WP/07/95

IMF Working Paper

Implications of More Precise Information for Technological Development and Welfare

Burkhard Drees and Bernhard Eckwert

INTERNATIONAL MONETARY FUND

 WP/07/95

IMF Working Paper

IMF Institute

Implications of More Precise Information for Technological Development and Welfare

Prepared by Burkhard Drees and Bernhard Eckwert[1]

Authorized for distribution by Jorge Roldos

April 2007

Abstract

This paper analyzes the dynamic interactions between the precision of information, technological development, and welfare within an overlapping generations model. More precise information about idiosyncratic production shocks has ambiguous effects on technological progress and welfare, which depend critically on the risk sharing capacity of the economy's financial system. For example, we show that with efficient risk sharing more precise information adversely affects the equilibrium risk allocation and creates a negative uncertainty-related welfare effect, at the same time as it accelerates technological progress and increases R&D investment.

JEL Classification Numbers: D8, D51

Keywords: information, technological development, growth, welfare

Author's E-Mail Address: bdrees@imf.org; beckwert@wiwi.uni-bielefeld.de

---

[1] Burkhard Drees is in the Asian Division of the IMF Institute. Bernhard Eckwert is Professor of Economics at the University of Bielefeld, Germany. We thank Udo Broll, John Morgan, Jorge Roldos, Keith Wong, and seminar participants at the IMF Institute, at the University of Hong Kong, and at the Technical University of Chemnitz for their comments.

Contents Page

I. INTRODUCTION

In the past decade, interest in studies of economic growth under uncertainty has increased considerably. The literature has emphasized the role of technological progress and the function of financial systems in endogenous growth models (Greenwood and Jovanovic, 1990, Romer, 1990, Greenwood and Smith, 1996, and Galetovic, 1996). In this paper we add a third factor—the precision of information about the future productivity of economic projects.

Is more precise information about production projects necessarily good for growth and economic welfare? To address this question, we analyze the interaction between (i) the precision of screening information about economic projects; (ii) the extent of risk sharing provided by the financial system; and (iii) technological progress, growth, and welfare. Specifically, under what conditions does more precise information about random technological shocks promote growth and improve welfare, and when might it reduce welfare and/or growth? We find that the implications of information precision depend critically on the degree of risk sharing in the economy. Our results thus highlight the connections between the risk sharing capacity of the financial system, and the growth and welfare implications of more precise information.

The literature on the nexus between the financial structure and technological development has produced inconclusive results about the causality of the link (Levine, 2004). Whether the financial structure affects growth or whether the financial system only reacts to technological development is a contentious issue which may depend on the interaction with the available information about economic fundamentals. Some studies suggest that financial intermediation improves the information about firms and economic conditions, thereby inducing a more efficient allocation of capital (Greenwood and Jovanovic, 1990, De la Fuente and Marin, 1996, Blackburn and Hung, 1998).

The interaction between public information and the financial structure is a delicate one. More precise information reduces uncertainty and in this sense performs a similar role as risk sharing markets. At the same time, however, more precise information interferes with the operation of risk sharing markets because risks that have been resolved through new information can no longer be hedged and must be borne by the agents individually. The welfare effect of more precise information therefore depends critically on the intertemporal technological spillovers and on the degree of risk sharing that is provided by the financial system.

Most of the literature on the role of information in equilibrium models is cast in a static theoretical framework. A static setting, however, does not permit a meaningful analysis of the interaction among information, technological development, and economic welfare. In this paper, we use a simple overlapping generations model with technological uncertainty to identify the channels through which publicly observable screening information about idiosyncratic production shocks affects the time path of the economy. Our dynamic model has three important components: (i) an information system that conveys signals about the quality of production projects; (ii) intertemporal technological externalities; and (iii) a financial system that to a certain degree provides opportunities to share production risks. Specifically, we model an overlapping generations economy where agents invest effort into research and development (R&D) to boost the uncertain future consumption output of their projects. The payoff risks that agents face depend on the precision of the information signals they receive about the future output of their projects. Depending on the financial system, some of the risk that remains after observing the signals can be hedged. Another key feature of the model is a technological externality between generations: higher aggregate output today will reduce the costs of R&D effort in the next period. As a result, current investment into research and development indirectly affects output in subsequent periods, creating positive externalities for future generations. Our dynamic setup thus rests on the premise that technological change arises from the behavior of economic agents in response to market signals (Easterly, 2001).

More precise information, i.e. more efficient screening for project quality, affects aggregate production, economic welfare, and the level of technological development in at least two ways: (1) more precise information, ceteris paribus, allows agents to make better decisions about their R&D efforts—a welfare effect we call 'uncertainty-related;' and (2) more precise information may increase or decrease the investment in R&D effort and thus may have long-lasting effects on technological progress as a result of the production externality—we call this effect 'externality-related.' Depending on the agents' preferences and depending on how much risk sharing the financial system provides, the two effects can work in the same direction or act in opposite directions.

Under a financial structure that precludes sharing of project risk, we find that more precise information stimulates technological progress and increases welfare unless agents' preferences exhibit sufficiently high risk aversion. By contrast, if the financial system provides efficient risk sharing, more precise information produces a negative uncertainty-related welfare effect while at the same time raising the level of technological development regardless of agents' attitude toward risk. But the overall effect on welfare cannot be determined because the costs and benefits from more precise information are distributed unevenly across generations. In the dynamic context with technolgical externalities, more precise information therefore has ambiguous implications for economic welfare. From a broader perspective, our findings thus cast some doubt on the notion that better screening of economic projects, for example through accounting and auditing information, is always beneficial.

