Strategic corporate hedging *

Caleb Cox †

Virginia Commonwealth University

Arzé Karam ‡

Durham University

Matthias Pelster §

Leuphana University of Lueneburg

December 5, 2016

Abstract We consider a dynamic multi-period framework of a Cournot duopoly and introduce a simultaneous hedging and a storage opportunity to allow players to manage risk before and after demand uncertainty is realized. Decision makers face a strategic dilemma: they must weigh the advantages of dealing with their risk exposure and the disadvantages of higher competition. Due to the storage opportunity, our multi-period setting differs from a repetition of the single-shot interaction. In equilibrium, firms consider the strategic impact of the hedging component, which increases competition. We provide supportive evidence of this theory in a laboratory experiment. Our experimental results suggest that the simultaneous hedging device significantly increases competition and negates duopoly profits.

Keywords: Corporate hedging, game theory, duopoly, strategic application, dynamic setting, laboratory experiments.

JEL Classification: D21, D22, D43, D53.

*This work was supported by the DUBS Seedcorn Fund from Durham University. We are grateful for comments from Jack Wahl, Udo Broll, Bernhard Ganglmair, participants of the 2014 Cambridge Business & Economics Conference, and participants of the Experimental Finance North American Finance Meeting 2016. Any errors, misrepresentations, and omissions are our own.

†Virginia Commonwealth University, Snead Hall, 301 W. Main Street, Box 844000, Richmond, VA, USA 23284, telephone: +1 804 828 7101 email: *cacox@vcu.edu*

‡Durham University, Mill Hill Lane, DH13LB, England, telephone: +44 191 3345460, email: *arze.karam@durham.ac.uk*

§Corresponding author: Scharnhorststr. 1, 21335 Lueneburg, Germany, telephone: +49 4131 677 2188, email: *pelster@leuphana.de*

1 Introduction

A large body of literature deals with corporate hedging decisions of the firm (e.g., Stulz, 1984; Smith and Stulz, 1985; Froot et al., 1993; Leland, 1998; Mello and Parsons, 2000). Managing risks can reduce expected bankruptcy costs, agency costs, information asymmetries, or expected taxes and thus increase shareholder value (e.g., Froot et al., 1993; Carter et al., 2006; Bolton et al., 2011; Campello et al., 2011; Mackay and Moeller, 2007; Chen and King, 2014).[1] Yet, in empirical studies, we often observe discrepancies between theoretically optimal strategies and corporate risk management practice (e.g., Tufano, 1996; Graham and Smith, 1999; Haushalter, 2000; Graham and Rogers, 2002). While many traditional studies propagate the full hedge on unbiased forward markets (e.g., Holthausen, 1979; Broll et al., 1995, 2001; Broll and Wong, 2013), many empirical studies document hedge ratios significantly smaller than one (underhedge) (e.g., Tufano, 1996; Haushalter, 2000; Brown et al., 2006; Jin and Jorion, 2006; Carter et al., 2006; Adam et al., 2015).

In reality, hedging in markets with imperfect competition is the norm in the profession. Theoretically, the literature provides a rationale for underhedging in imperfectly competitive markets, as in Allaz (1992); Allaz and Vila (1993) or Broll et al. (2009, 2011).[2] In such a setting, hedgers must account for the fact that corporate hedging has an impact on market competition, and consequently they may decide to hedge less to avoid lowering their profits (Le Coq and Orzen, 2006; Brandts et al., 2008; Ferreira et al., 2009; van Eijkel and Moraga-Gonzalez, 2010; Leautier and Rochet, 2014). It is clear that hedgers face a strategic dilemma in which they must weigh the benefits of hedging their risk against the adverse effects of an increase in market competition. In this paper, our main objective is to examine to what extent these strategic considerations explain underhedging behavior in a simultaneous hedging setting. We first develop a theoretical model to examine the effects of simultaneous hedging on decision makers in imperfectly competitive markets. Second, we test the predictions of the model in a laboratory experiment.

We use a simple duopoly model à la Allaz (1992) and Allaz and Vila (1993) in a modified, more general, and simultaneous setting with repeated interaction to examine how hedging affects market

[1] For literature discussing the goal of firms employing corporate hedging see, among others, Géczy et al. (1997); Kajüter (2012).

[2] Recent literature also uses managerial biases to explain discrepancies between the theory and practice of corporate risk management in more general settings. See, for example, Adam et al. (2015).

equilibrium. Furthermore, we test the predictions of this model in a laboratory experiment. The experimental setting allows us to evaluate how decision makers react to the strategic dilemma in a setting where decision makers do not have market beliefs that influence the decision. In our model, we first allow firms to engage on a forward market to manage their risk exposure toward demand uncertainty ex ante. Secondly, we allow firms the opportunity for storage and thus provide them the possibility of reacting to low demand realizations ex post. This feature also allows us to introduce real dynamics into the multi-period model. Hence, our model is not simply a repetition of the single-shot game. We restrict ourselves to the Cournot setting, as Kreps and Scheinkman (1983) argue that in an oligopoly under mild assumptions about demand, the unique equilibrium outcome is the Cournot outcome.[3] We also restrict ourselves to the duopoly setting to simplify the analysis and reduce the complexity for the participants of our experiment. However, from a mathematical standpoint, this restriction does not alter the main results. We analyze two settings which differ with respect to the ability of firms to adapt their real market (production) decisions.

Our paper significantly differs from the existing literature. Previous literature is restricted to a single shot interaction of players on the output market. For example, the papers by Broll et al. (2009) and Broll et al. (2011) consider a duopoly under exchange rate risk and provide theoretical evidence for the strategic influence of the hedging opportunity in a sequential setting, but their papers are restricted to a setting in which the participants of the duopoly interact only once on the output market. Equally, the experimental studies by Le Coq and Orzen (2006) and Ferreira et al. (2009) analyze similar settings. Hence, decision makers only consider short term utility. Any impact of their decisions on the future is ignored. In reality however, businesses usually interact more than once on the same output market. Similarly, the study by Brandts et al. (2008) exclusively focuses on the strategic impact of the hedging device and abstract from risk management considerations as their setting does not incorporate risk. In contrast, in our setting, players can utilize the risk management purpose of the hedging device and thus face the dilemma between hedging their risk exposure and maintaining high market prices. Finally, van Eijkel and Moraga-Gonzalez (2010) provide an empirical study on the Dutch wholesale market for natural gas. Yet, they are not able to separate the market views of managers from strategic applications of the hedging device while

[3] Even thought the Cournot model has been criticized for its theoretical foundations, the model is simple and has pleasing comparative statics and has proved useful in the literature (see, e.g. Mas-Colell et al., 1995; Martin, 1994; Maggi, 1996; Larue and Yapo, 2000).

our laboratory setting allows us to implement the desired variations with a high degree of control.

Our theoretical model highlights the strategic impact of the risk management decision in equilibrium. In our experiment, we provide strong evidence that subjects tend to take the adverse effects of their own financial decisions on market equilibrium into consideration. However, we do not find any evidence that decision makers consider the financial decisions of their competitors – which are common knowledge – in subsequent decisions. More specifically, we are able to provide evidence that underpins our theoretical findings: Subjects consider the strategic impact of the hedging decision and refrain from completely hedging their risk. Moreover, as the game is more similar to a simple repetition of the single-shot game in our second setting, subjects level of supply prevents duopoly profits, on average. To summarize, our results suggest that even in a simultaneous setting forward market hedging creates a strategic dilemma for producing firms and significantly increases competition.

The remainder of the paper is organized as follows. Sections 2 and 3 introduce the two different theoretical frameworks of a multi-period Cournot duopoly with uncertain demand which serve as the basis for the analysis. Detailed mathematical derivations and comparative static analyses can be found in the appendix, Section A. Section 4 discusses the setup of our laboratory experiment, and Section 5 presents the experimental results. The final section concludes.

2 The basic dynamic model

Our basic model considers a setting with three dates, $t = 0$, $t = 1$ and $t = 2$. Two firms are producing a homogeneous good, $q^i \geq 0$, $i = i, j$. There is no possibility for another competitor to enter the market, as the product requires a high level of technological knowledge. In this regard, the model is basic Cournot.

In $t = 0$ the decision maker can visibly specify his output. The production takes place between $t = 0$ and $t = 1$. Production gives rise to costs, $c^i q^i$, $i = i, j$ in $t = 1$. Additionally, production capacity is limited. In $t = 1$ and $t = 2$ firms have the opportunity to sell their production on the same market. However, we assume that firms are only able to produce the product in $t = 0$ due to technical issues. Hence, they have to distribute their production between periods. From a different perspective, this allows firms to react to bad price realizations in $t = 1$ due to low demand and store their production (or parts of their production) to sell at $t = 2$. The price at time t is determined by the inverse demand function, $\tilde{p}_t = \tilde{p}_t(Q_t) = \tilde{\varepsilon}_t M - bQ_t$, with $Q_t = \sum_i q_t^i = q_t^i + q_t^j$, where $\tilde{\varepsilon}_t$ expresses the uncertainty of the saturation of demand.[4] The probability distribution of $\tilde{\varepsilon}_t$ is common knowledge with $\tilde{\varepsilon}_t \in \mathbb{R}_+$, $\mathrm{E}_0[\tilde{\varepsilon}_t] = 1 \; \forall t$ and $\mathrm{E}_1[\tilde{\varepsilon}_2 \mid \varepsilon_1] = \varepsilon_1$.

As mentioned above, firms have the opportunity to keep inventory. In $t = 1$, with knowledge of the actual saturation of demand for this period, firms make their sales and thus also their storage decision. Sales and inventory have to add up to the production amount. The setting allows decision makers to react to unfavorable demand realizations. Firms are not obliged to sell their entire production at an unfavorable price or can sell more than initially intended if demand is surprisingly high.

In addition, firms are able to manage their exposure to price risk via an unbiased forward market. Jointly with the production decision, producers can choose their binding hedging decision h^i. Forward contracts have a maturity of one period. Since in reality forward contracts also have limited maturities we do not include contracts with a maturity of two periods or longer in our model. Hence, firms can purchase or sell forward contracts on the good they produce at time $t = 0$ with maturity in $t = 1$ and at $t = 1$ with maturity at $t = 2$. The forward price is the result of expected demand and supply as well as expected (equilibrium) decisions of the duopolist. Most forward market participants act rationally and have perfect knowledge. As a result, they are aware of the optimal decisions of the duopoly and act accordingly.[5]

$$p_1^f = \mathrm{E}[\tilde{\varepsilon}_1]M - b(\hat{s}^i + \hat{s}^j), \tag{1}$$

where $\hat{s}^i = s_{LH}^i(q^i, q^j, h^i, h^j)$ denotes the (anticipated) equilibrium choices of producing firms (see Equation (8)) for a given subgame-path. The forward rate for second-period contracts is not known at time $t = 0$. At this time, only the probability distribution of the forward rate is known. The forward rate relates to the spot rate and both rates are subject to the same sources of uncertainty, the demand uncertainty, as market participants update their expectations regarding the demand for

[4]Throughout the paper, a tilde denotes a random variable. When the tilde is missing, the variable signifies the realization of the stochastic parameter.

[5]Cyert and DeGroot (1970) make a similar argument, that the counterpart's choices cannot be observed in a simultaneous-move game and hence subjective expectations have to be considered.

the second period once they learn the demand for the initial period.[6] Hence, we will assume that the stochastic forward rate for the second period and the spot rate are subject to the same random variable, $\tilde{\varepsilon}_1$. As a result, the forward price for the second period fulfills

$$\begin{aligned}\tilde{p}_2^f &= \mathrm{E}_1[\tilde{p}_2 \mid \check{q}^i, \check{q}^j, \varepsilon_1] \\ &= \mathrm{E}_1[\tilde{\varepsilon}_2 \mid \varepsilon_1]M - b(\check{q}^i + \check{q}^j - \hat{s}^i - \hat{s}^j) \\ &= \varepsilon_1 M - b(\check{q}^i + \check{q}^j - \hat{s}^i - \hat{s}^j),\end{aligned}$$

where $\hat{}$ denotes the expected equilibrium value and $\check{}$ realized choices from previous interactions. Note that the forward price again depends on demand and supply. Market participants have knowledge about the amount produced by the firms, and the clearing of the forward market is closely connected to the clearing of the spot market in $t = 1$. As spot and forward market are equally sensitive against changes in supply by producing firms, we can simplify notation whenever the forward price is not yet fixed. In these cases, we denote $\tilde{M}_t^f = \mathrm{E}[\tilde{\varepsilon}_t]M$.

In $t = 1$ the demand uncertainty for the first period is resolved and becomes common knowledge. Using this knowledge firms choose their supply for the spot market, that is the amount that is to be sold immediately. The remainder of the production will be stored and sold in $t = 2$ at the then given price or at a fixed forward rate using forward contracts for the second period. Warehouse charges are k^i per unit. Illustration 1 visualizes the timing of the decisions.

At this point, we do not allow firms to enter production at time $t = 1$. Hence, firms cannot produce additional goods for the second period. Possible justifications for this limitation include the exclusive possibility to produce large lot sizes, high setup costs, or seasonal limitations in production.

In $t = 1$ the production and initial forward decisions have already been made. As they are common knowledge they have to be taken into account when choosing the supply. Therefore, the applied equilibrium concept is the subgame-perfect Nash equilibrium from Selten (1965). The strategy choice consists of the optimal production and hedging decisions as well as strategy sets for the supply that constitute a Cournot-Nash equilibrium for every possible production and forward decision.

[6] Several studies highlight the high correlation between spot and forward rates (see, e.g., Pelster and Springer, 2015, for a recent study using the wavelet-approach.).

