The Competitive Firm Under Price Uncertainty: The Role of Information and Hedging

by

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revised version, August 2007

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*We are grateful to two anonymous referees who made extremely useful comments and suggestions.

Abstract

We study the impact of transparency in a commodity market on the decision problem of a competitive firm under price uncertainty and hedging opportunities. Market transparency is modeled by means of the informational content of publicly observable signals which are correlated with the random price. We find that the impact of more transparency on labor employment and production depends on the firm's technology. In particular, more transparency may result in lower average output even though on average more labor has been used in the production process. We also analyze the link between market transparency and the welfare of the firm.

JEL classification: L21, L23, L25

Key words: Transparency, information system, price uncertainty, hedging, competitive firm.

1 Introduction

The uncertainty to which decision makers are exposed in an economy depends on the amount and the precision of information available to them. More reliable information, e.g. about prices, technology, or market conditions, allows a firm to make better decisions, thereby potentially improving its position in the market. Yet, if the information is of public nature, rather than privately owned by the firm, it will be used by other competing firms, too. Under such circumstances the information may affect endogenous market mechanisms, such as futures prices, with wider and potentially unwelcome implications for the individual firm.

The precision of information revealed to economic agents through an information system has recently been conceptually linked to the notion of (market) transparency. The policy oriented literature stresses the critical role of transparency for a strong and smoothly functioning economy (U.S. Securities and Exchange Commission (1994), Basel Committee of Banking Supervision (1999), International Monetary Fund (1999)). While the notion of transparency underlying such statements remains often vague, it usually refers to disclosure levels and to the quality of disclosure practices of corporations and official bodies.

This paper suggests a different notion of transparency for the commodity market and analyzes its role for the decision problem of a competitive firm under price uncertainty. The firm has access to a commodity futures market where it can hedge the price uncertainty connected with its production of a final good. The terms at which futures contracts are traded depend on the transparency of the commodity market. The notion of transparency used in this study is adopted from the work by Drees and Eckwert (2003). These authors have characterized market transparency using a criterion which is conceptually related to the literature that emerged from the seminal works by Blackwell (1953), Drèze (1960), and Hirshleifer (1971, 1975).[1] The commodity market transparency is linked to the informativeness

[1]Another concept of transparency that has been used in the policy-oriented literature is based on informational asymmetries among economic agents. According to this concept, reductions in information asymmetries between policy makers and the private sector improve the transparency of the economy (see Heinemann and Illing (2002) and Geraats (2006)).

of an observable signal which is correlated with the future price of the commodity. The signal conveys some noisy information about the unknown commodity price and, therefore, allows the firm to update its beliefs. The uncertainty to which the firm is exposed when it decides about resource allocation for production depends on the observed signal as well as on the information system within which the signal can be interpreted. We characterize the goods market as more transparent if the signal conveys more precise information about the unknown commodity price. Thus, more transparency means that the price uncertainty is reduced through the disclosure of more reliable public information.[2]

We find that more transparency may increase or decrease the (average) labor demand of the firm. The impact of more transparency on labor employment and production depends on the firm's technology. It is shown that a better information system may result in less average output even though on average more labor has been used in the production process. The impact of more transparency on the firm's welfare depends on the measure of risk aversion and on the concavity of the production technology. In particular, more transparency reduces the firm's welfare, if the firm is highly risk-averse and if marginal productivity decreases quickly; and the firm benefits from more market transparency if it is moderately risk-averse and marginal productivity decreases slowly.

The paper is organized as follows. In section 2 we present the firm's decision problem and introduce the concept of transparency which underlies our analysis. Section 3 contains the main results and Section 4 concludes.

2 The Model

We consider a competitive risk-averse firm which extends over two periods, $t = 0, 1$. The firm employs labor, L, as an input factor for the production of a homogenous good in period 0 and sells its product at a random price $\tilde{p}$ in $t = 1$. The unit price of labor is w. The tilde refers to the stochastic price which assumes values in

[2]In practice, this information may be disclosed by official bodies (e.g., government agencies or central banks), by major market participants with high public visibility, or even through endogenous market mechanisms.

$\Omega = [\underline{p}, \overline{p}]$, where $0 < \underline{p} < \overline{p} < \infty$. Production technology of the firm is given by a strictly concave function $f(L)$ with $f'(L) > 0, f''(L) < 0$.