II. The Model Economy

The economy is populated by a continuum of two-period lived agents in an overlapping generations environment. Each agent is a consumer-producer pair. We denote the generation of individuals born at time t-1 by G_t, t = 0, 1, 2 … . There is no population growth, and the size of each generation is normalized to one.

Nature assigns a project (production technology) to each agent. Young agents invest effort, *x*, which we interpret as research and development (R&D) investment, into their projects. In the next period, projects deliver random output that can be consumed by the agents. When young, each agent does not yet know the quality (productivity) of his project. Therefore, the R&D investment decision, *x*, which imposes a utility cost on the agent, is made under uncertainty. In the next period, the project yields the output $\tilde{q} = q(x, \tilde{A}) := x + \tilde{A}$, where $\tilde{A}$ is the stochastic 'quality' of the project, which takes values in $\mathrm{A} := [\underline{A}, \overline{A}] \in \Re_{++}$ with probability density *v*. We assume that this individual quality risk is identical across the different projects and that there is no aggregate uncertainty, i.e., the ex post distribution of the stochastic quality variable is exactly *v*.[2]

Before the agent decides on his R&D investment in his first period of life, he receives a publicly observable signal $y \in Y \subset \Re$ that contains information about his project's quality. The signals assigned to projects with quality *A* are distributed according to the density $f(\cdot \mid A)$. The function $f(\cdot \mid A)$ is also the ex post distribution of signals across projects with quality *A*.[3] By construction, the distributions of signals and of qualities are correlated and, hence, a project's signal reveals information about the project's unknown quality and can therefore be used as a screening device. Based on the signal, the agent forms expectations about his project's quality in a Bayesian way. As a result, an agent's choice of R&D investment takes into account the conditional distribution of his project's quality given the observed signal.

The distribution of signals received by agents of generation G_t has density

$$\mu(y) = \int_{\mathrm{A}} f(y \mid A) \nu(A) \, \mathrm{d}A \tag{1}$$

The average quality of projects with signal *y* is

---

[2] Feldman and Gilles (1985, p. 29, Proposition 2) have shown that a probabilistic setting exists where this version of a law of large numbers for large economies holds. In this setting, though, the individual risks are not independent.

[3] Again, this assumption is justified by the aforementioned result in Feldman and Gilles (1985).

$$\bar{A}(\nu_y) := \int_{\mathrm{A}} A\nu_y(A)\,\mathrm{d}A\,, \tag{2}$$

where ν_y denotes the density of the distribution of project quality conditional on the signal y,

$$\nu_y(A) = \frac{f(y\,|\,A)\nu(A)}{\mu(y)}\,. \tag{3}$$

All agents of generation G_t have identical preferences and maximize the von-Neumann Morgenstern lifetime utility function

$$U(c,x;Q_{t-1}) = u(c) - w(x;Q_{t-1})\,. \tag{4}$$

The effort associated with R&D investment, x, imposes a utility cost $w(x;Q_{t-1})$ on the agent in his first period of life. Aggregate production in the previous period, Q_{t-1}, serves as a proxy for the level of technological development in the economy and exerts a positive externality on the production technology in period t by reducing the utility cost $w(\cdot)$ associated with R&D investment.[4] In his second period of life, the agent derives utility from consumption c. For the time being we abstract from risk sharing arrangements, so each agent consumes the entire output of his project, $c = q(x,A) = x + A$. This restriction will be relaxed later on.

Assumption 1 *The functions* $w:\Re_+ \times \Re_{++} \to \Re$ *and* $u:\Re_+ \to \Re$ *are thrice continuously differentiable. In addition, they have the following properties:*

(i) *$w(x;Q)$ is increasing and convex in x, decreasing in Q, and satisfies $w(0;Q) = 0\ \forall Q$. In addition,* $w''_{xQ}(\cdot) \le 0,\ w'''_{xxx}(\cdot) \le 0$.

(ii) *$u(c)$ is increasing, strictly concave, and satisfies* $u'''(c) \ge 0\ \ \forall c$.

The restrictions on the third derivatives of $w(\cdot)$ and $u(\cdot)$ imply that the marginal utility cost in period 1 and marginal utility in period 2 decrease at a declining rate. All other specifications are standard.

When agents of generation G_t make their investment decisions, the agents differ only by the signals they have received about their projects. Given Q_{t-1}, the optimal investment and consumption decisions by an agent of generation G_t who receives signal y are determined by

[4] Externalities of this type are common in the literature on human capital formation (cf., e.g., Galor and Tsiddon, 1997, Eckwert and Zilcha, 2004).

$$\max_{x,\tilde{c}} E\left[u(\tilde{c}) - w(x;Q_{t-1})\middle| y\right] \tag{5}$$

$$\text{s.t. } \tilde{c} = q(x;\tilde{A}) = x + \tilde{A}\,.$$

The necessary and sufficient first-order condition to problem (5) is

$$w_x^{'}(x;Q_{t-1}) = E\left[u'(x+\tilde{A}) \mid y\right]. \tag{6}$$

From (6) we obtain the optimal choice of R&D investment as a function of the conditional distribution ν_y, i.e. $x = x(\nu_y)$.[5] In particular, any two agents of G_t who receive the same signal about their respective projects will make the same investment decision. We assume that the densities $\left\{f(\cdot \mid A), A \in \mathrm{A}\right\}$ satisfy the Monotone Likelihood Ratio Property (MLRP).[6] Since $u'(\cdot)$ is a decreasing function, (6) in combination with MLRP implies that a higher signal leads to less R&D investment. From (6) we can also derive upper and lower bounds for R&D effort. Let $\overline{x}$ and $\underline{x}$ be defined by

$$w_x^{'}(\overline{x};Q_{t-1}) = u'(\overline{x}+\underline{A})\,; \quad w_x^{'}(\underline{x};Q_{t-1}) = u'(\underline{x}+\overline{A})\,. \tag{7}$$

Clearly, $x(\nu_y) \in [\underline{x},\overline{x}] \subset \Re_{++}$. Note that the bounds $\underline{x}$ and $\overline{x}$ are independent of the information system.