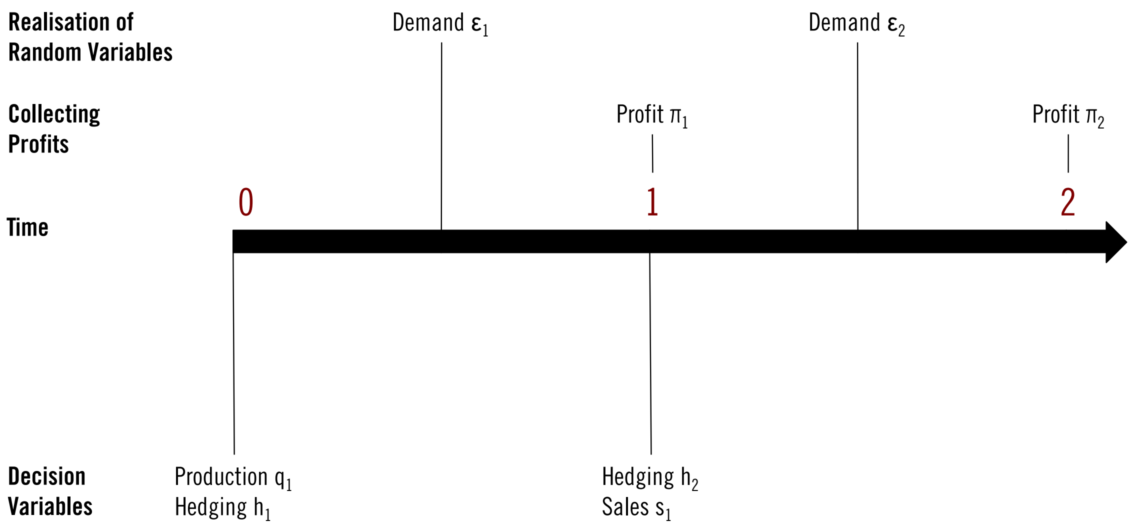


Figure 1: Timing of decision making

With the explained scheme the profits of firm i at times $t = 1$ and $t = 2$ are given by

$$\tilde{\pi}_1^i = (\tilde{\varepsilon}_1 M - b(s^i + s^j))s^i - c^i q^i + h_1^i(p_1^f - \tilde{p}_1) - k^i(q^i - s^i) \text{ and}$$
$$\tilde{\pi}_2^i = (\tilde{\varepsilon}_2 M - b(q^i + q^j - (s^i + s^j)))(q^i - s^i) + h_2^i(\tilde{p}_2^f - \tilde{p}_2)$$

with $s^i = s^i(\check{q}^i, \check{q}^j, \check{h}_1^i, \check{h}_1^j)$ resp. $s^j = s^j(\check{q}^i, \check{q}^j, \check{h}_1^i, \check{h}_1^j)$. That is, the supply in $t = 1$ is a function of decisions made in the previous stage. Additionally, $s^i \in [0, \check{q}^i]$, $i = i, j$.

Firms maximize $(\mu,\, \sigma)$-preferences. Here, $\mu = \mathrm{E}[\tilde{\pi}^i]$ denotes the expected value and $\sigma^2 = \mathrm{var}(\tilde{\pi}^i)$ the variance of the stochastic profit of firm i. We rely on the $(\mu,\, \sigma)$-approach as it provides a simple access to complex problems and consequently a cost-efficient access to information. Moreover, the $(\mu,\, \sigma)$-approach allows us to separate risk and time preferences.[7] Thus, the decision rule of firm i,

[7]For more detailed justification of the $(\mu,\, \sigma)$-approach see, e.g., Battermann et al. (2002) or Robison and Barry (1987).

$i = i, j$, is given by

$$\Phi^i = \sum_t (\delta^i)^{t-1} \Phi_t^i = \sum_t (\delta^i)^{t-1} (\mu_t - \frac{\alpha_i}{2} \sigma_t^2).$$

The temporal preferences of the decision makers are represented by the parameter δ^i, whereas α^i denotes the degree of risk aversion of firm i.[8] Note, that $\alpha^i \equiv 0$ denotes the special case of risk neutrality (and hence also the situation under certainty). We assume that all parameters are common knowledge.

In a subgame-perfect Nash equilibrium, the optimal supply decision in $t = 1$ fulfills[9]

$$\varepsilon_1 M - b(2s^i + s^j) + b\check{h}_1^i = \delta^i (M_2^f - b(2q^i + q^j - 2s^i - s^j)) - k^i. \tag{2}$$

Hence, for the optimal decision, marginal revenues which are realized in $t = 1$ equal marginal revenues realized in $t = 2$, adjusted for costs resulting from the shift of sales (costs for storage). Results show that firms choose their offer such that marginal revenues from the first period correspond to marginal revenues of the second period, corrected for costs and risk premium. Decision makers seek to smooth their profits. Moreover, the decision reflects the strategic impact of the hedging decision. As the forward price is fixed and no longer subject to the quantity offered, the decision maker is less sensitive towards price changes due to additional supply. Hence, with a larger forward position the decision maker also increases supply in $t = 1$.

Moreover, the forward market decision for the second period does not directly influence the sales decision in $t = 1$. However, the existence of a forward market enables firms to separate their sales decision in $t = 1$ from their risk preferences. Obviously, the degree of risk aversion and the expectations about the uncertainty of demand for the second period are not considered for the optimal sales decision. Nonetheless, the decision makers take their time preferences into account making their decisions. Hence, the optimal amount of sales cannot be entirely separated from the preferences of the decision maker. To account for this fact, we introduce the *weak separation property*:[10] The sales decision can be made independently of the degree of risk aversion and the

[8] The preference function describes risk-averse behavior as long as utility increases in expected profits and decreases in risk and marginal utility in expected profits does not increase ($\frac{\partial \Phi}{\partial \mu} > 0$, $\frac{\partial \Phi}{\partial \sigma} < 0$, and $\frac{\partial^2 \Phi}{\partial \mu^2} \leq 0$).

[9] A more detailed derivation of the results can be found in the Appendix, Section A.

[10] In comparison, the separation property states that decisions can be made independently of the decision maker's preferences and expectations, so that the decision is subject only to market data.

expectations of the decision maker. However, the decision maker takes time preferences into account. Note again, that the sales decision critically hinges on the agreed forward market position. In that regard, our paper underlines the results of Allaz (1992) and Allaz and Vila (1993): Hedging increases competition. The decision maker increases his supply on the spot market with his own forward position and decreases his supply on the spot market with his competitors forward position. Moreover, the magnitude of the adaption is smaller than one. Thus, for each additional forward contract, the spot position increases by less than one good.

Turning to the hedging decision, we can derive

Hypothesis 1 (Hedging choice in the second period)**.** *The producers will sell the entire production that is taken into storage on a forward market if the forward market is unbiased. As a consequence, the profit that firms realize in $t = 2$ becomes deterministic in $t = 1$.*

In $t = 0$, for initial decisions, decision makers cannot separate their production and their risk management decisions (see Equations (15) and (16) in the Appendix). Decision makers take their preferences and expectations as well as the strategic impact of the hedging decision into account. The sales decision of firms is subject to the hedging decision made in $t = 0$. The equilibrium industry supply increases with every additional forward contract decision makers engage in. Higher industry supply immediately yields lower market prices. Consequently, decision makers have to balance the reduced risk exposure due to a higher hedging position (risk management aspect) against the revenue potential of their sales. Decision makers that only focus on the risk management aspect will engage in large hedging position while those who only focus on the potential revenue and not on the risk will not engage in hedging at all. Due to the balancing of these extreme behaviors, we expect that

Hypothesis 2 (Hedging choice in the first period)**.** *Decision makers will choose an underhedge at time $t = 0$.*

Firms have to make their decisions without the possibility to fully lock in their profits. Even though firms have the opportunity to purchase forward contracts for their entire planning horizon, they cannot purchase long term protection. Instead, they can lock in their profits at $t = 1$ the earliest. Choosing a full hedge in $t = 1$ induces deterministic profits in $t = 2$. Hence, even if firms choose to select the full hedge in $t = 1$ and a hedge of the size of their entire production in $t = 0$, they are still exposed to a basis risk at the time of the roll-over. Popular examples show that these *roll-over risks* can cause significant problems (see, e.g., Culp and Miller, 1999, for the case of Metallgesellschaft). In the context of a roll-over, the market development of the forward market is of major importance. If the forward market price decreases, the hedger is able to realize a profit at the time of the roll-over. However, if the forward market price increases, additional costs occur to adjust the hedging position. Thus, firms are exposed to the roll-over risk and additionally do not completely hedge their intended sales or even production due to the strategic impact of their hedging decision. Firms are exposed to a significant amount of risk which will reduce their production.

At this point, we want to discuss issues of moral hazard on the forward market introduced by the possible exploitation of other forward market participants by the duopolists. Similar to the monopoly discussed by Muermann and Shore (2006), producers have incentives to use their spot market power to exploit forward market makers. Consider the following scenario: At time $t = 0$ the producer decides on the hedging quantity simultaneous with the production quantity. Taking the hedging decisions of the producers and expected future demand into account, a forward market price is set. However, clearance at the spot market is subject to the spot sales decision of the producer. High spot sales decisions ruin spot market prices and decrease revenues from spot sales for the producers. Yet, at the same time, the producer makes additional profits from his forward position at cost of the market maker. Note, that the clearance price at the forward market according to Equation 1 takes this moral hazard issue and optimal spot sales decisions of producers in $t = 1$ into account.

Also note that the setup of our multi-period model allows us to observe two distinct decision problems: At time $t = 0$, decision makers' hedging choices affect competition and market prices while decision makers' hedging choices at $t = 1$ have no implications on competition and can be made exclusively under risk management considerations.

3 The model with adjustable production decisions

Section 2 introduced a dynamic two period duopoly setting with demand uncertainty. Decision makers have the opportunity to react to low demand realizations by storing their good and sell at a later time. However, firms are only able to produce once. Hence, repeated interaction occurs, but is limited. To allow firms complete repeated interaction, we now additionally introduce the opportunity to adjust the production decision in $t = 1$. Thus, firms are able to adjust all of their decision variables in $t = 1$.

As a result, the new decision sequence takes the following form: In $t = 0$ firms set their production for the first period as well as their forward position. Production takes place between periods. In $t = 1$ demand uncertainty for the first period is resolved. Firms choose the supply at $t = 1$. Excess production is taken into storage. Also, the forward position from the first period is closed. In $t = 1$ firms set their production for the second period and their forward position with maturity at $t = 2$. Future demand is still uncertain at this point. Again, production takes place between periods. At the final date, firms sell their additional production and everything from storage. Figure 2 visualizes the setup of the model.

Consequently, profit of firm i at $t = 2$ is given by

$$\tilde{\pi}_2^i = \tilde{p}_2(Q_2)(q_1^i - s^i + q_2^i) - c_2^i q_2^i + h_2^i(\tilde{p}_2^f - \tilde{p}_2),$$

while the first period profit remains unchanged,

$$\tilde{\pi}_1^i = \tilde{p}_1(Q_1)s^i - c_1^i q_1^i + h_1^i(p_1^f - \tilde{p}_1) - k^i(q_1^i - s^i).$$

The inverse demand function at time t is still given by $\tilde{p}_t(Q_t) = \tilde{\varepsilon}_t M - bQ_t$, where Q_t denotes the industry supply at time t. In our model, we have $Q_1 = s^i + s^j$ and $Q_2 = q_1^i + q_1^j + q_2^i + q_2^j - (s^i + s^j)$, respectively.

The forward prices are determined by (expected) demand and (anticipated) supply. The forward

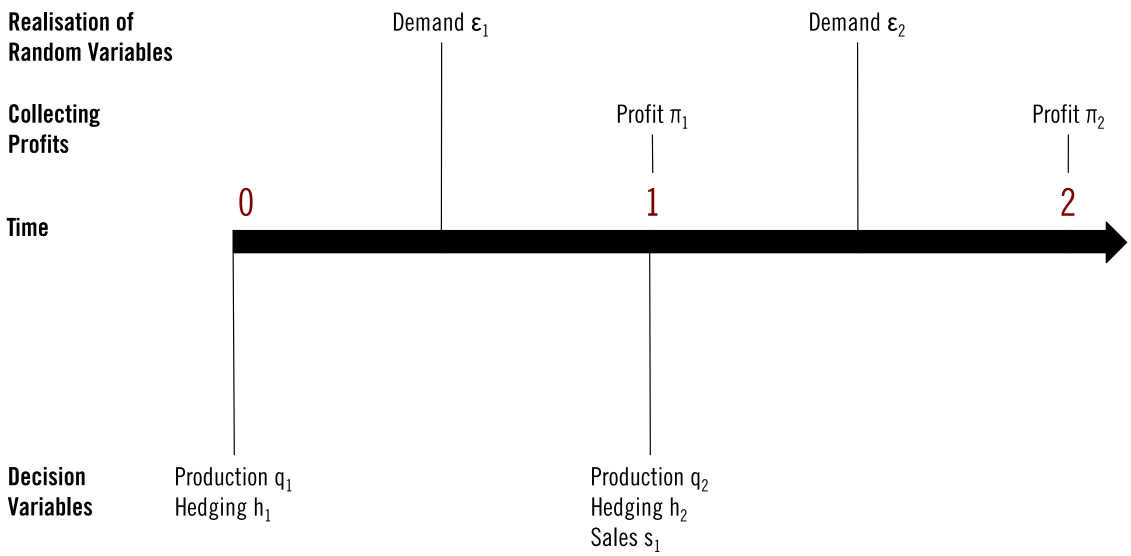


Figure 2: Timing of decision making with adjustable production decisions

price for the first period is given by

$$p_1^f = \mathrm{E}[\tilde{\varepsilon}_1]M - b(\hat{s}^i + \hat{s}^j),$$

and for the second period by

$$p_2^f = \mathrm{E}_1[\tilde{\varepsilon}_2 \mid \tilde{\varepsilon}_1]M - b(\check{q}_1^i + \check{q}_1^j - \hat{s}^i - \hat{s}^j + \hat{q}_2^i + \hat{q}_2^j).$$

The forward prices are determined under consideration of equilibrium strategies in $t = 1$, $\hat{s}^i = \hat{s}^i(q_1^i, q_1^j, h_1^i, h_1^j)$, $\hat{s}^j = \hat{s}^j(q_1^i, q_1^j, h_1^i, h_1^j)$, $\hat{q}_2^i = \hat{q}_2^i(q_1^i, q_1^j, h_1^i, h_1^j)$, and $\hat{q}_2^j = \hat{q}_2^j(q_1^i, q_1^j, h_1^i, h_1^j)$ as well as decision variables in $t = 0$, q_1^i, q_1^j, h_1^i, h_1^j. Equilibrium strategies are given by Equations (22) and (23) in the Appendix.

To solve the model, we again rely on the concept of Selten (1965) of a subgame-perfect Nash equilibrium. For time $t = 1$ decisions, the firm chooses its second period production under consideration of the amount in stock so that marginal costs equal marginal revenues. The decision can be separated from the degree of risk aversion and the expectations.

$$M_2^f - b(2(q_2^i + \check{q}_1^i - s^i) + q_2^j + \check{q}_1^j - s^j) = c_2^i. \tag{3}$$

The amount in stock immediately relates to the amount to be sold on the spot market in $t = 1$: The firm chooses the amount to be sold on the spot market in $t = 1$ to smooth its profits: realized marginal revenues from period one equal marginal revenues from the second period, corrected for storage costs and adjusted with respect to the risk management decision taken in $t = 0$:

$$\begin{aligned} \bar{\varepsilon}_1 M - b(2s^i + s^j) + b\check{h}_1^i &= \delta^i (M_2^f - b(2(q_2^i + \check{q}_1^i - s^i) + q_2^j + \check{q}_1^j - s^j)) - k^i \\ &= \delta^i c_2^i - k^i. \end{aligned} \tag{4}$$

This also equals marginal costs for the second period. The decision is independent of the degree of risk aversion of the firm. However, time preferences have to be taken into account. Note that Equation (4) is equivalent to Equation (2) from the basic dynamic model in Section 2. Both, marginal revenues from the first period as well as marginal revenues from the second period are deterministic or can be made deterministic, respectively. The former, because uncertain demand is realized and the latter because the firm can sell everything on a forward market with a deterministic forward rate. Determining the quantity of sales and the additional quantity of production takes place simultaneously with the decision process equaling the one under certainty. The optimal forward position in $t = 1$ can be determined in accordance with the full hedge theorem:

Hypothesis 3 (Hedging choice in the second period)**.** *Given an unbiased forward market, the firm sells its entire stock and additional production forward in $t = 1$. The firm chooses a full hedge:*

$$h_2^{i*} = q_2^i + \check{q}_1^i - s^i \tag{5}$$

As a result, profits in $t = 2$ are deterministic with $\pi_2^i = p_2^f(Q_2)(\check{q}_1^i - s^i + q_2^i) - c_2^i q_2^i$.

