Implications of Better Information for Technological Development and Welfare

by

Burkhard Drees and Bernhard Eckwert *

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Burkhard Drees
IMF Institute
International Monetary Fund
Washington, DC 20431
USA

Bernhard Eckwert
Department of Economics
University of Bielefeld
D–33501 Bielefeld
Germany

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Abstract

This paper uses an overlapping generations framework to analyze the interaction among information, technological development, and economic welfare under different financial structures. Agents invest into risky projects to which nature has assigned publicly observable signals. The signals contain noisy information about the technological quality of the projects. The returns to the projects are affected by the level of technological development, for which *aggregate* production in the previous period serves as a proxy. We find that the link between better information and technological development depends critically on the financial structure of the economy. In addition, our analysis highlights the inherently ambiguous role of more reliable information for economic welfare.

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1 Introduction

During the past decade interest in studies on economic growth under uncertainty has increased considerably. Economists have attempted to explain stationary as well as non-stationary economic fluctuations by incorporating random shocks into standard models of economic growth (Stockey and Lucas (1989), Taylor and Uhlig (1990), Becker and Zilcha (1997), Böhm and Chiarella (2005)). Another strand of the literature has emphasized the operation of the financial systems and the role of technological progress in endogenous growth models (Greenwood and Jovanovic (1990), Romer (1990), Greenwood and Smith (1996), Galetovic (1996)). This literature strongly suggests that three factors are of great importance for the development and welfare properties of dynamic economic systems: (1) information about the uncertain environment in which agents act, (2) the financial structure of the economy, and (3) technological change.

The literature that analyzes the nexus between financial structure and technological development has produced inconclusive results. In particular, the causality of the link between these two factors is still unclear. Does the financial structure affect growth, or does the financial system simply adjust to technological development? The answer to this question may depend on the interaction with a third factor, namely the precision of 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 financial structure is a delicate one. Better information reduces the uncertainty to which agents are exposed and, in this sense, performs a similar role as risk sharing markets. On the other hand, information typically interferes with the operation of risk sharing markets because risks that have already been resolved through new information can no longer be insured. The welfare effects of better information may therefore be completely different from those induced by a financial system that allows more efficient risk sharing.

In this paper we analyze in as simple a model as possible the interaction among information, technological development, and economic welfare under two different financial structures. The first structure precludes any risk sharing among agents, while the second structure allows efficient risk sharing conditional on the information that has been revealed. In our model financial intermediaries perform only one single function, they facilitate the trading and hedging of risk. The operations of financial intermediaries are affected by the information system, because the risks faced by investors depend on the reliability of the information signals they have received.

The framework we use for our study is an overlapping generations economy where agents invest effort into risky projects in order to produce a consumption good. Nature assigns a publicly observable signal to each project which contains some noisy information about the technological quality of the project. In the next period each project yields a random return. The distribution of the return depends on the effort that has been invested into the project and on the signal that has been assigned to it. Our dynamic setup rests on the premise that technological change arises from the behavior of economic agents responding to market incentives. The technological change affects project qualities in subsequent periods and thereby creates an externality for future generations of agents. We take aggregate production at time t as a proxy for the technological externality in period $t+1$: A higher level of *aggregate* production today reduces the production cost of each individual project tomorrow.

This paper addresses the effects of better information, i.e., more efficient screening for project quality, on economic welfare and on the proxy for the level of technological development. These effects are not independent of one another as the level of technological development exerts an externality on the welfare of future generations. This externality-related welfare effect is positive whenever the level of technological development rises. In addition, better information affects the uncertainty to which agents are exposed thereby causing an uncertainty-reducing welfare effect. Only when these two effects work in the same direction can the impact of better information on economic welfare unambiguously be assessed.

Under a financial structure that precludes risk sharing across different projects we find that more reliable information raises the level of technological development and increases welfare, if intertemporal substitution satisfies a concavity condition. If individual preferences are of the CARA-type, this condition is satisfied as long as absolute risk aversion is sufficiently small. By contrast, if the financial structure allows conditionally efficient risk sharing, then better information produces a negative uncertainty-reducing welfare effect while, at the same time, a higher level of technological development raises economic welfare. Thus, in a dynamic context with technological externalities more reliable information plays an inherently ambiguous role in an analysis of economic welfare.