Let $\overline{q}_t(\nu_y)$ be the average output of all projects with signal y in period t,

$$\overline{q}_t(\nu_y) := x(\nu_y) + \overline{A}(\nu_y) \tag{8}$$

where $\overline{A}(\nu_y)$ has been defined in (2). Aggregate production at date t can then be expressed as

$$Q_t := \int_Y \overline{q}_t(\nu_y)\mu(y)\ \mathrm{d}y = E[\tilde{A}] + \int_Y x(\nu_y)\mu(y)\ \mathrm{d}y. \tag{9}$$

---

[5] R&D investment, x, depends also on Q_{t-1} which, for ease of notation, has not been included as an argument. Equation (6) and Assumption 1 imply that $x(\cdot)$ is increasing in Q_{t-1}.

[6] Under MLRP, $y' > y$ implies that for any given (nondegenerate) prior distribution for $\tilde{A}$, the posterior distribution conditional on y' dominates the posterior distribution conditonal on y in the first-order stochastic dominance. Formally, $\int_{\mathrm{A}} \varphi(A)\nu_{y'}(A)\ \mathrm{d}A \geq \int_{\mathrm{A}} \varphi(A)\nu_y(A)\ \mathrm{d}A$ holds for any (integrable) increasing function φ. For further details, see Milgrom (1981).

Note that a higher level of technological development (aggregate output) in $t-1$ raises the level of technological development in *t.* This observation follows directly from (9) since $x(\cdot)$ is increasing in Q_{t-1} (see footnote 5). Next we formulate an equilibrium concept for this economy.

Definition 1 *Given the initial level of aggregate production, Q_0, an equilibrium consists of a sequence of R&D investment and consumption* $\{(x^i, c^i)_{i\in G_t}\}_{t=1}^{\infty}$ *such that:*

(i) *At each date t, given Q_{t-1}, the optimum for each agent $i \in G_t$ in problem (5) is given by (x^i, c^i).*

(ii) *The levels of technological development Q_t, t=1,2, ... , satisfy (9).*

III. Information Systems

At the time when investment decisions are made, agents do not know the qualities of their projects but they correctly understand that the distributions of signals and of project qualities are correlated. Therefore, each agent evaluates his project based on his signal, *y*, by updating the prior distribution, *v*, according to

$$\nu_y(A) = \frac{f(y \mid A)\nu(A)}{\mu(y)} \tag{10}$$

The function $f : Y \times \mathrm{A} \to \Re_+$ represents an information system that describes the correlation structure between signals and project qualities. For any quality level $A \in \mathrm{A}$, *f* specifies a conditional density function on the set of signals: $f(y|A)$ is the conditional density of all projects with quality *A* that have been assigned the signal *y*. The function $f(y|A)$ also represents the probability density that a project with quality *A* will receive the signal *y*. Having assumed MLRP, the output scheme for projects is monotonic, i.e., projects with higher signals have higher expected outputs.

The concept of informativeness that we use in this paper is based on the Blackwell (1953) sufficiency criterion. According to this criterion, an informaton system becomes less informative if the signals are subjected to a process of random 'garbeling:'

Definition 2 *An information system $\bar{f}$ is more precise than an information system $\hat{f}$, if there exists an integrable function $\lambda : Y^2 \to \Re_+$ such that*

$$\int_Y \lambda(y', y)\, \mathrm{d}y' = 1 \tag{11}$$

holds for all y, and

$$\hat{f}\left(y'|A\right)=\int_{Y}\bar{f}(y\mid A)\lambda\left(y',y\right)\,\mathrm{d}y \tag{12}$$

hold for all $A\in\mathrm{A}$.

Condition (11) indicates that each signal received under $\hat{f}$ can be interpreted as a random 'garbeling' of the signal sent under $\bar{f}$. The following lemma establishes a criterion consistent with Definition 2 that is useful for the study of information systems and their impact on welfare and economic growth.

Lemma 1 (Kihlstrom) *Let* $\bar{f}$ *and* $\hat{f}$ *be two information systems with associated density functions* $\bar{v}_y, \bar{\mu}, \hat{v}_y, \hat{\mu}$ *(defined in (1) and (3)). The system* $\bar{f}$ *is more precise than* $\hat{f}$*, if and only if*

$$\int_{Y}H(\bar{v}_y)\bar{\mu}(y)\,\mathrm{d}y\geq(\leq)\int_{Y}H(\hat{v}_y)\hat{\mu}(y)\,\mathrm{d}y$$

holds for every convex (concave) function H on the set of density functions over A.

The proof of Lemma 1 can be found in Kihlstrom (1984). The distributions $\bar{v}_Y$ and $\hat{v}_y$ are the posterior distributions of project qualities under the two information systems. Since agents are fully rational, $\bar{v}_y$ and $\hat{v}_y$ also represent individual posterior beliefs. Thus, according to Lemma 1, a more informative system raises (reduces) the expectation of any convex (concave) function of posterior beliefs—a result that will be used in proving some of the main results of this paper.

IV. Information, Welfare, and Technological Development

The informational content of the projects' signals affects individual investment decisions, aggregate production, and economic welfare. To avoid having to deal with distributional issues, we will use an ex ante welfare concept. Note that all agents of the same generation are identical *ex-ante*, i.e., before they observe the signals. We therefore define economic welfare, W_t, as the ex-ante expected utility of members of G_t. An information system $\bar{f}$ will be ranked higher than an information system $\hat{f}$ in terms of economic welfare, if *all* generations attain higher welfare under $\bar{f}$ than under $\hat{f}$.