The competition for both periods takes place at the same time and follows the basic rules known from

Cournot duopoly. If the competitor increases its supply by one unit, the firm reacts by decreasing its own supply by $\frac{1}{2}$. The equilibrium corresponds to the equilibrium from the one-shot Cournot duopoly under certainty.

Let us discuss the considerations of the decision makers. While reaction functions and production quantity in the single shot game establish a relation between the forward rate (or the price under certainty) and the production costs, $R^i(q^j) = \frac{M_f - bq^j - c^i}{2b}$ and $q^i = \frac{M_f - 2c^i + c^j}{3b}$, they now correspond to the realized spot rate instead of the forward rate and the costs of additional production and storage to determine the supply. Already accrued production costs are sunk costs and thus not relevant for future decisions. Instead, only the (at this time) deterministic marginal revenues of both periods are relevant. The ability to take the realized spot price into account crucially depends on the ability to store the good. Due to the storage option, the produced quantity and the supplied quantity may differ. Thus, the decision for the supply on the spot market can be made when the spot price is known. Obviously, this is not possible without the possibility to store the production good. The relation between production costs (and interest payments) and costs for storage reflects the advantageousness of storage towards renewed production for the next period.

The amount of additional production (Equation (23) in the Appendix) reflects the quantity known from the single shot game corrected for stored goods. We obtain the well known example from game theory: in a repeated game the result of the final interaction corresponds to the result of the single shot game (see, e.g., Vives, 1999).

In essence, the main difference to the model from Section 2 is the following: Setting the sales quantity occurs independently of prior production. Obviously, at most the maximum sales quantity is determined by the maximum of prior production, but interior solutions do not react to an increased production. Moreover, the simultaneous competition essentially converts the game to a repeated single shot game under certainty.

Turning to the influence of the hedging decision on sales, we find that hedging increases competition similar to our baseline model. As firms increase their hedging position, the supply on the spot market increases, which leads to decreasing spot prices. Firms react less sensitively toward decreasing spot prices, as they have already locked in some of their profits. Smaller profits on the spot market are compensated by higher profits from the forward market. Note however, that in our model setup, other forward market participants anticipate this behavior by the duopolists. Forward market participants are aware of the spot market power by producers and act accordingly. Nonetheless, competition on the spot market increases.

Although the main decisions in $t = 1$ remain unchanged (The firm smooths its profits over time depending on its time preferences and storage costs), the firm now is able to adjust marginal revenues for the second period to marginal costs for the second period due to the ability to adjust production. This significantly increases competition, as second period interaction in essence takes place under certainty. To summarize, we expect:

Hypothesis 4 (Spot sales decision with adjustable production)**.** *Spot sales decisions in the adjustable production setting will be significantly larger than in the basic dynamic model.*

Turning to the decision process in $t = 0$, the firm may use the option to take storage to be able to react to possible deviations from the expected price with excess production. More specific, the firm could produce more in order to be able to increase sales at $t = 1$ if demand is higher than expected. However, implications concerning the production of the competitor have to be taken into account. Additionally, decision makers have to consider the strategic impact of their risk management choice on competition as hedging increases the competitiveness on the spot sales market. Solving the firm's optimization problem, we show that the firm cannot separate real and financial decisions. If production in the first period and consecutive storage is cheaper than production in the second period the firm initially chooses a production above the intended amount of sales. The level of adaptation of production depends on the risk and the degree of risk aversion of the decision maker. Otherwise, the firm chooses its production according to its intended sales. Intended sales are set in an effort to equate marginal revenue an marginal costs as the following decision in $t = 1$ essentially takes place under certainty. The firm is not exposed to any long term risk, as it intends to sell its entire production at $t = 1$. Moreover, the firm is able to hedge first period risk using forward contracts. Consequently, production will be significantly higher than in a standard duopoly setting. Finally, firms use the option to take storage only in a strategic way to react to increases in production costs but not to be able to react to high demand realizations. However, ex post excess production can happen: if the realization of demand is not as expected but below the expected amount, firms react by taking production in store and decrease their supply.

Turning to the initial hedging decision, the strategic impact of the hedging component on competition in $t = 1$ again comes into play. Increasing the hedging position will increase competition on the output market. The expected industry supply increases with every additional forward contract which ultimately decreases profits. Firms engage in competition via their risk management decision and consequently take the strategic impact of their hedging decision into account. The optimal hedging choice equals expected spot sales corrected for the impact on competition. The magnitude of correction depends on the risk aversion and the price risk. To summarize:

Hypothesis 5 (Hedging choice in the first period)**.** *In $t = 0$, decision makers will choose an underhedge.*

Hence, forward markets increase competition on oligopolistic markets in two ways: First, the decision maker is able to deal with uncertainty via forward markets which in itself increases the industry supply. The industry supply equals the industry supply under certainty. Secondly, the strategic impact and the fact that forward prices do not react to increased supply in $t = 1$ increases competition even further.

4 Experimental Design

The experiment was programmed and conducted using z-Tree software (Fischbacher, 2007) at Durham University in Autumn 2015. Eight sessions were conducted in total, each with an even number of subjects between 10 and 16, for a total of 100 subjects. On average, subjects earned approximately £14 each. Each session lasted approximately 1 hour 45 minutes, on average.

There were two treatments, A and B, varied between subjects, with four sessions each. Treatment A is based on the basic dynamic model without adjustable production decisions, presented in Section 2, while Treatment B is based on the model with adjustable production decisions, presented in Section 3. In both treatments, we used parameters $M = 1$, $b = 1$, $c^1 = c^2 = 1$, $k^1 = k^2 = 0.25$. The initial random demand state ϵ_1 was drawn from $\{40, 60\}$ with equal probability. The subsequent random demand state ϵ_2 was drawn with equal probability from $\{50, 70\}$ conditional on high initial demand state, or from $\{30, 50\}$ conditional on low initial demand state.

Full experiment instructions for both treatments are included in the Appendix. In both treatments, subjects were randomly and anonymously matched into pairs of two at the start of each of 20 round (strangers matching).[11] At the end of the experiment, 2 of these 20 rounds were randomly selected for payment.

Each round in Treatment A was divided into 3 stages. In the first stage, each subject choose a production quantity and a forward market position. Since the game is complex, we provided a projection calculator tool to help subjects understanding of the game structure and incentives.[12] Projections of the calculator tool were based on own production and hedging choices of subjects and on guesses which subjects made about the same decision variables chosen by the other player. Based on these choices and guesses, subjects were shown projections of expected prices and profits and standard deviations of expected profits. Subjects could adjust their choices and guesses using sliders to see how projected prices, profits, and standard deviations changed before finalizing their choices. In the second stage, each subject learned the outcome of the first stage, and then chose spot market sales and another forward market position, and again made guesses about the decision variables of the other player. Again, projections and expected prices, profits, and standard deviations were shown to subjects, and subjects could change their choices and guesses to see how projections changed before making a final choice. In the third stage, subjects learned the final outcome of the round.

Each round in Treatment B was also divided into 3 stages similar to those in Treatment A. However, in the second stage of Treatment B, subjects chose a further production quantity in addition to spot market sales and a forward market position, and made guesses about these three decision variables for the other player. As in Treatment A, subjects were shown projections of expected prices, profits, and standard deviations based on their choices and guesses about the other player in the first and second stages, with projections updating with changes in these decision and guess variables before choices were finalized.

At the end of the experiment, subjects' risk preferences were elicited using a lottery choice procedure from Holt and Laury (2002). Subjects also answered a brief demographic survey. Details of both

[11] Due to a computer crash, one session had only 19 rounds.

[12] This approach has been used to aid subject understanding in other experimental studies of complicated strategic environments, such as Healy (2006), Van Essen (2012), and Van Essen et al. (2012).

tasks are included in the Appendix.

5 Experimental Results

We test the predictions from the baseline model, Model A, and the ones from the second model with adjustable production decisions, Model B. We use the data from the experiment we conducted to examine the effect of adjustable production and whether subjects use hedging strategically. Additionally, we test whether they use storage opportunity to smooth revenues over time. We run a number of paired t-tests on sales, hedging and production decisions in low and high demand states. Then, we use a panel model to regress the variable of interest (spot sales, first period hedging, second period hedging) on variables that should matter based on the theory, e.g. risk aversion, additional production indicator and demand state. We provide results on the data collected from the 20 rounds, and results on only the data collected from the last five rounds when subjects have gained some experience.

In Table 1, we present ex ante expected equilibrium choices using our experimental parameters and the average risk aversion elicited using the Holt and Laury (2002) lottery choice procedure. Equilibrium choices within the experiment can differ from reported values due to the influence of the random demand variable and the subgame path of the current game. The equilibrium values emphasize our hypothesis: In both models we observe the expected underhedge in the first period (hedging1) and the full hedge in the second period (hedging2). We observe the impact of the hedging device on competition when comparing first and second period supply in the double production setting. Moreover, the adjustable production significantly increases competition as the game essentially becomes a repeated single shot game under certainty.

There are differences between the models and the experimental design that might generate behavior inconsistent with the predictions. The models include one round in each period while the experiment includes 20 rounds. However, we believe that we can interpret results that are qualitatively similar to our equilibrium predictions as generalizable support for the hypotheses identified in the models. A more important difference between the models and the experiment is that the models assume that decision makers engage in strategic behavior. The experiment imposes no such restriction on

Table 1: Expected equilibrium values

We compute expected equilibrium values in $t = 0$ using the parameters employed for the experiment and the average risk aversion of our participants elicited using a lottery choice procedure from Holt and Laury (2002). The median number of "safe" choices is six which is consistent with $\alpha \approx .15$. We set the time preference parameter equal to one as subjects are paid at the end of the experiment independently of the timing of their profits in the game. The table shows the following variables: "quantity" is the quantity produced in the first period, "quantity2" is the quantity produced in the second period, "spot sales" is the quantity of sales, "hedging1" and "hedging2" are the quantities hedged in the first period and in the second period, respectively. We present equilibrium values for single production and for double production separately. In addition, we present equilibrium choices for the single production model under risk neutrality/certainty.

	Single production		Double production
	($\alpha = 0.15$)	($\alpha = 0$)	($\alpha = 0.15$)
quantity	3.68	32.58	24.23
hedging1	2.22	0.05	23.47
quantity2			16.33
spot sales	2.25	16.34	24.23
hedging2	1.43	16.24	16.33

players behavior. This represents one of the motivations for conducting an experiment. We do not observe a significant difference in the behavior of players by gender or by course of study. It seems there is consistency in their decisions independent of these characteristics.

Summary statistics are reported in Table 2. We take data for each player and each round, and then take the averages across players for single production and for the double production separately. We present also results across the 20 rounds and then across the last 5 rounds. We summarize here the results for the 20 rounds. For Model A, the average quantity produced (in the first period) is 34.74. The spot sales decision is around 20.50. The own first period hedging is 15.93 while the own second period hedging is 16.80 on average. For the double production model, the average quantity produced in the first period is 25.75 while the average quantity is 15.74 in the second period. Spot sales are on average 17.66. The average quantity hedged in the first period are 18.26 and 17.29 in the second period. Standard deviations of these averages within each round across player are low, suggesting that there is consistency in players' decisions.

Table 2: Summary Statistics

We compute the averages over players and rounds of the following variables: "quantity" is the quantity produced in the first period, "quantity2" is the quantity produced in the second period, "spot sales" is the quantity of sales, "hedging1" and "hedging2" are the quantities hedged in the first period and in the second period respectively. We present summary statistics for single production and for double production separately. Standard deviations are reported in parentheses.

	Single production		Double production	
	(20 rounds)	(Last 5 rounds)	(20 rounds)	(Last 5 rounds)
quantity	34.742	34.178	25.755	24.086
	(0.835)	(0.921)	(0.852)	(1.024)
quantity2			15.744	13.162
			(0.919)	(1.164)
spot sales	20.494	19.630	17.668	17.556
	(0.804)	(0.871)	(0.729)	(0.767)
hedging1	15.932	15.069	18.263	17.546
	(0.916)	(1.136)	(1.295)	(1.584)
hedging2	16.808	15.599	17.294	16.180
	(0.897)	(0.985)	(1.010)	(1.118)

Comparing the summary statistics with equilibrium choices, we note that especially in the single production model, choices are much larger than anticipated. More precisely, average choices do not seem to be consistent with risk aversion elicited from the Holt and Laury (2002). Instead, average choices correspond more with the risk neutrality case (the case under certainty). Subjects seem not to take the roll-over risk associated with the hedging choice into account. Rather, subjects seem to engage in production as if this roll-over risk does not exist. Double production averages are in the neighborhood of expected equilibrium choices (especially for quantity).

According to Equation (2), subjects set their spot sales to smooth profits over periods. This reflects the risk-mitigating impact of hedging decision, as subjects should be less sensitive to price changes given that the forward price is fixed. To test this prediction, we compute the marginal revenues set by subjects in both periods. Theory would predict that players make sure that marginal revenues of the first period equals to marginal revenues of the second period, adjusted for storage costs. To reduce the likelihood that subjects are unfamiliar with the strategic forces they face, we provide results as well on data collected in the last five rounds. We cannot reject the null hypothesis that marginal revenues are equal in both periods in high demand realizations. However, when demand is low, subjects choose to sell in a way that marginal revenue of the first period is significantly larger than marginal revenue of the second period. The explanation is that production was too high for the low state demand. Therefore, subjects set the first period marginal revenue to zero, which we cannot reject from one tailed t-test ($p = 0.9827$), and then sell the remaining quantity in the second period at (possibly) negative marginal revenue.