As of date 0, when the firm chooses labor input, L, the future price, $\tilde{p}$, is random. Prior to the firm's choice a publicly observable signal y realizes. This signal is the realization of a random variable $\tilde{y}$ which is correlated with $\tilde{p}$. Hence, the signal contains information about the unknown future market price and, at the time when the firm chooses labor input, the relevant expectation for $\tilde{p}$ is the updated (in a Bayesian way) posterior belief.

We assume that the firm has access to a commodity futures market where it can hedge the price risk. The futures market opens at date 0 after the signal has been observed. A futures contract pays one unit of the commodity at date 1. Hence the payoff is worth p. Let H be the futures commitment of the firm, i.e., H denotes the number of futures contracts sold by the firm. We assume that the futures market is unbiased, which implies that the futures market clears at a price, $p_f(y)$, that is equal to the condition mean of a contract's payoff, i.e.

$$p_f(y) = E[\tilde{p}|y]. \tag{1}$$

Both the payoff and the purchase price of the commodity futures contract fall due in period 1. The timing of events is as follows (see Fig 1):

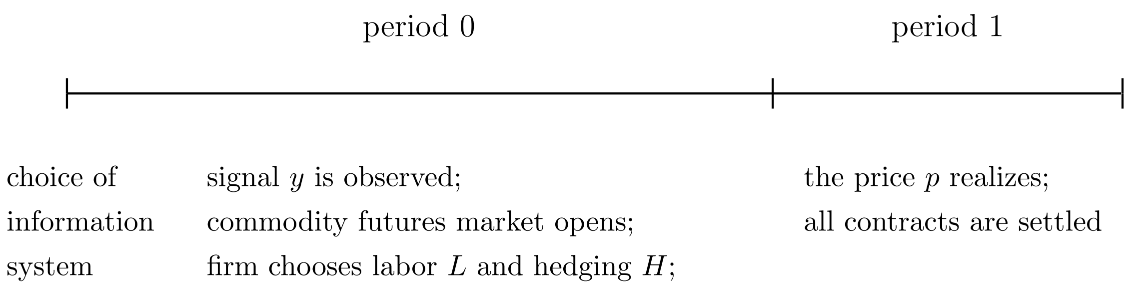

Figure 1

In the next subsections, we analyze the firm's optimal decision.

2.1 The Decision Problem of the Firm

The production decision is made after the signal has been observed, but before the commodity price is known. Therefore, the firm is subject to economic risk. In order to hedge the risk exposure, the firm sells H units of the good forward on the commodity futures market. The random operating profit of the firm is $\tilde{\Pi} = \tilde{p}f(L) - wL + H(p_f(y) - \tilde{p})$ and the firm's decision problem is

$$\max_{L,H} E[V(\tilde{\Pi})|y], \tag{2}$$

where $V : \mathbb{R} \to \mathbb{R}$ is a strictly increasing, strictly concave and twice continuously differentiable von-Neumann Morgenstern utility function. The firm maximizes (2) with respect to labor input, L, and future commitment H. The necessary first-order conditions, which are also sufficient, are

$$E\big[V'(\tilde{\Pi}^*)\big(\tilde{p}f'(L^*) - w\big)|y\big] = 0, \tag{3}$$

$$E\big[V'(\tilde{\Pi}^*)\big(p_f(y) - \tilde{p}\big)|y\big] = 0. \tag{4}$$

From (3) and (4) we obtain the optimal level of labor input, L^*, and the optimal forward commitment, H^*, as[3]

$$f'(L^*) = w/p_f(y), \tag{5}$$

$$H^* = f(L^*). \tag{6}$$

Equation (5) implies that the optimal level of labor input, L^*, is an increasing function of p_f. In view of (6), all price risks are fully hedged and, consequently, the firm's income is certain: $\Pi = p_f f(L^*) - wL^*$.

Next we define our notion of transparency for the goods market. The transparency on the market will be linked to the informational content of the signal y.

[3]Condition (6) follows from (4) since, according to (1), the commodity futures market is unbiased.

2.2 Information Systems and Commodity Market Transparency

We identify the transparency of the commodity market with the 'informativeness' of the signal $y \in Y \subset \mathbb{R}$, which is publicly observable.[4] The informativeness of the signal depends on the information system within which signals can be interpreted. An information system, denoted by g, specifies for each state of nature, p, a conditional probability function over the set of signals: $g(y|p)$. The positive real number $g(y|p)$ defines the conditional probability (density) that the signal y will be observed if the true (yet unknown) commodity price is p. The function $g(y|p)$, which generates the signals for a given price level, is common knowledge. Using Bayes's rule, the firm revises its expectations and maximizes utility on the basis of the updated beliefs.