A. More Precise Information in an Economy Without Risk Sharing

Welfare of generation G_t is defined by

$$W_t(f,Q_{t-1}) = E[V_t(\nu_y,Q_{t-1})] = \int_Y V_t(\nu_y;Q_{t-1})\mu(y)\,\mathrm{d}y \tag{13}$$

where

$$V_t(\nu_y,Q_{t-1}) := -w(x(\nu_y),Q_{t-1}) + \int_A u(x(\nu_y)+A)\nu_y(A)\,\mathrm{d}A\,. \tag{14}$$

$V_t(\nu_y,Q_{t-1})$ is the value function for generation G_t and represents the conditional expected utility of a member of G_t who carries out a project with signal y.

In this economic setting, there are two channels through which the precision of information can affect welfare: (i) more precise information reduces uncertainty and may allow agents to make more effective decisions, and (ii) more precise information may also affect (future) welfare via the aggregate output externality. The next proposition characterizes the first effect while abstracting from the externality channel.

Proposition 1 *If the information system $\bar{f}$ is more precise than the information system $\hat{f}$, then*

$$W_t(\bar{f},Q_{t-1}) \geq W_t(\hat{f},Q_{t-1})$$

is satisfied for any given $Q_{t-1} \geq 0$.

Proof: See appendix.

According to Proposition 1, more precise information improves welfare for a given generation for any fixed level of technological development. Because more precise information reduces the uncertainty that agents face when they make their decisions, we will call the welfare effect in Proposition 1 'uncertainty related.'

The proposition does not imply, however, that in equilibrium all generations benefit from a more precise information system. After all, the precision of information systems also affects the path of technological development and—through this externality—future welfare. Differentiating (13) with respect to Q_{t-1} and using the envelope theorem, we find

$$\frac{\partial V_t(\nu_y,Q_{t-1})}{\partial Q_{t-1}} = -\frac{\partial w(x(\nu_y),Q_{t-1})}{\partial Q_{t-1}} > 0\,.$$

Thus, Q_{t-1} affects the welfare of generation G_t positively, an effect that we will call 'externality-related.' In view of Proposition 1, more precise information results in an ex ante Pareto-improvement for the economy if it (weakly) raises the level of technological development at all dates. In that case the uncertainty-related welfare effect and the externality-related welfare effect are both positive. The next proposition indicates when this situation arises.

Proposition 2 *Assume that second-period marginal utility can be written as*

$$u'(x+A) = \rho(A)\vartheta(x) \tag{15}$$

where $\rho, \vartheta : \Re_+ \to \Re_+$ *and, according to Assumption 1,* $\vartheta(\cdot)$ *is a decreasing and convex function. If*[7]

$$\pi(x) := \frac{w_x'(x, Q_{t-1})}{\vartheta(x)} \tag{16}$$

is convex (concave), then more precise information lowers (raises) the level of technological development, Q_t*, for all* $t \geq 1$.

Proof: See appendix.

The class of utility functions that exhibit the separation property in (15) includes utility functions with constant absolute risk aversion and quadratic utility functions often used in finance to describe mean-variance preferences.

The function $\pi(x)$ represents a measure of marginal utility cost at time *t* per unit of marginal utility at time *t*+1. It can, therefore, be interpreted as a measure of intertemporal substitution of marginal utility (intertemporal substitution, for short). Intertemporal substitution is always increasing in *x*, because any additional unit of utility tomorrow comes at the expense of increasingly higher utility cost today.

Assuming that $\pi(\cdot)$ is convex or concave implies a joint restriction on intertemporal consumer preferences and on the production technology. Convexity of intertemporal susbstitution means that the sensitivity $\pi(\cdot)$ with respect to *x* is increasing in *x*. If $u(\cdot)$ is of the CARA-type, intertemporal substitution becomes more sensitive with higher absolute risk aversion. In this case, which is examined in the next section, as a rule of thumb,

---

[7] We have chosen not to include Q_{t-1} as an argument of the function $\pi(\cdot)$, because Q_{t-1} is fixed at date *t*.

intertemporal substitution is concave if risk aversion is sufficiently low; and it is convex, if risk aversion is sufficiently high.

Corollary 1 *Under the assumption of Proposition 2 (separation of second period marginal utility), welfare of all generations increases with more precise information, if the economy exhibits concave intertemporal substitution,* $\pi(x)$.

Proof: Since Q_0 is fixed, the first generation, G_1, benefits from a more precise information system according to Proposition 1. All other generations benefit even more, because for them the welfare gain from a higher level of technological development adds to the positive welfare effect in Proposition 1. □

To gain an intuitive understanding of the results in Proposition 2 and Corollary 1, let us assume that intertemporal substitution, $\pi(x)$, is convex (e.g., due to high risk aversion). In that case, R&D investment, $x(\cdot)$, is concave in the information conveyed by the signal (cf. proof of Proposition 2). This implies that R&D depends more sensitively on the screening information if the signal about project quality is high, i.e., if the signal represents 'good news'. Similarly, R&D investment becomes increasingly less sensitive to the screening information when the signal reveals 'bad news' about project quality. In this sense R&D investment responds more sensitively to good news than to bad news. At the same time, a more precise information system enhances the reliability of the signals. This means that a high signal becomes even better news than before, thereby inducing lower R&D investment in the respective project; and a low signal becomes worse news than before, resulting in more R&D.[8] However, since R&D reacts (negatively) more sensitively to good news than to bad news, the overall impact is negative, and therefore the level of technological development declines as the signals become more informative.