2 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 that consists of all individuals born at time $t-1$ by G_t, $t = 0, 1, \cdots$. There is no population growth, and the size of each generation is normalized to one.

Nature assigns a project (production technology) to each agent. When 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 know the quality (productivity) of his net 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 an output $\tilde{q} = q(x, \tilde{A}) := x + \tilde{A}$, where $\tilde{A}$ is a stochastic component with probability density ν taking values in $\mathcal{A} := [\underline{A}, \overline{A}] \subset \mathbb{R}_{++}$. The realization A of $\tilde{A}$ will be interpreted as the quality of the project. Thus, each agent perceives the quality of his project as uncertain. 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 ν.[1]

[1]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,

Before the agent decides on his R&D investment in his first period of life, he receives a publicly observable signal $y \in Y \subset \mathbb{R}$ that contains information about the project's quality. The signals assigned to projects with quality A are distributed according to the density $f(\cdot|A)$. The function $f(\cdot|A)$ is also the ex post distribution of signals across projects with quality A.[2] By construction, the distributions of signals and of qualities are correlated and, hence, the signal assigned to a project reveals some information about the project's unknown quality and can therefore be used as a screening device. Based on the screening information conveyed by the signal, the agent forms expectations about his project's quality in a Bayesian way. As a consequence, 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

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

The average quality of projects with signal y is

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

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

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

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

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

the individual risks are not independent.

[2] Again, this assumption is justified by the aforementioned result in Feldman and Gilles (1985, p. 29, Proposition 2).

The effort associated with R&D investment, x, imposes a utility cost $v(x; Q_{t-1})$ 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. It exerts a positive externality on the production technology in period t by reducing the utility cost $v(\cdot)$ associated with R&D investment.[3] 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, i.e., $c = q(x, A) = x + A$. This restriction will relaxed later on.

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

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

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

The restrictions on the third derivatives of $v(\cdot)$ 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.

At the time when agents of generation G_t make investment decisions the qualities of their projects are not yet known. These agents, therefore, differ only by the signals they have received about their projects. Given Q_{t-1} the optimal investment and consumption decisions of an agent in G_t with signal y are determined by

$$\max_{x,\tilde{c}} \ E[-v(x; Q_{t-1}) + u(\tilde{c})|y] \quad (5)$$
$$\text{s.t.} \quad \tilde{c} = q(x, \tilde{A}) = x + \tilde{A}.$$

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

$$v'(x; Q_{t-1}) = E[u'(x + \tilde{A})|y]. \quad (6)$$

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

From (6) we obtain the optimal choice of R&D investment as a function of the conditional distribution ν_y, i.e., $x = x(\nu_y)$.[4] 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 $\{f(\cdot|A), A \in \mathcal{A}\}$ satisfy the Monotone Likelihood Ratio Property (MLRP).[5] 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 may also derive upper and lower bounds for R&D effort. Let $\overline{x}$ and $\underline{x}$ be defined by

$$v'(\overline{x}; Q_{t-1}) = u_2'(\overline{x} + \underline{A}); \qquad v'(\underline{x}; Q_{t-1}) = u_2'(\underline{x} + \overline{A}). \tag{7}$$

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

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

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

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

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

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 4). Next we formulate an equilibrium concept for this economy.

[4]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}.

[5]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 conditional on y in the first-order stochastic dominance. Formally, $\int_{\mathcal{A}} \varphi(A)\nu_{y'}(A)\mathrm{d}A \geq \int_{\mathcal{A}} \varphi(A)\nu_y(A)\mathrm{d}A$ holds for any (integrable) increasing function φ. For further details see Milgrom (1981).