Let $\pi : \Omega \to \mathbb{R}_+$ be the (Lebesgue-) density function for the prior distribution over Ω. The density for the prior distribution over signals in Y is given by

$$\nu(y) \quad = \quad \int_\Omega g(y|p)\pi(p)\,\mathrm{d}p \qquad \text{for all } y. \tag{7}$$

The density function for the updated posterior distribution over Ω is[5]

$$\nu(p|y) \quad = \quad g(y|p)\pi(p)/\nu(y). \tag{8}$$

Blackwell (1953) suggested a criterion that ranks different information systems according to their informational contents. Suppose g^1 and g^2 are two information systems with associated density functions $\nu^1(\cdot)$ and $\nu^2(\cdot)$. The following criterion induces an ordering on the set of information systems.

Definition 1 (Informativeness) *Let g^1 and g^2 be two information systems. g^1 is said to be more informative than g^2 (expressed by $g^1 \succ_{\inf} g^2$,), if there exists an integrable function $\lambda : Y^2 \to \mathbb{R}_+$ such that*

$$\int_Y \lambda(y', y)\,\mathrm{d}y' = 1, \tag{9}$$

[4]This concept of transparency is due to Drees and Eckwert (2003). Studying issues of international trade, these authors have applied the concept to markets of foreign currency exchange.

[5]To ease notation we distinguish between the functions $\nu(y)$ and $\nu(p|y)$ only by their arguments.

holds for all $y \in Y$, and

$$g^2(y'|p) = \int_Y g^1(y|p)\lambda(y', y)\,\mathrm{d}y \tag{10}$$

holds for all $p \in \Omega$.

According to this criterion $g^1 \succ_{\text{inf}} g^2$, holds if g^2 can be obtained from g^1 through a process of randomization. The probability density $\lambda(y', y)$ in equation (9) transforms a signal y into a new signal y'. If the y'-values are generated in this way, the information system g^2 can be interpreted as being obtained from the information system g^1 by adding random noise. Note that $\lambda(\cdot, \cdot)$ in (10) is independent of p. Therefore, the signals under information system g^2 convey no information about the value of $\tilde{p}$ that is not also conveyed by the signals under information system g^1. As a consequence, the *a priori* posterior price uncertainty under g^1 will be lower than under g^2.

Our notion of commodity market transparency is based on the informational content of the signal. A signal that conveys information about the random commodity price affects the conditional price uncertainty in the economy.[6] We characterize the commodity market as more transparent if the signal, y, conveys more precise information about $\tilde{p}$. Thus, higher market transparency implies that the conditional price uncertainty is reduced through the dissemination of more reliable information.

Definition 2 (Commodity Market Transparency) *Let g^1 and g^2 be two information systems for the random commodity price $\tilde{p}$. The commodity market is said to be more transparent under g^1 than under g^2, if $g^1 \succ_{\text{inf}} g^2$.*

The following Lemma contains a property of information systems that turns out to be a convenient tool for our analysis. The lemma formulates an alternative transparency criterion that is equivalent to the condition stated in Definition 2.

[6] Of course, this conditional uncertainty may be hedged (partially or in full) by an economic agent if risk sharing arrangements are available. Less conditional uncertainty due to better information therefore does not necessarily imply that the agent is exposed to less risk. In our model, for example, the firm eliminates any conditional price risk from its profits through trade on the futures market regardless of the signal's precision.

Lemma 1 *The commodity market is more transparent under g^1 than under g^2 if and only if*

$$\int_Y F\big(\nu^1(\cdot|y)\big)\nu^1(y)\,\mathrm{d}y \geq \int_Y F\big(\nu^2(\cdot|y)\big)\nu^2(y)\,\mathrm{d}y$$

holds for every convex function $F(\cdot)$ on the set of density functions over Ω.

A proof of Lemma 1 can be found in Kihlstrom (1984). Note that $\nu^1(\cdot|y)$ and $\nu^2(\cdot|y)$ are the posterior beliefs under the two information systems. Thus, Lemma 1 implies that more transparency (weakly) raises the expectation of any convex function of posterior beliefs. For concave functions, F, the inequality is reversed.

In the next section we will apply these concepts to the firm's decision problem as described above.