A.1. An Example: CARA Preferences

To illustrate the critical role of risk aversion for the implications of the precision of information on welfare and technological development, we choose a second period utility function $u(\cdot)$ with constant absolute risk aversion (CARA). Specifically we assume

$$w\left(x, Q_{t-1}\right) = \frac{x^{2-\beta}}{Q_{t-1}}, \qquad u(c) = -e^{-\alpha c} \tag{17}$$

[8] Recall that by equation (6) higher signals lead to lower R&D investment.

where $\beta \in (0,1)$, $x \in [\underline{x}, \overline{x}] \subset \Re_{++}$, and $\alpha > 0$ is the coefficient of absolute risk aversion. The second period utility function $u(\cdot)$ has the separation property (15) with $\vartheta(x) = \exp(-\alpha x)$ and $\rho(A) = \alpha \exp(-\alpha A)$. Intertemporal substitution can be calculated as

$$\pi(x) = \frac{(2-\beta)x^{1-\beta}}{Q_{t-1}e^{-\alpha x}} \qquad x \in [\underline{x}, \overline{x}]. \tag{18}$$

By differentiating (18), we obtain the following result:

Lemma 2 *Intertemporal substitution* $\pi(x)$ *is*

(i) *concave in x, if* $\alpha \le (1-\beta)\beta / 2\overline{x}$ *;*

(ii) *convex in x, if* $\alpha > \beta / 2\underline{x}$ *.*

The proof is straightforward and therefore omitted.

Corollary 2 *In the economy with CARA-preferences,*

(i) *more precise information raises the level of technological development,* Q_t*, and economic welfare,* W_t*, for all* $t \ge 1$*, if*

$$\alpha \le \frac{(1-\beta)\beta}{2\overline{x}}; \tag{19}$$

(ii) *more precise information lowers the level of technological development,* Q_t*, for all* $t \ge 1$*, if*

$$\alpha \ge \frac{\beta}{2\underline{x}}. \tag{20}$$

Proof: In the proof of Proposition 2 it was shown that $x(\nu_y)$ is concave (convex) in the posterior distribution ν_y, whenever $\pi(\cdot)$ is a convex (concave) function. Under the restriction (19), $\pi(\cdot)$ is a concave function according to Lemma 2 and, hence, $x(\nu_y)$ is convex. Lemma 1 then yields the result in part (i). The second part follows by analogous reasoning, noting that $\pi(\cdot)$ is convex under the restriction in (20). □

Agents of the first generation always benefit from a more precise informative system, because it reduces the uncertainty they face.[9] Future generations G_t, $t > 0$, are affected in addition by technological externality Q_{t-1}, which depends on the information system. Future generations unambiguously benefit from a more precise information system only if the externality works in the same direction as the uncertainty-related welfare effect characterized in Proposition 1, i.e., if agents have sufficiently low absolute risk aversion.

B. More Precise Information in an Economy With Risk Sharing

Thus far, the economic environment contained no mechnism that allowed agents to share their project risks. In economic settings where agents can share risks, more precise information typically affects the equilibrium risk allocation and, thereby, economic welfare. It is well known that in some cases better information can be welfare-reducing (Hirshleifer, 1971, 1975, Schlee, 2001, Drees and Eckwert, 2003).

Consider the case where an intermediary, such as an insurance company, offers insurance against project risks. Suppose the insurance contracts are fairly priced conditional on the quality signal. If the signal *y* has been assigned to an agent's project, the agent can sell the project's future random output, or part of it, at a price reflecting its current fair value conditional on the signal *y*.

More precisely, the intermediary offers to sell insurance contracts to the agent on the following terms: each contract involves the obligation for the agent to pay *A* units of the consumption good to the intermediary next period, if the project quality turns out to be *A*. In return, next period the agent will receive from the intermediary a predetermined payment of $\overline{A}(v_y)$, which is the average quality of projects with signal *y* as defined in equation (2). Note that the intermediary always breaks even because the contracts are fairly priced and the law of large numbers holds conditional on each signal realization *y*.

Consider an agent of generation G_t, who has a project with signal *y*. The agent's optimal investment, consumption, and hedging decisions are determined by

$$\max_{x,\tilde{c},h} E\left[u(\tilde{c}) - w(x;Q_{t-1}) \middle| y\right] \qquad (21)$$

$$\text{s. t. } \tilde{c} = x + \tilde{A} + h[\overline{A}(v_y) - \tilde{A}]$$

where *h* denotes the number of insurance contracts the agent buys. The necessary and sufficient first-order conditions to problem (21) are

[9] Their welfare is obviously not affected by the production externality.

$$h = 1 \tag{22}$$

$$w'(x;Q_{t-1}) = u'(x + \bar{A}(\nu_y)). \tag{23}$$

According to (23), R&D investment $x(\cdot)$ depends on the posterior distribution ν_y only via $\bar{A}(\nu_y)$: the "transformed" signal, $\bar{A}(\nu_y)$, aggregates all relevant information contained in the signal y. We may therefore express the optimal choice of R&D as $x(\bar{A}(\nu_y))$.[10] From (23) we derive

$$x'(\bar{A}(\nu_y)) = \left[-1 + \frac{w''_{xx}(x;Q_{t-1})}{u''(x + \bar{A}(\nu_y))}\right]^{-1} \in [-1, 0). \tag{24}$$