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* $Q_t, t = 1, 2, \cdots,$ *satisfy (9).*

2.1 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 qualities across projects are correlated. Therefore, the evaluation of a project will be based on the project's signal, y, which will be used to update the prior distribution, ν, according to

$$\nu_y(A) = f(y|A)\nu(A)/\mu(y). \tag{10}$$

The function $f : Y \times \mathcal{A} \to \mathbb{R}_+$ represents an information system that describes the correlation structure between signals and project qualities. For any quality level $A \in \mathcal{A}$, 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, we know that the output scheme for projects is monotonic, i.e., projects with higher signals have higher expected outputs.

Our concept of informativeness is based on the Blackwell (1953) sufficiency criterion. According to this criterion, an information system becomes less informative if the signals are subjected to a process of random 'garbeling':

Definition 2 *Information system* $\bar{f}$ *is more informative than information system*

$\hat{f}$*, if there exists an integrable function* $\lambda : Y^2 \rightarrow \mathbb{R}_+$ *such that*

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

holds for all y*, and*

$$\hat{f}(y'|A) = \int_Y \bar{f}(y|A)\lambda(y', y)\mathrm{d}y \tag{12}$$

holds for all $A \in \mathcal{A}$*.*

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* $\bar{\nu}_y, \bar{\mu}, \hat{\nu}_y, \hat{\mu}$ *(defined in (1) and (3)).* $\bar{f}$ *is more informative than* $\hat{f}$*, if and only if*

$$\int_Y G(\bar{\nu}_y)\bar{\mu}(y)\,\mathrm{d}y \overset{(\leq)}{\geq} \int_Y G(\hat{\nu}_y)\hat{\mu}(y)\,\mathrm{d}y$$

holds for every convex (concave) function G *on the set of density functions over* $\mathcal{A}$*.*

The proof of Lemma 1 can be found in Kihlstrom (1984). The distributions $\bar{\nu}_y$ and $\hat{\nu}_y$ are the posterior distributions of project qualities under the two information systems. Since agents are fully rational, $\bar{\nu}_y$ and $\hat{\nu}_y$ 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.

3 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 the signals of their projects have realized. We therefore define economic welfare, W_t, of generation G_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 $\hat{f}$.

3.1 Better 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

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

$V_t(\nu_y, Q_{t-1})$, the value function for generation G_t, 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) better information reduces uncertainty and may allow agents to make more effective decisions, and (ii) better 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 informative 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 all $Q_{t-1} \geq 0$.

Proof: See appendix.

According to Proposition 1, better information improves welfare for a given generation for any fixed level of technological development. Better information reduces the uncertainty that agents face when they make their decisions. The welfare effect in Proposition 1, which we will call 'uncertainty reducing', is unambiguously positive.

The proposition does not imply, however, that in equilibrium all generations benefit from a better 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

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

Thus, Q_{t-1} affects the welfare of generation G_t, an effect that we will call 'externality-related'. In view of Proposition 1, better 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-reducing 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 $\rho, \vartheta : \mathbb{R}_+ \to \mathbb{R}_+$ and, according to Assumption 1, $\vartheta(\cdot)$ is a decreasing and convex function. If [6]

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

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

Proof: See appendix.

[6] 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.

The class of utility functions that exhibit the separation property in (15) includes utility functions of the CARA-type 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 substitution means that the sensitivity of $\pi(\cdot)$ 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, as a rule of thumb, intertempotal 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 better information, if the economy exhibits concave intertemporal substitution,* $\pi(x)$.

Proof: Since Q_0 is fixed, the first generation, G_1, benefits from a better 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 Propostion 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. 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 better 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.[7] However, since R&D reacts more sensitively to good news than to bad news, the overall impact is negative, and therefore the level of technological development declines.

3.1.1 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). Specificially we assume

$$v(x, Q_{t-1}) = \frac{x^{2-\beta}}{Q_{t-1}}, \qquad u(c) = -e^{-ac} \tag{17}$$

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

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

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

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

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

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

(ii) *convex in* x *if* $a \geq \beta/2\underline{x}$.

The proof is straightforward and therefore omitted.