3 Transparency, Production, and Welfare

Next we analyze the interaction between the input and output decisions and price transparency on the commodity market, as well as the implications of this interaction for the welfare of the firm. Denoting by $\hat{L}$ the average level of labor input, and by $L^*\big(p_f(y)\big)$ the solution to (5) for fixed w, we get

$$\hat{L} := \int_Y L^*\big(p_f(y)\big)\nu(y)\,\mathrm{d}y. \tag{11}$$

Proposition 1 characterizes the link between the average level of labor employed and market transparency by imposing restrictions on the production technology.

Proposition 1 *More price transparency in the commodity market leads to higher (lower) average labor input, if*

$$-\big[f'(L)\big]^2/f''(L) \tag{12}$$

is monotone increasing (decreasing) in L on the range $\big[(f')^{-1}(w/\underline{p}),(f')^{-1}(w/\overline{p})\big]$.

Proof: Since $p_f(y) = E[\tilde{p}|y] = \int_\Omega p\nu(p|y)\,\mathrm{d}p$ is linear in the posterior belief $\nu(\cdot|y)$, Lemma 1 implies that the average level of labor input increases with more transparency, if $L^*(p_f)$ is convex in p_f. And the average level of labor input declines with more transparency, if $L^*(\cdot)$ is concave. It therefore remains to be shown that $L^*(\cdot)$ is convex (concave), whenever the term in (12) is monotone increasing (decreasing) in L.

From (5) we conclude

$$f''\big(L^*(p_f)\big)L^{*\prime}(p_f) = -\frac{w}{p_f^2} \overset{(5)}{=} -\frac{\big[f'\big(L^*(p_f)\big)\big]^2}{w}\,,$$

or,

$$L^{*\prime}(p_f) = -\big[f'\big(L^*(p_f)\big)\big]^2/f''\big(L^*(p_f)\big)w > 0\,. \qquad (13)$$

Thus $L^*(\cdot)$ is strictly monotone increasing. (13) then implies that $L^*(p_f)$ is convex (concave) in p_f, if the term in (12) is monotone increasing (decreasing) in L. Note that $L^*(p_f)$ lies in the range indicated in Proposition 1, since $p_f(y) \in [\underline{p}, \overline{p}]$. □

The term in (12) captures an important feature of the curvature of the production function. This term is decreasing, if the production function is 'sufficiently concave', i.e., if marginal productivity declines quickly enough relative to $\sqrt{-f''(L)}$. For logarithmic technology, $f(L) = \frac{1}{\alpha}\log(1+\alpha L)$, the term in (12) is constant and equal to $1/\alpha$. In this case, price transparency does not affect average labor input. If the production function exhibits more concavity than the log (in the above sense), then more price transparency reduces average employment; and average employment rises with more transparency, if the production function is only moderately concave (less concave than the log).

The above proposition allows a cautious conclusion about the role of price transparency for the labor market of an economy. Circumstantial evidence suggests that marginal returns decline faster in less technologically advanced production processes like agriculture or construction, compared with high-tech sectors such as the software or electronics industry. Proposition 1 therefore suggests that in less developed economies, which operate at a low technological level, more price transparency may reduce the average employment level; and in technologically advanced economies, by contrast, more price transparency may produce positive average employment effects.

Next we analyze the impact of market transparency on the average output volume, denoted by X,

$$X := \int_Y f\big(L^*(p_f(y))\big)\nu(y)\,\mathrm{d}y. \tag{14}$$

More transparency may either reduce or stimulate the average production volume. Which case applies depends on the firm's production technology.

Proposition 2 *More price transparency in the commodity market leads to higher (lower) average production, if*

$$-[f'(L)]^3/f''(L) \tag{15}$$

is increasing (decreasing) in L *on the range* $\big[(f')^{-1}(w/\underline{p}), (f')^{-1}(w/\overline{p})\big]$.