Results from regressing spot sales on theoretically important variables are reported in Table 3. We regress spot sales on players' own quantity produced and own hedging in the first period as well as on quantity produced and hedging of their competitors. The "double production" variable is a dummy equal to 0 for single production (Model A) and equal to 1 for double production (Model B); "safechoices" is the number (from 0 to 10) of choices in the risk task where the subject chose the less risky option; the "highstate" variable is a dummy equal to 1 if high demand realization occurs and 0 otherwise. We add two demographic variables:[13] (1) the "Gender" dummy is equal to 1 if the player is a male and 0 otherwise; (2) the "Major" dummy is equal to 1 if the player's

[13] 53% of players were in finance and economics and 32% of players were male.

field of study is Finance, Accounting or Economics and 0 otherwise. According to theory, sales decisions should be significantly larger for the double production case. The positive dummy variables "double production" provides supporting evidence for this hypothesis (Hypothesis 4). Moreover, sales decision should be independent of degree of risk aversion. The existence of a forward market allows players to separate between their sales decision in the first period and their risk preferences. Consistent with this prediction, "safechoices" is not significantly correlated with spot sales, in either model. To examine whether players consider financial risk management decisions when making sales decisions, i.e., whether the hedging choice has strategic impact on the sales decision, we examine whether spot sales increase with players own hedging and decreases with their opponent's hedging. The own first period hedging is significantly different from zero but only in the single production model. According to theory, the coefficient on own hedging of the first period should be $+\frac{2}{3}$. However, the coefficient is much smaller than what the theory predicts for both models, but still significantly positive. Furthermore, spot sales should decrease with hedging of the competitors, the coefficient should be $-\frac{1}{3}$ according to theory. However, results in Table 3 suggest that the coefficients are positive but not significantly different from zero, for the two models.

According to our Hypothesis 1 and 3, subjects should employ a full hedge in the second period to ensure deterministic profits in the final stage. To test this prediction, we examine the statistical significance of the difference between the second period hedging and the quantity available to sell in Period 2, that is the final stage. Results on the full sample suggest that there is an under hedge, as the difference is statistically negative. By considering the last five rounds however, results suggest that we cannot reject the null hypothesis: subjects tend to hedge fully for Model A (p-value is 0.1039 for double production=0) but we reject the null hypothesis for Model B (underhedge). We regress the second period hedging on variables that should matter according to theory. We expect to find that second period hedging increases with quantities produced in the first period for the Model A-group and in both periods in the Model B-group, and decreases with the state of demand. In the latter, we expect that players would sell more when high state of demand occurs. Finally, we expect the second period hedging decision to be independent of risk aversion of players. Results reported in Table 4 suggest that own hedging in the second period indeed increases significantly with the quantities produced in the two periods, decreases significantly with the states of demand,

Table 3: Spot Sales Tobit regressions

Models 1-3 report results on data from all 20 rounds, whereas models 4-6 report results on only data of the last five rounds. Models 1 and 4 combine data on Models A and B, while Models 2 and 5 are restricted to Model A, and Models 3 and 6 are restricted to Model B. The "double production" variable is a dummy equals to 0 for single production and to 1 for double production; "safechoices" is the number (from 0 to 10) of choices in the risk task where the subject chose the less risky option; "highstate" variable is a dummy equals to 1 if high demand realization occurs and 0 otherwise. We add two demographic variables: (1) "gender" dummy is equal to 1 if the player is a male and 0 otherwise; (2) "major" dummy is equal to 1 if the player field of study is Finance, Accounting or Economics and 0 otherwise.

	(1)	(2)	(3)	(4)	(5)	(6)
quantity	0.597***	0.580***	0.591***	0.574***	0.555***	0.556***
	(0.0341)	(0.0486)	(0.0499)	(0.0469)	(0.0710)	(0.0674)
otherquantity	-0.0343	-0.0523	-0.00909	0.0241	0.0615	-0.000629
	(0.0201)	(0.0289)	(0.0280)	(0.0345)	(0.0623)	(0.0366)
hedging1	0.0508*	0.122***	-0.0136	0.0514	0.123*	0.000637
	(0.0243)	(0.0356)	(0.0360)	(0.0293)	(0.0511)	(0.0395)
otherhedging1	0.0258	0.0248	0.0230	0.0218	0.0384	0.0177
	(0.0163)	(0.0301)	(0.0170)	(0.0226)	(0.0322)	(0.0245)
highstate	2.422***	2.583**	2.170***	2.409***	1.922*	2.507**
	(0.502)	(0.796)	(0.582)	(0.590)	(0.949)	(0.774)
double producion	1.875*			3.281**		
	(0.896)			(1.232)		
safechoices	-0.0912	-0.221	-0.0642	-0.330	-0.582	-0.204
	(0.175)	(0.366)	(0.187)	(0.182)	(0.365)	(0.189)
period	0.0328	-0.0562	0.135**	0.0554	-0.190	0.264
	(0.0331)	(0.0481)	(0.0442)	(0.139)	(0.210)	(0.196)
riskconsist	-0.00500	1.075	-1.130	-0.0556	1.012	-0.853
	(0.769)	(1.214)	(0.849)	(0.925)	(1.330)	(1.240)
gender	-0.389	-0.0668	-0.379	0.0345	0.368	0.298
	(0.813)	(1.105)	(0.990)	(0.867)	(1.115)	(1.267)
major	-0.216	-1.090	0.927	0.375	0.239	0.851
	(0.763)	(1.139)	(0.796)	(0.820)	(1.194)	(0.975)
constant	-0.976	0.102	0.647	-2.114	1.018	-0.923
	(2.289)	(3.574)	(2.365)	(3.688)	(5.167)	(4.650)
sigma	7.033***	7.290***	6.565***	5.752***	6.010***	5.319***
	(0.278)	(0.441)	(0.329)	(0.304)	(0.442)	(0.402)
Observations	1990	1030	960	590	302	288

Standard errors clustered by subject in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Second period Hedging Tobit regressions

Models 1-3 report results on data from all 20 rounds, whereas models 4-6 report results on only data of the last five rounds. Models 1 and 4 combine data on Models A and B, while Models 2 and 5 are restricted to Model A, and Models 3 and 6 are restricted to Model B. The "double production" variable is a dummy equals to 0 for single production and to 1 for double production; "safechoices" is the number (from 0 to 10) of choices in the risk task where the subject chose the less risky option; "highstate" variable is a dummy equals to 1 if high demand realization occurs and 0 otherwise. We add two demographic variables: (1) "gender" dummy is equal to 1 if the player is a male and 0 otherwise; (2) "major" dummy is equal to 1 if the player field of study is Finance, Accounting or Economics and 0 otherwise.

	(1)	(2)	(3)	(4)	(5)	(6)
quantity	0.180**	0.237**	0.0611	0.162*	0.206*	0.0105
	(0.0591)	(0.0863)	(0.0603)	(0.0732)	(0.0944)	(0.0940)
quantity2	0.229**		0.244***	0.358***		0.326**
	(0.0705)		(0.0728)	(0.104)		(0.109)
otherquantity	0.0544	0.0939	0.00460	0.0706	0.100	0.0446
	(0.0378)	(0.0556)	(0.0471)	(0.0645)	(0.0960)	(0.0745)
otherhedging1	0.00734	0.0211	0.000351	0.0491	-0.123	0.142**
	(0.0243)	(0.0396)	(0.0293)	(0.0443)	(0.0743)	(0.0473)
highstate	-1.543*	-0.882	-2.117*	-1.350	1.365	-2.937*
	(0.611)	(0.884)	(0.844)	(1.048)	(1.656)	(1.430)
double production	-0.442			-1.842		
	(1.963)			(2.326)		
safechoices	0.152	-0.660	0.472	0.219	-0.349	0.489
	(0.371)	(0.552)	(0.397)	(0.409)	(0.493)	(0.520)
period	-0.0745	-0.156	-0.0171	-0.515*	-0.307	-0.562
	(0.0581)	(0.0832)	(0.0821)	(0.218)	(0.272)	(0.327)
riskconsist	-1.502	0.457	-2.640	-1.956	-0.298	-3.435
	(1.674)	(2.145)	(1.846)	(1.650)	(2.204)	(1.855)
gender	-1.662	-4.207	1.065	-2.522	-4.828*	-0.548
	(1.703)	(2.355)	(1.869)	(1.745)	(2.337)	(2.181)
major	-0.453	-5.007*	4.353*	0.434	-4.517	5.613*
	(1.674)	(2.166)	(2.133)	(1.845)	(2.368)	(2.455)
constant	10.38**	13.35**	9.155*	17.05**	17.14*	15.56
	(3.782)	(4.974)	(4.058)	(6.264)	(7.202)	(8.128)
sigma	12.44***	12.63***	11.51***	10.55***	10.07***	10.06***
	(0.649)	(0.843)	(0.902)	(0.721)	(0.845)	(1.042)
Observations	1990	1030	960	590	302	288

Standard errors clustered by subject in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

and is independent of the risk aversion of subjects as expected.

When deciding own hedging in the first period, subjects should take into account the impact of their decision on prices. An increase of first period hedging will increase competition on the market and thus decrease profits. Therefore, subjects would be more likely to make their hedging decision by taking into account its impact on competition and refrain from completely hedging their risk exposure. According to Hypothesis 2 and 5, the initial hedging decision should therefore be an underhedge. This means that we should observe an initial hedging decision smaller than expected sales. Results from t-tests provide strong supportive evidence to this prediction (t-statistics range between approximately -7 and -15 for the two models and by controlling for the last five rounds). We observe a significant underhedge, suggesting that players do take into account the strategic impact of their first period hedging decision. Our results suggest that the extent of the underhedge decreases with experience as the difference for the final five rounds is smaller than for the entire experiment. Comparing actual sales with the initial hedging decisions reveals that subjects choose a supply that yields an ex-post full hedge for the double production case. Subjects set spot sales equal to hedging1 (p-value ranges between 0.221 and 0.985 for the two models and by controlling for demand realizations), and significantly lower than quantity for both demand realizations. This indicates that subjects deviate from the ex-ante equilibrium strategy and only sell that part of their production with fixed (forward) prices. For the single production setting, the difference between first period own hedging and realized spot sales is significantly negative (ex-post underhedge) and more pronounced when high demand realizations occurs.

We regress the own first period hedging on variables that matter according to theory, namely quantity produced in the first period, and risk aversion. We also control for some demographic variables. We expect to find first period hedging to increase with quantity. Note that this is consistent with the hypothesis that players under-hedge. Results reported in Table 5 suggest that own hedging in the first period is significantly correlated to quantity only in the two models restricted to Model A. Moreover, own hedging in the first period is not correlated to the risk aversion coefficients, even when considering the last five rounds. Finally, and similar to the second period hedging choice, we observe a tendency of males to hedge less than females, though not always statistically significant.

Table 5: First period Hedging Tobit regressions

Models 1-3 report results on data from all 20 rounds, whereas models 4-6 report results on only data of the last five rounds. Models 1 and 4 combine data on Models A and B, while Models 2 and 5 are restricted to Model A, and Models 3 and 6 are restricted to Model B. The "double production" variable is a dummy equals to 0 for single production and to 1 for double production; "safechoices" is the number (from 0 to 10) of choices in the risk task where the subject chose the less risky option. We add two demographic variables: (1) "gender" dummy is equal to 1 if the player is a male and 0 otherwise; (2) "major" dummy is equal to 1 if the player field of study is Finance, Accounting or Economics and 0 otherwise.

	(1)	(2)	(3)	(4)	(5)	(6)
quantity	0.107	0.209*	-0.0262	0.177	0.375**	-0.0554
	(0.0723)	(0.0864)	(0.112)	(0.109)	(0.129)	(0.168)
double production	3.047			4.217		
	(1.822)			(2.299)		
safechoices	0.542	0.225	0.647	0.697	0.436	0.857
	(0.400)	(0.550)	(0.574)	(0.472)	(0.664)	(0.702)
period	-0.133*	-0.157*	-0.134	0.0844	-0.0129	0.127
	(0.0609)	(0.0779)	(0.0952)	(0.198)	(0.287)	(0.257)
riskconsist	-4.203*	-3.362	-5.146*	-4.632*	-4.307	-5.573*
	(1.789)	(2.519)	(2.287)	(2.342)	(3.799)	(2.741)
gender	-3.453	-5.963*	0.0227	-2.988	-5.454*	0.193
	(2.015)	(2.324)	(3.508)	(2.463)	(2.710)	(4.509)
major	2.083	0.375	3.874	1.873	0.00503	4.486
	(1.743)	(2.068)	(2.887)	(2.085)	(2.437)	(3.410)
constant	13.53***	13.20**	18.17***	6.787	4.810	13.22
	(3.773)	(5.029)	(4.806)	(5.993)	(8.280)	(7.397)
sigma	12.62***	11.28***	13.61***	12.42***	10.85***	13.38***
	(0.791)	(0.672)	(1.465)	(0.998)	(1.041)	(1.725)

Standard errors clustered by subject in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To summarize, our experimental results present evidence that subjects are aware of the strategic impact of the hedging device. However, we do not find evidence that subjects take their competitors' financial decisions into account when setting their supply. Moreover, in the double production case we provide strong evidence that the hedging device significantly increases competition even in a simultaneous setting. We find that in this setting doupoly profits vanish due to high supply. These results supplement the findings by Brandts et al. (2008) who document that, in absence of risk and a strategic dilemma, the introduction of a forward market significantly increases competition on the market. Moreover, our results are related to the observations of Mueller (2006) who finds that players in a Cournot duopoly with multiple production periods do not act significantly different from the standard one-period markets which contradicts theoretical predictions. In Model B of our study, first period choices are significantly larger than in the one-period interaction due to the strategic impact of the hedging device. Finally, we find weak evidence that subjects use storage opportunity to smooth profits over time.

6 Conclusion

In this paper, we theoretically and experimentally investigate the influence of a simultaneous hedging device on firm choices and competition in incomplete markets. In markets with imperfect competition, the risk management device introduces a strategic dilemma for competitors. On the one hand, corporate hedging has adverse effects on the competitiveness on the market (Allaz, 1992; Allaz and Vila, 1993). On the other hand, the hedging device allows producers to deal with their risk exposure. Consequently, firms must weigh the advantages of being able to hedge their risk exposure against the disadvantages of higher competition.

We considered a multi-period duopoly under demand uncertainty with a hedging opportunity and the possibility to take storage in a simple framework with (μ, σ)-preferences. We theoretically establish the following results: firms of a duopoly consider the impact of their hedging choice on equilibrium and consequently are willing to take a risky position in order to mitigate the adverse effect of the hedging component on market prices. Hence, we find that the hedging component increases competition.

In the experimental part of our study, we find support of our theoretical results. Subjects refrain from completely hedging their risk, i.e. taking a full hedge. However, subjects do not consider information about the hedging decision of their competitor (which is common knowledge) in subsequent decisions. As the game is more similar to a simple repetition of the single shot game in the second setup, competition increases to a level which completely negates duopoly profits.