Thus, R&D investment $x(\bar{A}(\nu_y))$ is decreasing in $\bar{A}(\nu_y)$, and consumption $c = x(\bar{A}(\nu_y)) + \bar{A}(\nu_y)$ is increasing in $\bar{A}(\nu_y)$. By MLRP, these monotonicity properties also hold with regard to the realization of the signal y. Finally, aggregate production at date t can be written as

$$Q_t = E[\tilde{A}] + \int_Y x(\bar{A}(\nu_y))\mu(y)\ \mathrm{d}y. \tag{25}$$

To assess the role of information for economic welfare, consider the value function for generation G_t,

$$\hat{V}_t\left(\bar{A}(\nu_y), Q_{t-1}\right) = -w\left(x(\bar{A}(\nu_y)); Q_{t-1}\right) + u\left(x(\bar{A}(\nu_y)) + \bar{A}(\nu_y)\right). \tag{26}$$

Welfare of generation G_t, defined as ex-ante expected lifetime utility of a member in G_t, is given by $\hat{W}_t\left(f, Q_{t-1}\right) = E[\hat{V}_t(\bar{A}(\nu_y), Q_{t-1})]$.

Proposition 3 *If the information system $\bar{f}$ is more precise than the information system $\hat{f}$, then*

$$\hat{W}_t(\bar{f}, Q_{t-1}) \le \hat{W}_t(\hat{f}, Q_{t-1})$$

---

[10] Again, we have suppressed the argument Q_{t-1}. Equation (23) and Assumption 1 imply that $x(\cdot)$ is increasing in Q_{t-1}: $\dfrac{\mathrm{d}x(\cdot)}{\mathrm{d}Q_{t-1}} = \dfrac{v''_{xQ}(\cdot)}{-v''_{xx}(\cdot) + u''(\cdot)} > 0$.

holds for all $Q_{t-1} \geq 0$.

Proof: See appendix.

According to Proposition 3, the presence of risk sharing arrangements reverses the direction of the uncertainty-related welfare effect. In the case without risk sharing we saw that more precise information reduces the uncertainty that agents face when they make their investment decisions—an effect that tended to improve their ex ante welfare. With insurance contracts that share risks, the situation is different. While a more precise information system reduces the uncertainty at the time of the investment decision, more precise signals also imply that less risk can be shared and more risk has to be borne by the risk-averse agents themselves. So, although the insurance contracts are priced fairly and the risk allocation is conditionally efficient given the signal realizations, more precise information makes the risk allocation less efficient from an ex ante prespective. This mechanism, which imposes welfare costs on risk-averse agants, was first analyzed by Hirshleifer (1971, 1975) and is therefore often referred to as the 'Hirshleifer Effect.' More recently, it has been studied by Citanna and Villanacci (2000), Eckwert and Zilcha (2001), Drees and Eckwert (2003), and others.

While more precise information reduces welfare for a given level of technological development (see Proposition 3), it raises the level of technological development at all dates.

Proposition 4 *More precise information raises the level of technolgical development,* Q_t*, for all* $t \geq 1$.

Proof: See appendix.

In the absence of risk sharing arrangements, we found that more precise information slows technological progress unless the economy exhibits sufficiently low risk aversion. Under conditionally efficient risk sharing, by contrast, more precise information stimulates technological progress regardless of agents' attitudes toward risk since R&D investment is always convex in the transformed information signal, $\overline{A}(\nu_y)$ (see proof of Proposition 4). This means that R&D investment depends less sensitively on the screening information if the transformed signal about project quality is high, i.e., if the signal represents 'good news'. Similarly, R&D investment becomes increasingly more sensitive to the screening information when the transformed signal reveals 'bad news' about project quality. In this sense R&D investment responds less sensitively to good news than to bad news. At the same time, a more precise information system enhances the reliability of the signals, and a high signal becomes even better news than before, resulting in less R&D investment in the project; and a low signal becomes worse news than before, resulting in more R&D investment. However, since R&D investment reacts (negatively) more sensitively to bad news than to good news, the overall impact is positive, and therefore the level of technological development rises as the signals become more informative.

Nonetheless, more precise information has an ambiguous impact on economic welfare. On the one hand, the equilibrium risk allocation deteriorates because more reliable signals destroy some risk sharing opportunities in the economy, and the resulting welfare losses increase with the risk aversion of agents.[11] On the other hand, more precise information promotes technological development at all dates, creating positive externalities for future generations. In this sense, one could say that faster technological progress is bought at the expense of more risk being borne by the agents themselves.

Generally, in this case the equilibrium allocations under different information systems cannot be ranked according to the Pareto criterion because the benefits and costs of better information are distributed unevenly across generations. Under a more precise information system, the first generation suffers welfare losses since it does not benefit from the positive externality of faster technological progress in the future. The welfare implications for all other generations are ambiguous and depend on the trade-off between the uncertainty-related welfare effect (which in this case is negative) and the externality-related welfare effect (which in this case is positive). This trade-off depends on the agents' attitudes toward risk and the production technology. For pure exchange economies with efficient risk sharing arrangements, Schlee (2001) showed that under weak conditions better information makes all agents worse off. Our analysis demonstrates that this result cannot be generalized to economies with production externalities.[12] We summarize the main results in the following table.

[11] If agents are risk-neutral, the value function in the proof of Proposition 3 is linear in the posterior distribution ν_y and, hence, the Hirshleifer Effect completely vanishes.

[12] Results that are similar in spirit have been obtained by Eckwert and Zilcha (2003). These authors show that even in the absence of externalities the conclusions in Schlee (2001) can be overturned, if production processes are modeled explicitly.

Table 1. Welfare Effects of More Precise Information

Degree of Risk Sharing	Absolute Risk Aversion	Uncertainty-related Effect	Externality-related Effect	Overall Welfare Effect
No risk sharing	Low	+	+	+
	High	+	–	?
Full risk sharing	Low or High	–	+	?