Proof: The same reasoning as in the proof of Proposition 1 shows that the average production volume increases (decreases) with more transparency, if $f\big(L^*(p_f)\big)$ is convex (concave) in p_f. Thus we need to show that $f\big(L^*(p_f)\big)$ is convex (concave) whenever the term in (15) is monotone increasing (decreasing) in L. Differentiating $f\big(L^*(p_f)\big)$ and using (13) yields

$$\frac{\partial f(L^*(p_f))}{\partial p_f} = f'\big(L^*(p_f)\big)L^{*\prime}(p_f) \overset{(13)}{=} -\big(f'(L^*(p_f))\big)^3/f''\big(L^*(p_f)\big)w. \tag{16}$$

(16) implies that $f\big(L^*(p_f)\big)$ is convex (concave), if $-[f'(L)]^3/f''(L)$ is increasing (decreasing) in L. □

If the term in (12) is decreasing in L and, hence, average labor employment declines with more transparency, then the term in (15) is also decreasing in L; hence, average production declines as well. Yet, it is possible that with more transparency average labor employment increases and, at the same time, average output declines. We illustrate this possibility by means of an example which uses a Cobb-Douglas production technology. Assume that the firm's technology can be described by the production function $f(L) = L^\beta$. We know already that average labor employment increases with more transparency. Now consider average production:

$$-[f'(L)]^3/f''(L) = \frac{\beta^2}{1-\beta}L^{2\beta-1} \tag{17}$$

The term in (17) is decreasing for $\beta < 1/2$. Thus, for $\beta < 1/2$ average output declines while, at the same time, average labor employment increases with more price transparency. In a sense, more transparency makes the production process less efficient because, on average, less output is produced with more labor.

Thus, the results in our propositions do not necessarily confirm the conjecture that more transparency promotes economic activity. In particular, it may well happen that the average employment level increases with more transparency, while average production of output declines. The intuition for this result is as follows. Under a better information system labor employment and production react more sensitively to changes in the signal, because the signal is more reliable.[7] Therefore, with more transparency, good signals lead to an additional increase in employment and production while bad signals cause an additional decline in employment and output. However, the additional employment of labor at times when good signals are observed has low marginal productivity because the production technology is concave. Therefore the increase in output is small. At times when bad signals are observed labor has high marginal productivity. The decline in labor employment therefore causes a large reduction in output. Thus, under a better information system more labor will be employed when marginal productivity of labor is low, and less labor will be employed when marginal productivity is high. This mechanism, which is strong if marginal productivity decreases quickly, may result in less average output under a better information system even though on average more labor has been used in the production process.

We finally turn to an analysis of the welfare implications of more price transparency on the commodity market. Define for any realization of the signal y the value function $\hat{V}\big(p_f(y)\big)$ as the level of the firm's expected utility,

$$\hat{V}\big(p_f(y)\big) := V\Big(p_f(y) f\big(L^*(p_f(y))\big) - wL^*\big(p_f(y)\big)\Big). \tag{18}$$

[7] Labor employment and production depend on y only via the futures price $p_f(y)$. Under a more transparent information system the distribution of $p_f(y)$ will become more spread out: according to (1), the futures price combines the realization of the signal, y, with the prior of $\tilde{p}$, and it assigns more weight to the signal if the signal is a more reliable indicator for the expectation of $\tilde{p}$. Therefore, a more reliable signal leads to a futures price which is more dispersed because it is more sensitive to the realization of the signal.

Welfare, $W(g)$, is defined as the *ex ante* expected utility of the firm prior to the realization of the signal,

$$W(g) := E\big[\hat{V}\big(p_f(\tilde{y})\big)\big] = E\Big[V\Big(p_f(\tilde{y})f\big(L^*(p_f(\tilde{y}))\big) - wL^*\big(p_f(\tilde{y})\big)\Big)\Big]. \tag{19}$$

By definition, higher transparency on the commodity market increases welfare, if the firm is better off with more precise information, i.e., if $W(g^1) \geq W(g^2)$ whenever $g^1 \succ_{\text{inf}} g^2$.

Differentiating (18) and making use of the envelope theorem yields after some rearrangements

$$\frac{\partial^2 \hat{V}(p_f)}{\partial p_f^2} \cdot \Lambda = -\frac{\varepsilon[f, L^*]}{\varepsilon[f', L^*]} + \frac{V''(\Pi^*)}{V'(\Pi^*)} p_f f(L^*), \tag{20}$$

where $\Lambda := p_f f(L^*)/V'(\Pi^*)[f(L^*)]^2 > 0$ and ε denotes the elasticity, e.g., $\varepsilon[f, L^*] = f'(L^*)L^*/f(L^*)$. In view of Lemma 1, more transparency on the commodity market increases (decreases) welfare, if $\hat{V}(p_f)$ is convex (concave), i.e., if the RHS of (20) is positive (negative).[8] The first term on the RHS in (20) is positive since the production function is increasing and concave, and the second term is negative due to risk aversion. These two terms reflect the interaction between the Blackwell effect and the Hirshleifer effect. The Blackwell effect (first term) represents the increase in welfare that results from the fact that the firm can make a better decision when it acts in a more transparent environment. This effect depends on the concavity of the production function:[9] if the production function is 'very concave', i.e., if the marginal productivity decreases quickly, then the Blackwell effect is small. By contrast, the Blackwell effect becomes very large if the marginal productivity is almost constant.