References

Adam, T. R., C. S. Frenando, and E. Golubeva (2015): "Managerial overconfidence and corporate risk management," *Journal of Banking and Finance*, 60, 195–208.

Allaz, B. (1992): "Oligopoly, uncertainty and strategic forward transactions," *International Journal of Industrial Organization*, 10, 297–308.

Allaz, B. and J. Vila (1993): "Cournot Competition, Forward Markets and Efficiency," *Journal of Economic Theory*, 59, 1–16.

Battermann, H., U. Broll, and J. Wahl (2002): "Die Aversionselastizität und ihr Einfluss auf die Portefeuilleentscheidung," *Financial Markets and Portfolio Management*, 16, 522–527.

Bolton, P., H. Chen, and N. Wang (2011): "A Unified Theory of Tobin's q, Corporate Investment, Financing, and Risk Management," *The Journal of Finance*, 66, 1545–1578.

Brandts, J., P. Pezanis-Christou, and A. Schram (2008): "Competition with forward contracts: a laboratory analysis motivated by electricity market design," *The Economic Journal*, 118, 192–214.

Broll, U., K. Chow, and K. P. Wong (2001): "Hedging and nonlinear risk," *Oxford Economic Papers*, 53, 281–296.

Broll, U., J. E. Wahl, and C. Wessel (2011): "Export, Exchange Rate Risk and Hedging: The Duopoly Case," *German Economic Review*, 12, 490–502.

Broll, U., J. E. Wahl, and I. Zilcha (1995): "Indirect hedging of exchange rate risk," *Journal of International Money and Finance*, 14, 667–678.

Broll, U., P. Welzel, and K. P. Wong (2009): "Export and Strategic Currency Hedging," *Open Economies Review*, 20, 717–732.

Broll, U. and K. P. Wong (2013): "The firm under uncertainty: real and financial decisions," *Decisions in Economics and Finance*, 36, 125–136.

Brown, G. W., P. R. Crabb, and D. Haushalter (2006): "Are Firms Successful at Selective Hedging?" *The Journal of Business*, 79, 2925–2949.

Campello, M., C. Lin, Y. Ma, and H. Zou (2011): "The Real and Financial Implications of Corporate Hedging," *The Journal of Finance*, 66, 1615–1647.

Carter, D. A., D. A. Rogers, and B. J. Simkins (2006): "Hedging and Value in the U.S. Airline Industry," *Journal of Applied Corporate Finance*, 18, 21–33.

Chen, J. and T.-H. D. King (2014): "Corporate Hedging and the cost of debt," *Journal of Corporate Finance*, in press.

Culp, C. L. and M. H. Miller (1999): *Corporate Hedging in Theory and Practice: Lessons from Metallgesellschaft*, London: Risk Publications.

Cyert, R. and M. DeGroot (1970): "Bayesian analysis and duopoly theory," *Journal of Political Economy*, 1168–1184.

Ferreira, J. L., P. Kujal, and S. Rassenti (2009): "The Strategic Motive to Sell Forward: Experimental Evidence," *Universidad Carlos III de Madrid Working Paper*, 09-26.

Fischbacher, U. (2007): "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 10, 171–178.

Froot, K., D. Scharfstein, and J. Stein (1993): "Risk Managements Coordinating Corporate Investment and Financing Policies," *The Journal of Finance*, 48, 1629–1658.

Géczy, C., B. A. Minton, and C. Schrand (1997): "Why Firms Use Currency Derivatives," *The Journal of Finance*, 52, 1323–1354.

Graham, J. R. and D. A. Rogers (2002): "Do firms hedge in response to tax incentives?" *The Journal of Finance*, 57, 815–839.

Graham, J. R. and C. W. Smith (1999): "Tax incentives to hedge," *The Journal of Finance*, 54, 2241–2262.

Haushalter, D. G. (2000): "Financing policy, basis risk, and corporate hedging: evidence from oil and gas producers," *The Journal of Finance*, 55, 107–152.

Healy, P. J. (2006): "Learning dynamics for mechanism design: An experimental comparison of public goods mechanisms," *Journal of Economic Theory*, 129, 114–149.

Holt, C. A. and S. K. Laury (2002): "Risk Aversion and Incentive Effects," *The American Economic Review*, 92, 1644–1655.

Holthausen, D. M. (1979): "Hedging and the Competitive Firm under Price Uncertainty," *The American Economic Review*, 69, 989–995.

Hull, J. C. (2012): *Risk Management and Financial Institutions*, Wiley Finance.

Jin, Y. and P. Jorion (2006): "Firm Value and Hedging: Evidence from U.S. Oil and Gas Producers," *The Journal of Finance*, 61, 893–919.

Kajüter, P. (2012): *Risikomanagement im Konzern - Eine empirische Analyse börsennotierter Aktienkonzerne*, München: Verlag Franz Vahlen.

Kreps, D. M. and J. A. Scheinkman (1983): "Quantity precommitment and Bertrand competition yield Cournot outcomes," *The Bell Journal of Economics*, 14, 326–337.

Larue, B. and V. Yapo (2000): "Asymmetries in Risk and in Risk Attitude: The Duopoly Case," *Journal of Economics and Business*, 52, 435–453.

Lautier, D. and F. Raynaud (2011): "Statistical properties of derivatives: a journey in term structures," *University of Fribourg Econophysics Working Paper Series.*

LE COQ, C. AND H. ORZEN (2006): "Do forward markets enhance competition? Experimental evidence," *Journal of Economic Behavior and Organization*, 61, 415–431.

LEAUTIER, T.-O. AND J.-C. ROCHET (2014): "On the strategic value of risk management," *International Journal of Industrial Organization*, 37, 153–169.

LELAND, H. E. (1998): "Agency costs, and capital structure," *The Journal of Finance*, 53, 1213–1243.

MACKAY, P. AND S. MOELLER (2007): "The value of corporate risk management," *The Journal of Finance*, 62, 1379–1419.

MAGGI, G. (1996): "Strategic trade policies with endogenous mode of competition," *The American Economic Review*, 86, 237–258.

MARTIN, S. (1994): *Advanced Industrial Economics*, Cambridge, MA.: Basil Blackwell.

MAS-COLELL, A., M. WHINSTON, AND J. GREEN (1995): *Microeconomic Theory*, Oxford: Oxford University Press.

MELLO, A. AND J. PARSONS (2000): "Hedging and liquidity," *Review of Financial Studies*, 13, 127–153.

MUELLER, W. (2006): "Allowing for two production periods in the Cournot duopoly: Experimental evidence," *Journal of Economic Behavior & Organization*, 60, 100–111.

MUERMANN, A. AND S. H. SHORE (2006): "Strategic trading and manipulation with spot market power," *CFS Working Paper*, 2006/07.

PELSTER, M. AND T. SPRINGER (2015): "Applicability of the Wavelet-Approach for Corporate Hedging," *International Journal of Portfolio Analysis and Management*, in press.

ROBISON, L. AND P. BARRY (1987): *The competitive firm's response to risk*, New York: Macmillan Publishing Company.

ROETHIG, A. (2008): *The Impact of Backwardation on Hedgers' Demand for Currency Futures Contracts: Theory versus Empirical Evidence*, Darmstadt: Publications of Darmstadt Technical University.

SELTEN, R. (1965): "Spieltheoretische Behandlung eines Oligopolmodells mit Nachfrageträgheit," *Zeitschrift für die gesamte Staatswissenschaft*, 121, 301–324, 667–689.

SMITH, C. W. AND R. M. STULZ (1985): "The determinants of firms' hedging policies," *Journal of Financial and Quantitative Analysis*, 20, 391–405.

STULZ, R. M. (1984): "Optimal hedging policies," *Journal of Financial and Quantitative Analysis*, 19, 127–140.

TUFANO, P. (1996): "Who manages risk? The gold mining industry," *The Journal of Finance*, 51, 1097–1137.

VAN EIJKEL, R. AND J. L. MORAGA-GONZALEZ (2010): "Do Firms sell forward for Strategic Reasons? An Application to the Wholesale Market for Natural Gas," *Tinbergen Institute Discussion Paper*, 2010-058/1.

Van Essen, M. (2012): “Information complexity, punishment, and stability in two Nash efficient Lindahl mechanisms,” *Review of Economic Design*, 16, 15–40.

Van Essen, M., N. Lazzati, and M. Walker (2012): “Out-of-equilibrium performance of three Lindahl mechanisms: Experimental evidence,” *Games and Economic Behavior*, 74, 366–381.

Vives, X. (1999): *Oligopoly Pricing: Old Ideas and New Tools*, Cambridge, MA: MIT Press.

Appendix

A Mathematical derivations and comparative statics

A.1 Solution to the basic model

In order to find a subgame-perfect Nash equilibrium we first have to find the Cournot-Nash equilibrium in $t = 1$ for all possible production and forward decisions. Then we go back to $t = 0$ and determine the optimal output and hedging decisions which consider the effects on the quantity sold in $t = 1$ as well as the subsequent hedging decision.

A.1.1 Solution to the model in $t = 1$

First, we determine the optimal supply in $t = 1$ and the roll-over hedging decision. In $t = 1$ all decisions from the preliminary period, the realization of the demand uncertainty of the first period, and the forward rate for the second period are common knowledge. Thus the optimization problem of firm i, $i = i, j$, $i \neq j$, reads:

$$\max_{s^i, h_2^i} \Phi_L^i,$$

with

$$\Phi_L^i = (\varepsilon_1 M - b(s^i + s^j))s^i - c^i q^i + \check{h}_1^i(p_1^f - (\varepsilon_1 M - b(s^i + s^j)) - k^i(q^i - s^i) \\ + \delta^i((\bar{\varepsilon}_2 M - b(\check{q}^i + \check{q}^j - s^i - s^j))(\check{q}^i - s^i) + h_2^i(M_2^f - \bar{\varepsilon}_2 M) - \frac{\alpha^i}{2}\operatorname{var}(\tilde{\varepsilon}_2)M^2(\check{q}^i - s^i - h_2^i)^2). \quad (6)$$

Both, $\check{q}^i$ and $\check{h}_1^i$ are fixed and cannot be adapted at this stage. Also, the forward market price for the first period is agreed on and not subject to change. The first order conditions are

$$\varepsilon_1 M - b(2s^i + s^j) + b\check{h}_1^i + k^i \\ + \delta^i(-\bar{\varepsilon}_2 M + b(2\check{q}^i + \check{q}^j - 2s^i - s^j) + \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(\check{q}^i - s^i - h_2^i)) = 0 \; \forall \; \varepsilon_1 \quad (7)$$

and

$$\delta^i(M_2^f - \bar{\varepsilon}_2 M + \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(\check{q}^i - s^i - h_2^i)) = 0 \; \forall \; M_2^f.$$

Subtracting these yields Equation (2).

Solving Equation (2) for s^i yields firm i's reaction function for a given sales decision of the competitor, s^j,

$$Rs^i(s^j) = \frac{\bar{\varepsilon}_1 M - bs^j - \delta^i(M_2^f - b(2\check{q}^i + \check{q}^j - s^j)) + b\check{h}_1^i + k^i}{2b(1 + \delta^i)}.$$

The reaction functions possess a negative slope, which is smaller than one according to amount. It is $\frac{\partial Rs^i(s^j)}{\partial s^j} = -\frac{1}{2}$. Thus the amounts sold are strategic substitutes. The Nash equilibrium can be calculated by solving the system of equations for $i = i, j,\ i \neq j$,

$$s_{LH}^i = \frac{1}{3b(1+\delta^i)(1+\delta^j)} \Big(\bar{\varepsilon}_2 M(\delta^j - 2\delta^i + \delta^i\delta^j) - k^j(1+\delta^i) + 2k^i(1+\delta^j) + b(2(2\check{q}^i + \check{q}^j)\delta^i - \check{h}_1^j(1+\delta^i)) - (\check{q}^i + 2\check{q}^j - 3\check{q}^i\delta^i)\delta^j + 2\check{h}_1^i(1+\delta^j)) + \bar{\varepsilon}_1 M(1 - \delta^i + 2\delta^j) \Big). \quad (8)$$

Note that $M_2^f = \bar{\varepsilon}_2 M$.

Equilibrium choices highlight the strategic impact of the hedging decisions for the interactions to follow. Taking the derivative of the (8) with respect to $\check{h}_1^i$ and $\check{h}_1^j$ yields

$$\frac{\partial s_{LH}^i}{\partial \check{h}_1^i} = \frac{2}{3(1+\delta^i)} > 0$$

and

$$\frac{\partial s_{LH}^i}{\partial \check{h}_1^j} = -\frac{1}{3(1+\delta^j)} < 0$$

respectively.

Hedging decision in $t = 1$

Definition 6. *The forward market is called* unbiased, *if at a given industrial production Q the forward price equals the expected spot price.*

If the forward price is smaller than the expected spot price, the forward market is referred to as to be in backwardation. *The risk premium is positive.*

If the forward price is greater than the expected spot price, the forward market is referred to as to be in contango. *In this case, the risk premium is negative.*[14]

The optimal hedging position in $t = 1$ is given by

$$\begin{aligned} h_2^i &= \check{q}^i - s^i + \frac{M_2^f - \bar{\varepsilon}_2 M}{\alpha^i \operatorname{var}(\tilde{\varepsilon}_2) M^2} && (9) \\ &= \check{q}^i - s^i. && (10) \end{aligned}$$

Comparative statics After solving the second phase of the interaction some analyzes of sensitivity are carried out. The most important question to answer is how the quantity offered by one

[14]See, e.g., Hull (2012).
Several studies analyze forward markets to determine the state of the forward market. For example, Lautier and Raynaud (2011) or Roethig (2008) consider several forward markets and find that the state of the forward market depends on the underlying. The authors find that some commodity markets always experience backwardation while others experience contango. Hence, there is no clear empirical evidence as to whether forward markets are biased or unbiased.

firm reacts towards an increase of production, either by the firm itself or by the competitor. Thus we deduce the derivatives

$$\frac{\partial Rs^i(s^j)}{\partial q^i} = \frac{\delta^i}{1+\delta^i} > 0 \tag{11}$$

and

$$\frac{\partial Rs^i(s^j)}{\partial q^j} = \frac{\delta^i}{2(1+\delta^i)} > 0. \tag{12}$$

Both reaction functions are characterized by a positive slope. However, the slope is smaller than 1 and $\frac{1}{2}$, respectively. Moreover, the slope only depends on the time preferences of the decision maker. As the production increases, the amount offered on the spot market in $t = 1$ increases as well, but to a smaller extend. This is expected, as the firms have to distribute their production over two periods. Additionally, we can conclude that the offered spot quantity increases more when the own production rises than it does when the competitor's production increases. The factor $\frac{1}{2}$ from Equation (12) is well known from the standard Cournot model.