V. Conclusion

In this paper we analyzed the dynamic aspects of the interaction between the precision of information, technological development, and economic welfare. We found that more precise publicly observable information about idiosyncratic production shocks affects the time path of the economy through an uncertainy-related welfare effect and—via the assumed intertemporal production externality—through an externality-related welfare effect. These two effects can, under certain circumstances, point in opposite directions (see Table 1).

Our analysis thus highlights the inherently ambiguous role of more precise information for technological progress and economic welfare. In particular, our model shows that the mechanism through which more precise information affects technological development and economic welfare depends critically on the risk sharing capacity of the economy's financial system. In the absence of any risk sharing arrangements, more precise information allows agents to improve their investment decisions without adverse risk sharing effects. As a result, the uncertainty-related welfare effect is positive. At the same time, more precise information slows technological progress if intertemporal substitution is convex in the agents' R&D investment (or in the case of CARA preferences, if absolute risk aversion is high). If there is efficient risk sharing, however, more precise information adversely affects the (unconditional) equilibrium risk allocation and creates a negative uncertainty-related welfare effect, at the same time as more precise information accelerates technical progress and thus has positive externality-related welfare effects.

What is the practical relevance of these results? The paper may shed some light on the channels through which better accounting information may affect economic growth and economic welfare. To the extent that accounting information can be viewed as containing forward-looking information about the quality of projects or corporations, our model can be interpreted as examining the effect of better accounting standards. From that perspective, our analysis would suggest that, even though better accounting information may increase technological progress and R&D investment, more precise accounting information does not imply that economic welfare necessarily increases, particularly in economies with advanced financial systems that allow considerable risk sharing. Our findings might thus serve as a cautionary note that in environments where incomplete information interacts with risk sharing opportunities, simple, seemingly obvious conclusions are not always correct.

That said, our theoretical study is obviously subject to a number of limitations. First, we have chosen as simple a model as possible to combine aspects of welfare, technological development, and precision of information. This approach allowed us to characterize in formal terms, and to discuss in economic terms, the main mechanisms through which the precision of information affects the economy. Due to the model's simplicity, however, we examine only the extreme cases of autarky and full risk sharing between agents. In the absence of risk sharing, the autarkic agents merely interact through the technological externality between generations. If risk sharing is possible, agents also interact on risk sharing markets. A richer set of interactions between generations and among heterogeneous members of the same generation—maybe through financial contracts with partial risk sharing—might yield further insights into the role of information for the dynamic evolution of production economies. This is left for future research. We also leave for future research further investigations related to the question what kind of government policies might be suitable to correct or to mitigate the distortions caused by the intertemporal externality of technological progress.

Appendix

In this appendix, we prove Propositions 1-4.

Proof of Proposition 1: We show that $V(\nu_y, Q_{t-1})$ is convex in the posterior distribution ν_y. The claim then follows from Lemma 1. Assume $\nu_y = \alpha\bar{\nu}_y + (1-\alpha)\hat{\nu}_y$, $\alpha \in [0,1]$.

$$V(\nu_y, Q_{t-1}) = \alpha\Big[-w(x(\nu_y), Q_{t-1}) + \int_{A} u(x(\nu_y) + A)\bar{\nu}_y(A)\, \mathrm{d}A\Big]$$

$$+(1-\alpha)\Big[-w(x(\nu_y), Q_{t-1}) + \int_{A} u(x(\nu_y) + A)\hat{\nu}_y(A)\, \mathrm{d}A\Big]$$

$$\leq \alpha\Big[-w(x(\bar{\nu}_y), Q_{t-1}) + \int_{A} u(x(\bar{\nu}_y) + A)\bar{\nu}_y(A)\, \mathrm{d}A\Big]$$

$$+(1-\alpha)\Big[-w(x(\hat{\nu}_y), Q_{t-1}) + \int_{A} u(x(\hat{\nu}_y) + A)\hat{\nu}_y(A)\, \mathrm{d}A\Big]$$

$$= \alpha V(\bar{\nu}_y, Q_{t-1}) + (1-\alpha)V(\hat{\nu}_y, Q_{t-1}).$$

The inequality holds because $x(\bar{\nu}_y)$ and $x(\hat{\nu}_y)$ solve the agent's decision problem, if the posterior belief is given by $\bar{\nu}_y$ and $\hat{\nu}_y$, respectively. □

Proof of Proposition 2: We show that under the restrictions of the proposition $x(\nu_y)$ is concave (convex) in the posterior distribution ν_y, if $\pi(x)$ is a convex (concave) function. The claim then follows from (9) in combination with Lemma 1.

First we observe that $\pi(x)$ is increasing since $v(x, Q_{t-1})$ is convex in x. Now let $\bar{\nu}_y$ and $\hat{\nu}_y$ be two information systems and define $\nu_y := \alpha\bar{\nu}_y + (1-\alpha)\hat{\nu}_y$, $\alpha \in [0,1]$. Using (15), the first order condition (6) can be written as

$$1 = \int_{A} \frac{\rho(A)}{\pi(x(\nu_y))}\nu_y(A)\, \mathrm{d}A$$

$$= \frac{1}{\pi(x(\nu_y))}\Big[\alpha\int_A \rho(A)\bar{\nu}_y(A)\, \mathrm{d}A + (1-\alpha)\int_A \rho(A)\hat{\nu}_y(A)\, \mathrm{d}A\Big]$$

$$= \frac{1}{\pi(x(\nu_y))} \left[\alpha\pi(x(\bar{\nu}_y)) + (1-\alpha)\pi(x(\hat{\nu}_y)) \right]. \tag{27}$$