The Hirshleifer effect captures the welfare losses that result from the elimination of risk hedging opportunities that go hand-in-hand with more market transparency: the futures market allows the firm to hedge against that part of the price risk that has not yet been resolved by the signal. In other words, the more informative the

[8] Note, again, that $p_f(y)$ is linear in the posterior belief $\nu(\cdot|y)$.

[9] In fact, the Blackwell effect, $-\varepsilon[f, L^*]/\varepsilon[f', L^*]$, can be interpreted as a special measure of concavity of the production function f.

signal is the smaller is the portion of the price risk that can be hedged. Since the firm is risk-averse, this effect reduces the welfare of the firm. The welfare loss is larger if the firm is more risk-averse.

Summarizing, the welfare implications of more price transparency on the commodity market are determined by the interaction of the (positive) Blackwell effect and the (negative) Hirshleifer effect. If the firm is highly risk-averse and/or if the production function is strongly concave, the Hirshleifer effect dominates the Blackwell effect and, hence, more transparency is undesirable from the perspective of the firm. By contrast, if the firm is moderately risk-averse, or even risk neutral, and/or the marginal productivity decreases slowly, the Blackwell effect is dominant. In this case the firm benefits from more market transparency.[10]

In order to gain some further intuition for the results in this section, let us consider the extreme constellation where g^1 is fully informative and g^2 is uninformative.[11] Under g^1, the signal reveals the price and, hence, $p_f = \tilde{p}$. This implies $\hat{L}_{g^1} = E\big[L^*(\tilde{p})\big]$. Under g^2, the signal contains no information and, hence, $p_f = E[\tilde{p}]$. This implies $\hat{L}_{g^2} = L^*\big(E[\tilde{p}]\big)$. By Jensen's inequality, $\hat{L}_{g^1} \overset{(\leq)}{\geq} L_{g^2}$ if $L^*(\cdot)$ is convex (concave), i.e., if the term in (12) is monotone increasing (decreasing). Proposition 2 can be illustrated in a similar way.

Regarding the firm's welfare, under g^2 the firm sells at the constant price $E[\tilde{p}]$ and makes the non-random profit $\Pi_{g^2} = E[\tilde{p}]f\big(L^*(E[\tilde{p}])\big) - wL^*(E[\tilde{p}])$. Under g^1, the random profit is $\tilde{\Pi}_{g^1} = \tilde{p}f\big(L^*(\tilde{p})\big) - wL^*(\tilde{p})$. Since $pf\big(L^*(p)\big) - wL^*(p)$ is convex in p, Jensen's inequality implies $E\big[\tilde{\Pi}_{g^1}\big] \geq \Pi_{g^2}$. Thus, an almost risk-neutral firm prefers g^1 to g^2. Yet, as under g^1 the profit is risky while under g^2 it is risk-free, a very risk-averse firm prefers g^2 to g^1. This result is obviously consistent with the more general welfare analysis in this section.

[10]For a further discussion of these effects in a different setting, see Eckwert and Zilcha (2001,2003), and Schlee (2001).

[11]We are grateful to an anonymous referee who suggested and worked out this discussion.

4 Concluding Remarks

In this paper we have studied the role of transparency in a commodity market for the production decision of a competitive firm. Transparency was defined in terms of the informativeness of a signal that conveys some information about the random commodity price.

As a main result, our analysis has shown that more transparency in the commodity market may increase the average level of labor employment while, at the same time, the average level of production declines. Also, more transparency may increase or decrease the welfare of the firm depending on a subtle interaction between improved decision making (Blackwell effect) and less efficient ex ante risk sharing (Hirshleifer effect) under a more reliable information system.

In deriving these results we have assumed that the commodity futures market is unbiased. This assumption is quite critical and our findings cannot be expected to be fully robust with regard to this specification. For example, in a biased futures market the futures price might be so low that the firm finds it optimal to abstain from hedging altogether. In such a situation no risk sharing takes place which implies that the Hirshleifer effect is nil. As a consequence, the firm unambiguously benefits from more market transparency due to the positive Blackwell effect.

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