The shifts of the reaction functions tend to result in a bigger supply by both firms. However, subject to the decision makers' time preferences there are some exceptions, in which the firm offers less on the spot market even though its reaction function was pushed outwards. This is the case if the reaction function of the competitor experiences an even stronger shift. Hence, the equilibrium is subject to the relation between time preferences of the decision makers. We have

$$\frac{\partial s^i_{LH}}{\partial q^i} = 1 - \frac{1}{3}\Big(\frac{4}{1+\delta^i} - \frac{1}{1+\delta^j}\Big)$$

and

$$\frac{\partial s^i_{LH}}{\partial q^j} = \frac{2(\delta^i - \delta^j)}{3(1+\delta^i)(1+\delta^j)}.$$

As already pointed out, the forward market position strategically influences the supply of the duopolists on the spot market in $t = 1$. This is due to the impact of the forward market decision on the reaction functions of the decision makers. The quantity of the effect is determined by the derivatives

$$\frac{\partial Rs^i(s^j)}{\partial h^i} = \frac{1}{2(1+\delta^i)} > 0 \tag{13}$$

and

$$\frac{\partial Rs^i(s^j)}{\partial h^j} = 0. \tag{14}$$

Note that even though the reaction function is not modified with respect to the hedging decision of the competitor, the equilibrium outcome is still affected as shown above.

For the optimal forward decisions, the following holds:

$$\frac{\partial h^i_2}{\partial q^i} = 1$$

and

$$\frac{\partial h_2^i}{\partial q^j} = 0.$$

The adjustment of the forward position is perfectly correlated with the increase in production. However, an increase in production by the competitor does not have direct implications on the optimal hedging position.

Apart from the selected output other parameters influence the offered quantity in the first interaction. Obviously, a higher realized demand and rising storage costs lead to an increase of the offer. It is $\frac{\partial Rs^i(s^j)}{\partial \varepsilon_1} = \frac{M}{2b(1+\delta^i)} > 0$ and $\frac{\partial s_L^i}{\partial \varepsilon_1} > 0$ resp. $\frac{\partial Rs^i(s^j)}{\partial k^i} = \frac{1}{2b(1+\delta^i)} > 0$ and $\frac{\partial s_L^i}{\partial k^i} > 0$.

The effects of a change in temporal preferences of the investors cannot be determined clearly. The effects depend on the selected outputs, the quantity offered by the competitor and some fixed model parameters such as temporal preferences or storage costs.

A.1.2 Solution to the model in $t = 0$

Subject to the solution from $t = 1$, that is the optimal expected amount sold and the forward position for the second period, we are now able to determine the subgame-perfect equilibrium. Note, that random variables which are realized in $t = 1$ are still stochastic at time $t = 0$. Hence, in the following, $\tilde{\varepsilon}_1$ and $\tilde{M}_2^f$ are stochastic. In $t = 0$ the firms maximize the preference function

$$\begin{aligned}\Phi_L^i = &(\bar{\varepsilon}_1 M - b(\hat{s}^i + \hat{s}^j))\hat{s}^i - c^i q^i + h_1^i(M_1^f - \bar{\varepsilon}_1 M) - k^i(q^i - \hat{s}^i) - \frac{\alpha^i}{2}\operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^i - h_1^i)^2 \\ &+ \delta^i((\bar{\varepsilon}_2 M - b(q^i + q^j - \hat{s}^i - \hat{s}^j))(q^i - \hat{s}^i) + \hat{h}_2^i(\bar{M}_2^f - \bar{\varepsilon}_2 M) - \frac{\alpha^i}{2}(\operatorname{var}(\tilde{\varepsilon}_2)M^2(q^i - \hat{s}^i - \hat{h}_2^i)^2 + \operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{h}_2^i)^2)).\end{aligned}$$

Note, that in $t = 0$ both, the forward price and the expected spot market price are equally sensitive to changes in production and expected supply. This allows us some simplifications with respect to the forward market price. Thus, the first order conditions are

$$\begin{aligned}&-c^i - k^i + \delta^i(\bar{\varepsilon}_2 M - b(2q^i + q^j - 2\hat{s}^i - \hat{s}^j) - \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q^i - \hat{s}^i - \hat{h}_2^i)) \\ &\qquad + \frac{\partial \hat{s}^i}{\partial q^i}(\bar{\varepsilon}_1 M - b(2\hat{s}^i + \hat{s}^j) + k^i - \alpha^i \operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^i - h_1^i) \\ &\qquad + \delta^i(-\bar{\varepsilon}_2 M + b(2q^i + q^j - 2\hat{s}^i - \hat{s}^j) + \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q^i - \hat{s}^i - \hat{h}_2^i))) + \frac{\partial \hat{s}^j}{\partial q^i}(-b\hat{s}^i + \delta^i b(q^i - \hat{s}^i)) \\ &\qquad + \frac{\partial \hat{h}_2^i}{\partial q^i}(\delta^i(M_2^f - \bar{\varepsilon}_2 M) + \alpha^i(\operatorname{var}(\tilde{\varepsilon}_2)M^2(q^i - \hat{s}^i - \hat{h}_2^i) - \operatorname{var}(\tilde{\varepsilon}_1)M^2\hat{h}_2^i)) = 0 \end{aligned} \tag{15}$$

and

$$\begin{aligned}&M_1^f - \bar{\varepsilon}_1 M + \alpha^i \operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^i - h_1^i) + \frac{\partial \hat{s}^i}{\partial h_1^i}(\bar{\varepsilon}_1 M - b(2\hat{s}^i + \hat{s}^j) + k^i - \alpha^i \operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^i - h_1^i) \\ &+ \delta^i(-\bar{\varepsilon}_2 M + b(2q^i + q^j - 2\hat{s}^i - \hat{s}^j) + \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q^i - \hat{s}^i - \hat{h}_2^i))) + \frac{\partial \hat{s}^j}{\partial h_1^i}(-b\hat{s}^i + \delta^i b(q^i - \hat{s}^i)) = 0.\end{aligned} \tag{16}$$

The first order conditions take $\frac{\partial \hat{h}_2^j}{\partial q^i} = 0$ into account. Moreover, $\frac{\partial \hat{s}^i}{\partial h_1^i} = \frac{2}{3(1+\delta^i)}$ and $\frac{\partial \hat{s}^j}{\partial h_1^i} = -\frac{1}{3(1+\delta^j)}$ highlight the strategic impact of the risk management decisions. Finally, $\frac{\partial \hat{h}_2^i}{\partial q^i} = 1$.

Similarly to the approach from Section A.1.1 we can specify the reaction functions of firm i and determine its production and hedging decisions for a given output and risk management position of the competitor j, $Rq^i(q^j, h_1^j)$ and $Rh_1^i(q^j, h_1^j)$. To do so, we have to solve Equations (15) and (16) for q^i and h_1^i, respectively ($\forall\ i = i, j,\ i \neq j$). Furthermore, we can determine the Nash equilibrium by solving the set of equations of necessary conditions.

A.2 Solution to the model with adjustable production decisions

Following the concept of a subgame-perfect Nash equilibrium by Selten (1965), we first determine the equilibrium in $t = 1$ for every possible outcome of the interaction in $t = 0$.

A.2.1 Solution to the model in $t = 1$

The optimization problem of decision maker i in $t = 1$ reads

$$\max_{q_2^i, h_2^i, s^i} \Phi^i$$

with

$$\begin{aligned}\Phi^i = \;& p(Q_1)s^i - c_1^i \check{q}_1^i + \check{h}_1^i(p_1^f - (\varepsilon_1 M - b(s^i + s^j))) - k^i(\check{q}_1^i - s^i) \\ & + \delta^i(\bar{p}(Q_2)(q_2^i + \check{q}_1^i - s^i) - c_2^i q_2^i + h_2^i(M_2^f - \bar{\varepsilon}_2 M) - \frac{\alpha^i}{2}\operatorname{var}(\tilde{\varepsilon}_2)M^2(q_2^i + \check{q}_1^i - s^i - h_2^i)^2).\end{aligned}$$

$\check{q}_1^i$, $\check{q}_1^j$ as well as $\check{h}_1^i$ and $\check{h}_1^j$ are fixed and the realization of the demand in $t = 1$ is known. Similar to Section 2, the decision variables q_2^i, h_2^i and s^i are functions of the decision variables of the previous period of both players. For example, we have $s^i = s^i(\check{q}_1^i, \check{q}_1^j, \check{h}_1^i, \check{h}_1^j)$. Moreover, $s^i \in [0, \check{q}_1^i]$.
The optimum can be found by solving for the first order conditions:

$$\begin{aligned}&\bar{\varepsilon}_1 M - b(2s^i + s^j) + b\check{h}_1^i + k^i - \delta^i(\bar{\varepsilon}_2 M - b(2q_2^i + q_2^j + 2\check{q}_1^i + \check{q}_1^j - 2s^i - s^j) \\ &\qquad - \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q_2^i + \check{q}_1^i - s^i - h_2^i)) = 0, \quad (17)\end{aligned}$$

$$\begin{aligned}&\delta^i(\bar{\varepsilon}_2 M - b(2q_2^i + q_2^j + 2\check{q}_1^i + \check{q}_1^j - 2s^i - s^j) - c_2^i \\ &\qquad - \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q_2^i + \check{q}_1^i - s^i - h_2^i)) = 0 \quad (18)\end{aligned}$$

and

$$\delta^i(M_2^f - \bar{\varepsilon}_2 M + \alpha^i \operatorname{var}(\tilde{\varepsilon}_2)M^2(q_2^i + \check{q}_1^i - s^i - h_2^i)) = 0. \quad (19)$$

Addition of (18) and (19) yields the separation theorem, Equation 3. Moreover, subtraction of (17) and (19) yields Equation 4. Finally, rearranging Equation (19) yields Equation (5).

The Nash equilibrium in $t = 1$ which follows every possible outcome of the interaction in $t = 0$ directly follows from solving the system of equations given by the reaction functions of the firms, (3) and (4), for s^i and q_2^i, respectively. The reaction functions read

$$Rs^i(s^j) = \frac{\varepsilon_1 M - bs^j - \delta^i c_2^i + b\check{h}_1^i + k^i}{2b} \tag{20}$$

and

$$Rq_2^i(q_2^j) = \frac{M_2^f - b(\check{q}_1^j - s^j + q_2^j) - c_2^i}{2b} - (\check{q}_1^i - Rs^i(s^j)) \tag{21}$$

for all $i, j,\ i \neq j$. Thus, the sales volume in $t = 1$ and the additional production for the second period are ($\forall\ i, j,\ i \neq j$)

$$s^{i*} = \frac{\varepsilon_1 M + 2b\check{h}_1^i - b\check{h}_1^j - 2\delta^i c_2^i + \delta^j c_2^j + 2k^i - k^j}{3b} \leq q_1^i \tag{22}$$

and

$$\begin{aligned} q_2^{i*}(\check{q}_1^i, \check{h}_1^i, \check{h}_1^j) &= \frac{M_2^f - 2c_2^i + c_2^j}{3b} - (\check{q}_1^i - s^{i*}) \\ &= \frac{M_2^f - 2c_2^i(1+\delta^i) + c_2^j(1+\delta^j) + \varepsilon_1 M + 2b\check{h}_1^i - b\check{h}_1^j + 2k^i - k^j}{3b} - \check{q}_1^i. \end{aligned} \tag{23}$$

Comparative statics of the sales decision The corresponding reaction function fulfills

$$\frac{\partial Rs^i(s^j)}{\partial \check{q}_1^i} = \frac{\partial Rs^i(s^j)}{\partial \check{q}_1^j} = 0.$$

However, the quantity of supply on the spot market in $t = 1$ is subject to the hedging decision of the previous stage

$$\begin{aligned} \frac{\partial Rs^i(s^j)}{\partial \check{h}_1^i} &= \frac{1}{2}, \\ \frac{\partial Rs^i(s^j)}{\partial \check{h}_1^j} &= 0. \end{aligned}$$

This leads to a change in equilibrium supply for firm i given by

$$\begin{aligned} \frac{\partial s^{i*}}{\partial \check{h}_1^i} &= \frac{2}{3}, \\ \frac{\partial s^{i*}}{\partial \check{h}_1^j} &= -\frac{1}{3}. \end{aligned}$$

Comparative statics of competitor's decision Implications concerning the production of the competitor can be quantified with $\frac{\partial Rq_2^i(q_2^j)}{\partial q_1^i} = \frac{1}{2}$ and $\frac{\partial h_1^{j*}}{\partial q_1^i} = 0$. Thus, the forward position of the competitor does not react to an increased production.

A.2.2 Solution to the model in $t = 0$

Taking the optimal decisions for time $t = 1$ into account we now proceed to determine the optimal decisions at the beginning of the game. We already established that both, the amount of additional production and the quantity of supply, can be determined independently of the degree of risk aversion and expectations. Moreover, the quantity of supply at the final date $t = 2$ is independent of the prior sold quantity since the possibility to adjust production allows firms to achieve the desired level. The optimal risk management decision taken in $t = 1$ depends on the state of the forward market: If the forward market is unbiased, the firm optimally chooses a full hedge. If the forward market is biased, the firm adjusts its forward position accordingly. Taking the decisions in $t = 1$ into account, we can simplify the profit of date $t = 2$:

$$\tilde{\pi}_2^i = \tilde{G} + c_2^i(q_1^i - \hat{s}^i).$$

$\tilde{G}$ denotes the revenues from the forward sale and the costs of production while $c_2^i(q_1^i - \hat{s}^i)$ denotes not incurring production costs because goods from stock are used to provide the supply. At time $t = 0$, $\tilde{G}$ is fixed with regard to the decisions due to the considerations of following decisions, but of uncertain amount. That is, $\tilde{G}$ is stochastic. If the forward market is unbiased, G turns deterministic in $t = 1$, because the firm sells its entire supply for $t = 2$ on a forward market in $t = 1$. However, if the forward market is biased, G will stay stochastic until $t = 2$ and the realization of the uncertain demand due to the speculative term in the hedging component.

Turning to the decision problem of firm i, $i = i, j$, $i \neq j$, for the initial period, we have to take into account that in $t = 1$, each firm can at most sell the produced quantity. That is, we have to respect additional boundary conditions. The optimization problem reads

$$\max_{q_1^i, h_1^i} \Phi^i$$

where

$$\begin{aligned}\Phi^i = \; & (\bar{\varepsilon}_1 M - b(\hat{s}^i + \hat{s}^j))\hat{s}^i - c_1^i q_1^i + h_1^i(M_1^f - \bar{\varepsilon}_1 M) - k^i(q_1^i - \hat{s}^i) \\ & - \frac{\alpha^i}{2} \operatorname{var}(\tilde{\varepsilon}_1) M^2 (\hat{s}^i - h_1^i)^2 + \delta^i(\tilde{G} + c_2^i(q_1^i - s^i) - \frac{\alpha^i}{2}(\operatorname{var}(\tilde{G}) + \operatorname{var}(\tilde{\varepsilon}_1) M^2 (q_1^i - \hat{s}^i)^2)).\end{aligned}$$

Remember

$$\hat{s}^{i*} = \frac{\varepsilon_1 M + 2b\check{h}_1^i - b\check{h}_1^j - 2\delta^i c_2^i + \delta^j c_2^j + 2k^i - k^j}{3b} \leq q_1^i. \qquad \text{(22 revisited)}$$

The term $\frac{\alpha^i}{2}\operatorname{var}(\tilde{\varepsilon}_1)M^2(q_1^i - \hat{s}^i)^2$ denotes the open risky position due to the roll over hedge, in analogue form of Section 2.

