspend, including the impact of the ratio variable to fixed cost ratio, would be beneficial. Moreover, our study suggests that uncertainties on input markets which affect the variable to fixed costs ratio deserve attention.
References


McDonald, R., Siegel, D., 1985. Investment and the Valuation of Firms When There is an Option to Shut Down. International Economic Review 26, 331-349.


McDonald, R., Siegel, D., 1985. Investment and the Valuation of Firms When There is an Option to Shut Down. International Economic Review 26, 331-349.