Suppose that $\pi(x)$ is convex, i.e.,

$$\pi\left(\alpha x(\bar{\nu}_y) + (1-\alpha)x(\hat{\nu}_y)\right) \leq \alpha\pi(x(\bar{\nu}_y)) + (1-\alpha)\pi(x(\hat{\nu}_y)) \tag{28}$$

is satisfied. In this case, (17) and (18) imply

$$\pi(x(\nu_y)) \geq \pi\left(\alpha x(\bar{\nu}_y) + (1-\alpha)x(\hat{\nu}_y)\right). \tag{29}$$

Since $\pi(x)$ is an increasing function, we conclude

$$x(\nu_y) \geq \alpha x(\bar{\nu}_y) + (1-\alpha)x(\hat{\nu}_y). \tag{30}$$

Hence, $x(\nu_y)$ is a concave function. If $\pi(x)$ is concave, the inequalities in (28), (29), (30) are all reversed, indicating that $x(\nu_y)$ is a convex function. □

Proof of Proposition 3: In view of Lemma 1, we have to show that for given Q_{t-1} the value function (26) is concave in the posterior distribution ν_y. Since $\bar{A}(\nu_y)$ is linear in ν_y, the value function will be concave in ν_y if it is concave in $\bar{A}(\nu_y)$. Differentiating (26) with respect to $\bar{A}(\nu_y)$ and using the envelope theorem we get

$$\frac{\mathrm{d}^2 \hat{V}_t(\bar{A}(\nu_y), Q_{t-1})}{\mathrm{d}(\bar{A}(\nu_y))^2} = u''(\cdot)\left[x'(\bar{A}(\nu_y)) + 1\right] \leq 0,$$

where the inequality follows from (24). Thus the value function is concave in the posterior distribution ν_y. □

Proof of Proposition 4: In view of (24), $x'(\bar{A}(\nu_y))$ is increasing in $\bar{A}(\nu_y)$ (cf. Assumption 1 and recall that $x(\bar{A}(\nu_y))$ is decreasing in $\bar{A}(\nu_y)$). Thus, since $\bar{A}(\nu_y)$ is linear in ν_y, $x(\bar{A}(\nu_y))$ is convex in ν_y. The claim in the proposition now follows from an application of Lemma 1 to the representation of Q_t in (25). □

References

Blackburn, K. and Hung, V. T. Y., 1998, "A Theory of Growth, Financial Development, and Trade," *Economica*, Vol. 65, pp. 107-24.

Blackwell, D., 1953, "Equivalent Comparison of Experiments," *Annals of Mathematical Statistics*, Vol. 24, pp. 265-272

Citanna, A. and Villanacci, A., 2000, "Incomplete Markets, Allocative Efficiency, and the Information Revealed by Prices," *Journal of Economic Theory*, Vol. 90, pp. 222-253.

De la Fuente, A. and Marin, J. M., 1996, "Innovation, Bank Monitoring, and Endogenous Financial Development," *Journal of Monetary Economics*, Vol. 38, pp. 269-301.

Drees, B. and Eckwert, B., 2003, "Welfare Effects of Transparency in Foreign Exchange Markets: The Role of Hedging Opportunities," *Review of International Economics*, Vol. 11(3), pp. 453-463.

Easterly, W., 2001, *The Elusive Quest for Growth* (Cambridge: MIT Press).

Eckwert, B. and Zilcha, I., 2001, "The Value of Information in Production Economies," *Journal of Economic Theory*, Vol. 100, pp. 172-186.

______ 2003, "Incomplete Risk Sharing Arrangements and the Value of Information," *Economic Theory*, Vol. 21, pp. 43-58.

______ 2004, "Economic Implications of Better Information in a Dynamic Framework," *Economic Theory*, Vol. 24, pp. 561-81.

Feldman, M. and Gilles, C., 1985, "An Expository Note on Individual Risk without Aggregate Uncertainty," *Journal of Economic Theory*, Vol. 35, pp. 26-32.

Galetovic, A., 1996, "Specialization, Intermediation and Growth," *Journal of Monetary Economics*, Vol. 38, pp. 549-59.

Galor, O. and Tsiddon, D., 1997, "The Distribution of Human Capital and Economic Growth," *Journal of Economic Growth*, Vol. 2, pp. 93-124.

Greenwood, J. and Jovanovic, B., 1990, "Financial Development, Growth, and the Distribution of Income," *Journal of Political Economy*, Vol. 98 pp. 1076-1107.

Greenwood, J. and Smith, B., 1996, "Financial Markets in Development, and the Development of Financial Markets," *Journal of Economic Dynamics and Control*, Vol. 21, pp. 145-181.

Hirshleifer, J., 1971, "The Private and Social Value of Information and the Reward to Incentive Activity," *American Economic Review*, Vol. 61, pp. 561-574.

______ 1975, "Speculation and Equilibrium: Information, Risk and Markets," *Quarterly Journal of Economics*, Vol. 89, pp. 519-542.

Kihlstrom, R. E., 1984, "A 'Bayesian' Exposition of Blackwell's Theorem on the Comparison of Experiments," in *Bayesian Models in Economic Theory* ed. by M. Boyer and R. E. Kihlstrom (Amsterdam: North Holland).

Levine, R., 2004, "Finance and Growth: Theory and Evidence," NBER working paper 10766.

Milgrom P. R., 1981, "Good News and Bad News: Representation Theorems and Applications," *Bell Journal of Economics*, Vol. 12, pp. 380-391.

Romer, P. M., 1990, "Endogenous Technological Change," *Journal of Political Economy*, Vol. 98, pp. 71-102.

Schlee, E., 2001, "The Value of Information in Efficient Risk Sharing Arrangements," *American Economic Review*, Vol. 91(3), pp. 509-524.