To find the maximum of the preference function and the market equilibrium we first calculate the interior solutions of the optimization problem. We obtain

$$-c_1^i - k^i + \delta^i(c_2^i - \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(q_1^i - \hat{s}^i)) = 0$$

and

$$\begin{aligned}(M_1^f - \bar{\varepsilon}_1 M) + \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^{i*} - h_1^i) + \frac{\partial \hat{s}^{i*}}{\partial h_1^i}\Big((\bar{\varepsilon}_1 M - b(2\hat{s}^{i*} + \hat{s}^{j*})) + k^i \\ - \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^{i*} - h_1^i) + \delta^i(-c_2^i + \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(q_1^i - \hat{s}^{i*}))\Big) + \frac{\partial \hat{s}^{j*}}{\partial h_1^i}(-b\hat{s}^{i*}) = 0.\end{aligned}$$

Remember, that $\frac{\partial \hat{s}^{i*}}{\partial \check{h}_1^i} = \frac{2}{3}$ and $\frac{\partial \hat{s}^{i*}}{\partial \check{h}_1^j} = -\frac{1}{3}$. Hence, for the FOC results

$$\begin{aligned}(M_1^f - \bar{\varepsilon}_1 M) + \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^{i*} - h_1^i) + \frac{2}{3}\Big((\bar{\varepsilon}_1 M - b(2\hat{s}^{i*} + \hat{s}^{j*})) + k^i \\ - \alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2(\hat{s}^{i*} - h_1^i) + \delta^i(-c_2^i + \alpha^i(\operatorname{var}(\tilde{\varepsilon}_1)M^2(q_1^i - \hat{s}^{i*})))\Big) - \frac{1}{3}(-b\hat{s}^{i*}) = 0.\end{aligned}$$

We take the optimal solutions of the following interaction (Equation (22)) into account and immediately observe that the firm cannot separate real and financial decisions. Instead, decision makers have to consider the strategic impact of their risk management choice on competition.
Solving the system of equations for both firms yields the equilibrium choices, for the production as well as the risk management decision. For the equilibrium choices, we obtain

$$q_1^{i*} = s_0^{i*} + \frac{\delta^i c_2^i - c_1^i - k^i}{\delta^i\alpha^i\operatorname{var}(\tilde{\varepsilon}_1)M^2} \tag{24}$$

and

$$\begin{aligned}h_1^{i*} = s_0^{i*} \\ + \frac{\alpha^j\operatorname{var}(\tilde{\varepsilon}_1)M^2(\delta^i c_2^i - \delta^j c_2^j + k^j - k^i) - b(7\bar{\varepsilon}_1 M - 6M_1^f + 2c_1^i + 2c_1^j + 5k^i - 5\delta^i c_2^i)}{b(5b + (\alpha^i + \alpha^j)\operatorname{var}(\tilde{\varepsilon}_1)M^2)},\end{aligned}$$

where

$$\begin{aligned}s_0^{i*} = \frac{1}{b^2(5b + (\alpha^i + \alpha^j)\operatorname{var}(\tilde{\varepsilon}_1)M^2)} \cdot \Big(\alpha^i\alpha^j\operatorname{var}(\tilde{\varepsilon}_1)M^4(\delta^j c_2^j - \delta^i c_2^j + k^i - k^j) \\ + b^2(-6c_1^i + 4c_1^j + 3M_1^f - \mathrm{E}[\tilde{\varepsilon}_1]M) + bM^2\operatorname{var}(\tilde{\varepsilon}_1)(\alpha^j(3M_1^f - 2c_1^i - 2k^j + 2\delta^j c_2^j \\ - 3\mathrm{E}[\tilde{\varepsilon}_1]M + \alpha^i(2c_1^j + 3k^i - 3(M_1^f + \delta^i c_2^i) + 4\mathrm{E}[\tilde{\varepsilon}_1]M))\Big).\end{aligned}$$

Note, that the optimal sales decision in $t = 1$ can change with respect to demand realizations.

The representation of Equation (24) allows us to easily distinguish between the relevant cases. For $\delta^i c_2^i - c_1^i - k^i > 0$ or, equivalently, $\delta^i c_2^i > c_1^i + k^i$ the decision makers chooses to produce more than he intends to sell in $t = 1$. In other words, the expected amount of sales in $t = 1$, $\hat{s}^{i*}$, is corrected with regard to the cost factors, the degree of risk aversion and the amount of the risky position, measured with the variance. In this case, the firm makes strategic use of its storage opportunity to reduce costs.

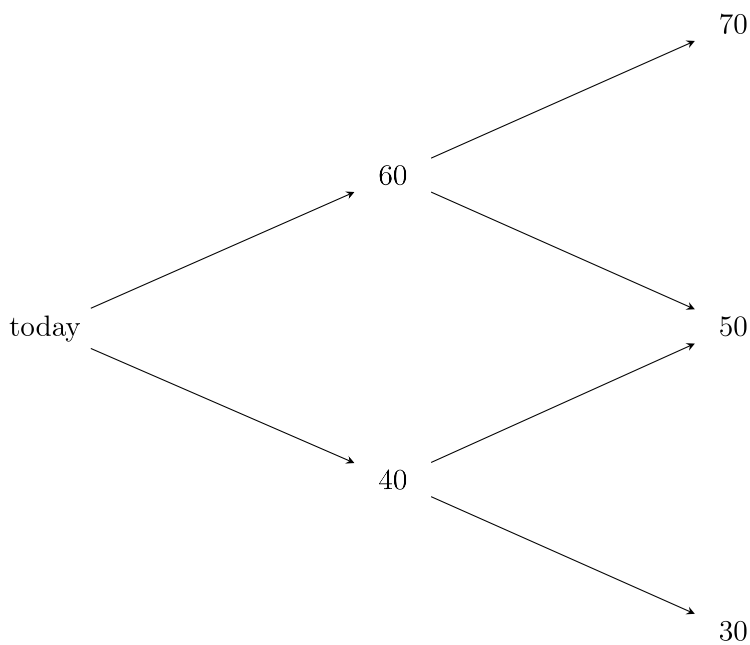
However, if firms are not exposed to a significant increase in production costs or an increase in production costs together with very low storage costs, the decision maker produces just as much as he wants to sell; that is $q_1^{i*} = \hat{s}^i$. In this case, firms do not choose to produce a surplus to be able to react to unexpectedly high demand realizations (that is, if production costs are approximately stable over time).

B Experiment Instructions: Treatment A

Within the experiments, you will take the role of the manager of a producing firm. Your firm is one of two firms in a market. Your compensation for participating in the experiments will depend on the profits you generate with your firm.

Each round of the experiment is divided into Stage 0, Stage 1, and Stage 2. Output is produced in Stage 0 and sold in Stage 1 and Stage 2.

Overall demand is uncertain: At the first point in time you will either face high (60) or low demand (40). Similarly, at the second point in time, demand will either increase or decrease (with the same probability) according to the following graph.



The price is determined following a linear demand function:

$$\text{spot market price} = \text{uncertain total demand} - \text{industry supply.}$$

The industry supply is the sum of your supply and the supply of your competitor.

To deal with the uncertainty, you are able to engage in risk management and trade the product on a forward market. The forward price is subject to expected demand and supply, that is, the forward market price depends on the production and hedging choice of you and your competitor. You can see the forward market price determined by your choices using the calculator tool.

$$\text{forward market price} = \text{expected total demand} - \text{expected industry supply.}$$

Figure B shows the timing of your decisions and the decision problem. You have four decision variables, two for each period. For the first period you decide on the amount of production, and how much of your (intended) first period sales you want hedge on the forward market. For the second period you decide on the amount you want to sell immediately (the rest of the production will be sold at the end of time), and how much of your sales at the end of time you want to hedge on the forward market. Note, that you are only able to produce once - at the beginning of time. Also note, that you can only sell what you produced. Hence, if you want to sell anything at the second point in time, you have to store some of your production.

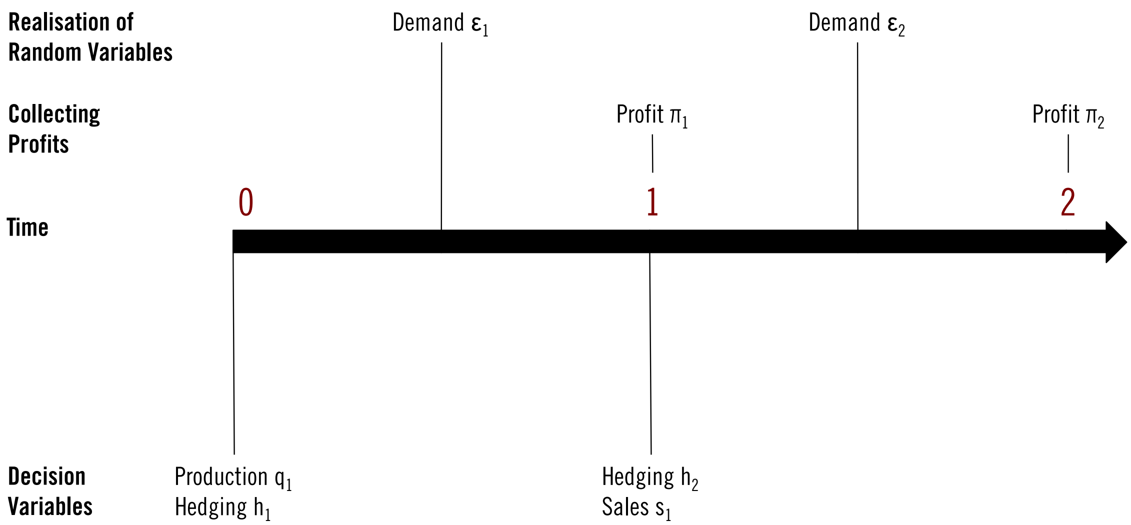


Figure A.1: Timing of decision making

The profits of your firm are given according to

$$\begin{aligned}\text{profit period 1} &= \text{spot market price}_1 \cdot \text{supply}_1 - \text{production costs} \\ &\quad + \text{profits or losses from hedging decision}_1 - \text{storage costs} \quad \text{and}\end{aligned}$$

$$\text{profit period 2} \quad = \quad \text{spot market price}_2 \ \cdot \ \text{supply}_2 \ + \ \text{profits or losses from hedging decision}_2.$$

and will simply be added after the experiment.

Production costs equal 1 per unit and storage costs equal 0.25 per unit.

Profits / losses from the hedging decision are given by

$$\text{profits or losses from hedging decision} = \text{hedging amount} \cdot (\text{forward price} - \text{spot price}).$$

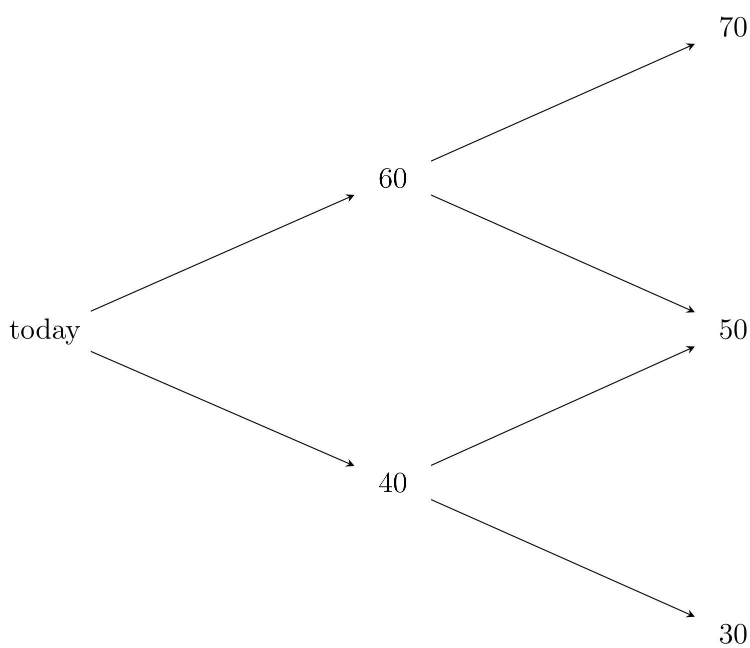
The experiment will run for 20 rounds (each round consisting of Stage 0, Stage 1, and Stage 2). In each round, you will be randomly and anonymously rematched with another participant in the experiment. At the end of the experiment, 2 of the 20 rounds will be randomly selected for payment. You will be paid only for the 2 randomly selected rounds, and not for the other 18 rounds that are not randomly selected for payment.

C Experiment Instructions: Treatment B

Within the experiments, you will take the role of the manager of a producing firm. Your firm is one of two firms in a market. Your compensation for participating in the experiments will depend on the profits you generate with your firm.

Each round of the experiment is divided into Stage 0, Stage 1, and Stage 2. Output is produced in Stage 0 and sold in Stage 1 and Stage 2.

Overall demand is uncertain: At the first point in time you will either face high (60) or low demand (40). Similarly, at the second point in time, demand will either increase or decrease (with the same probability) according to the following graph.



The price is determined following a linear demand function:

$$\text{spot market price} = \text{uncertain total demand} - \text{industry supply}.$$

The industry supply is the sum of your supply and the supply of your competitor.

To deal with the uncertainty, you are able to engage in risk management and trade the product on a forward market. The forward price is subject to expected demand and supply, that is, the forward market price depends on the production and hedging choice of you and your competitor. You can see the forward market price determined by your choices using the calculator tool.

$$\text{forward market price} = \text{expected total demand} - \text{expected industry supply.}$$

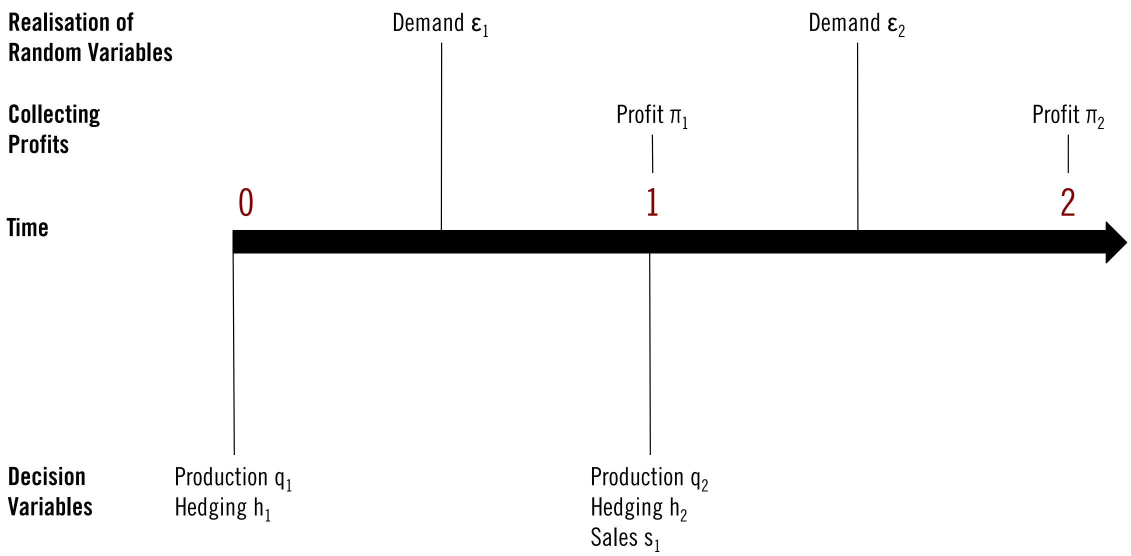


Figure A.2: Timing of decision making with adjustable production decisions

Figure C shows the timing of your decisions and the decision problem. You have five decision variables, two for the first period, and three for the second period. For the first period you decide on the amount of (initial) production, and how much of your (intended) first period sales you want hedge on the forward market. For the second period you decide on the amount of your initial production you want to sell immediately (the rest of the production will be sold at the end of time), how much you want to produce to sell at the end of time, and how much of your sales at the end of time you want to hedge on the forward market.

The profits of your firm are given according to

$$\begin{aligned}\text{profit period 1} = \text{spot market price}_1 \cdot \text{supply}_1 - \text{production costs}_1 \\ + \text{profits / losses from hedging decision}_1 - \text{storage costs} \quad \text{and}\end{aligned}$$

$$\text{profit period 2} = \text{spot market price}_2 \cdot \text{supply}_2 - \text{production costs}_2 \\ + \text{profits / losses from hedging decision}_2.$$

and will simply be added after the experiment.

Production costs equal 1 per unit and storage costs equal 0.25 per unit.

Profits / losses from the hedging decision are given by

$$\text{profits / losses from hedging decision} = \text{hedging amount} \cdot (\text{forward price} - \text{spot price}).$$

The experiment will run for 20 rounds (each round consisting of Stage 0, Stage 1, and Stage 2). In each round, you will be randomly and anonymously rematched with another participant in the experiment. At the end of the experiment, 2 of the 20 rounds will be randomly selected for payment. You will be paid only for the 2 randomly selected rounds, and not for the other 18 rounds that are not randomly selected for payment.

D Experiment Screenshots

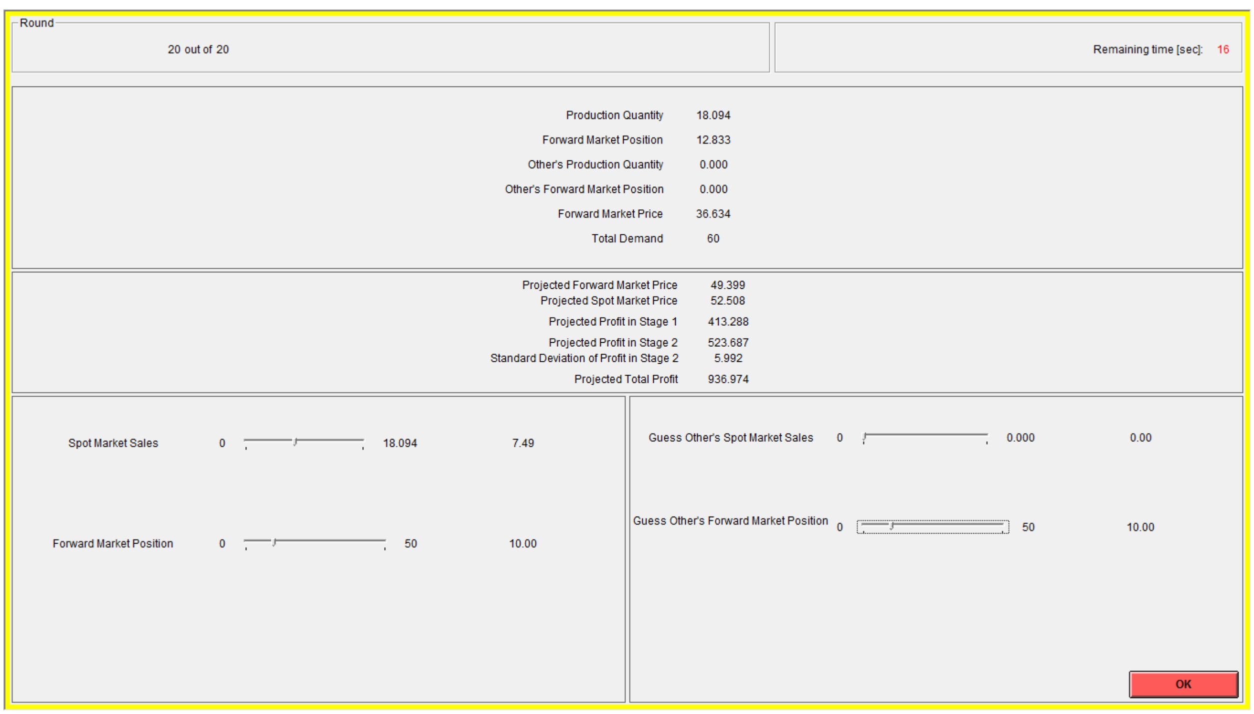


Figure A.3: Treatment A Decision Screen 2

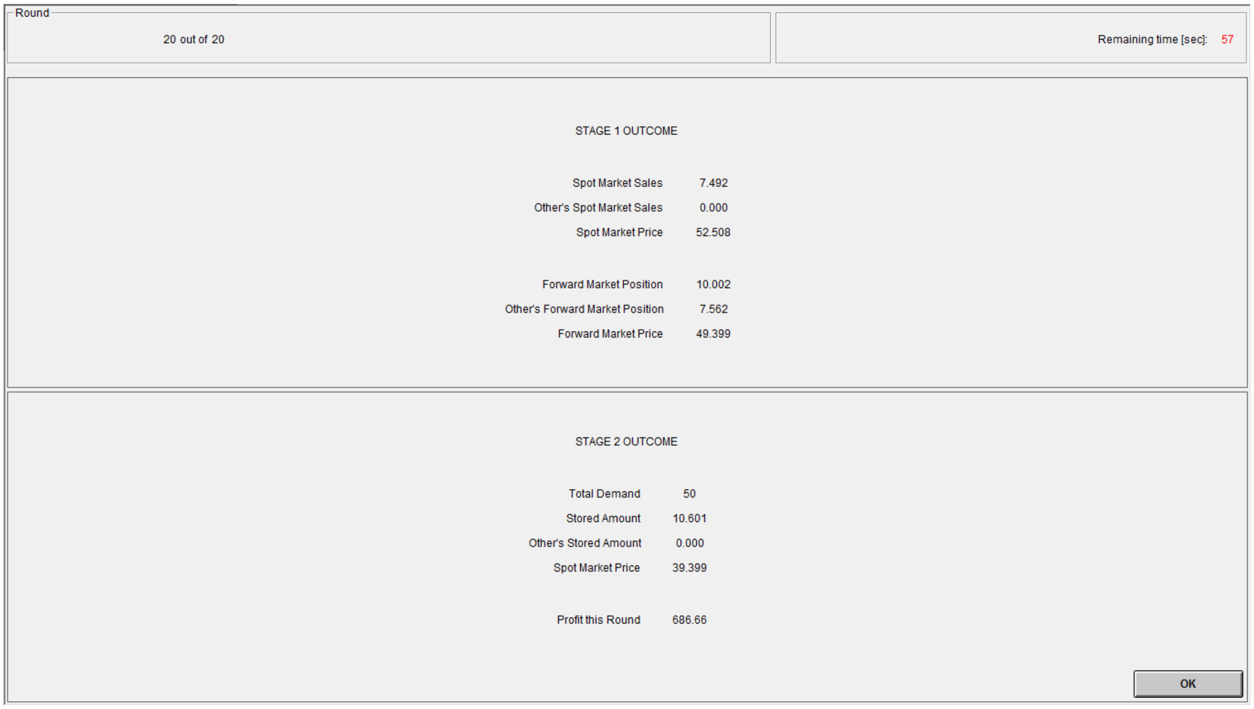


Figure A.4: Treatment A Feedback Screen

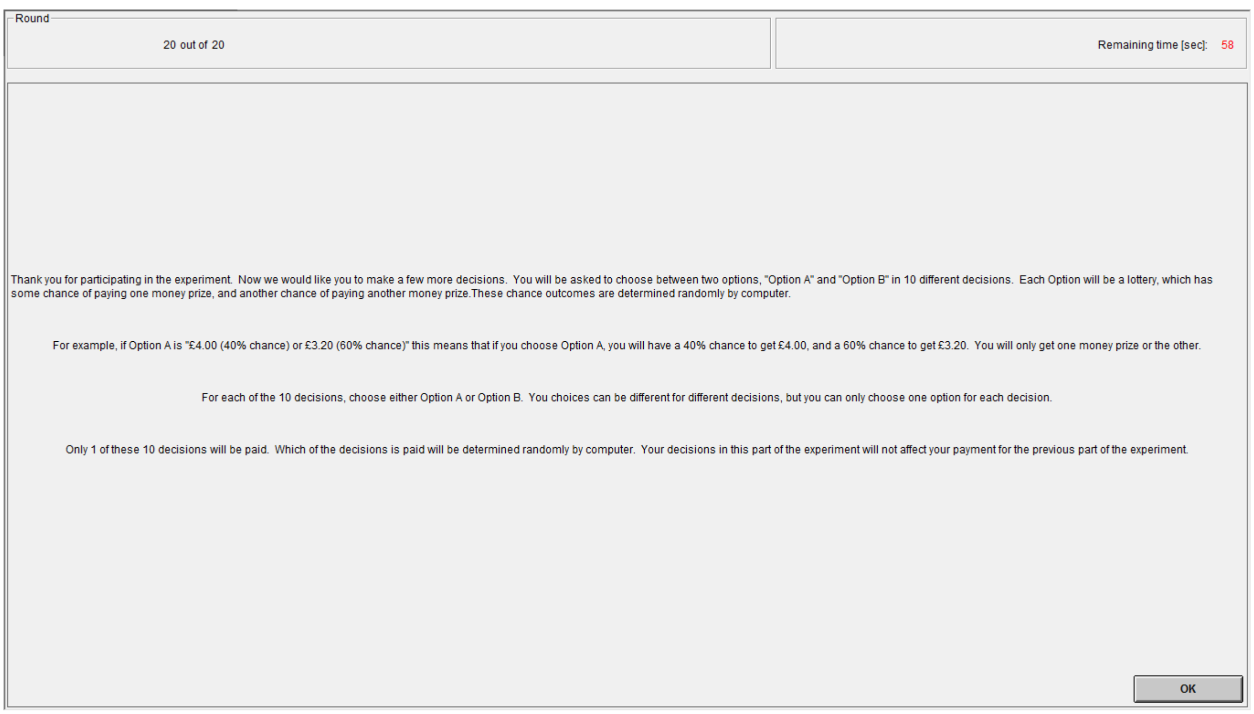


Figure A.5: Risk Elicitation Instructions Screen

Figure A.6: Risk Elicitation Decision Screen

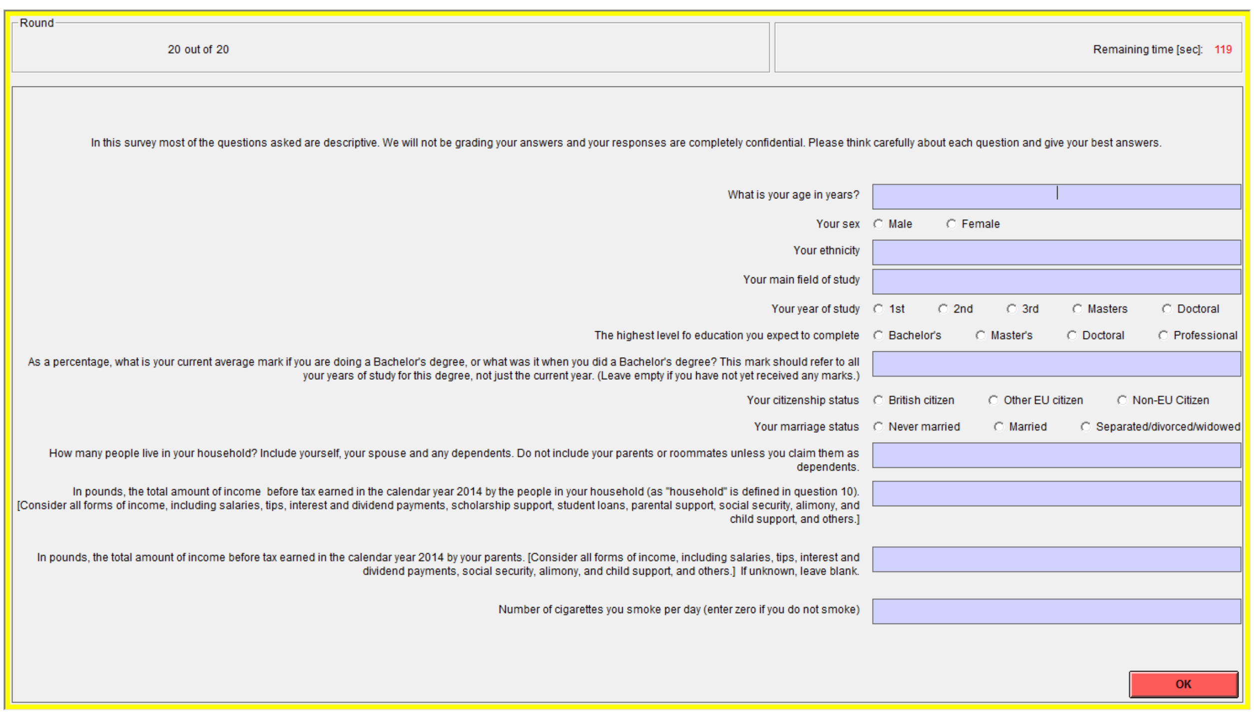


Figure A.7: Demographic Survey Screen