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

(i) *better information raises the standard of technological development,* Q_t*, and economic welfare,* W_t*, for all* $t \geq 1$*, if*

$$a \leq \frac{(1-\beta)\beta}{2\overline{x}}\,; \tag{19}$$

(ii) *better information lowers the standard of technological development,* Q_t*, for all* $t \geq 1$*, if*

$$a \geq \frac{\beta}{2\underline{x}}\,. \tag{20}$$

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 convex (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 informative system, because more precise information reduces the uncertainty they face but does not act through the externality channel. Future generations G_t, $t > 1$, are affected in addition by the technological externality Q_{t-1}, which depends on the information system. Future generations unambiguously benefit from a better information system only if the externality works in the same direction as the uncertainty-reducing welfare effect characterized in Proposition 1. The two effects point in the same direction as long as agents have sufficiently low absolute risk aversion.

3.2 Better information in an economy with risk sharing

Thus far, the economic environment contained no mechanisms 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, or insurance company, offers insurance against project risks. The insurance contracts are fairly priced conditional on the (quality) signal of a project. 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 the agent will receive a predetermined/fixed payment of $\bar{A}(\nu_y)$ (defined in equation (2)) from the intermediary next period. Note that the intermediary always breaks even because the contracts are fairly priced and the law of large numbers holds even 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

$$\begin{aligned} & \max_{x,\tilde{c},h} E[\,-v(x;Q_{t-1}) + u(\tilde{c})|y] \\ \text{s.t.} \quad & \tilde{c} = x + \tilde{A} + h[\bar{A}(\nu_y) - \tilde{A}]\,, \end{aligned} \tag{21}$$

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

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

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

According to (23), R&D investment $x(\cdot)$ depends on the posterior distribution ν_y

only via $\bar{A}(\nu_y)$. We may therefore express the optimal choice of R&D as $x(\bar{A}(\nu_y))$.[8] From (23) we derive

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

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,

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

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

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

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

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

[8]Again, we have suppressed the argument Q_{t-1}. Equation (23) and Assumption 1 imply that $x(\cdot)$ is increasing in Q_{t-1}:

$$\frac{\mathrm{d}x(\cdot)}{\mathrm{d}Q_{t-1}} = \frac{v''_{xQ}(\cdot)}{-v''_{xx}(\cdot) + u''(\cdot)} > 0\,.$$

Proof: See appendix.

According to Proposition 3 the presence of risk sharing arrangements reverses the direction of the uncertainty-reducing welfare effect. In the case without risk sharing we saw that better 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. Although better information reduces uncertainty at the time of the investment decision, more precise signals 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, the risk allocation becomes less efficient from an ex ante perspective. This mechanism, which imposes welfare costs on risk-averse agents, 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 better information reduces welfare for a given level of technological development (see Proposition 3), better information raises the level of technological development at all dates.

Proposition 4 *Better information raises the level of technological development,* Q_t*, for all* $t \geq 1$.

Proof: See appendix.

In the absence of risk sharing arrangements, we found that information weakens technological development unless the economy exhibits sufficiently low risk aversion. Under conditionally efficient risk sharing, by contrast, better information stimulates technological development regardless of agents' attitudes toward risk. Nonetheless, better 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. The resulting welfare losses increase with the risk aversion of agents.[9] On the other hand, better information promotes technological development at all dates, creating positive externalities for future generations.

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 better information system, the first generation suffers welfare losses since it does not benefit from the positive externality of faster technological progess in the future. The welfare implications for all other generations depend on the trade-off between the uncertainty-reducing welfare effect (which in this case is negative) and an externality-related welfare effect (which in this case is positive). This trade-off depends on the agents' attitudes towards 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.[10]

4 Conclusion

Most of the literature about the role of information in equilibrium models is cast within a static theoretical framework. A static setting, however, does not allow a meaningful analysis of the interactions among information, technological development, and economic welfare. In this paper, we have therefore chosen a simple overlapping generations model with technological uncertainty to identify and analyze the channels through which publicly observable screening information about idiosyncratic production shocks affects the time path of the economy. An improvement of the information system triggers an uncertainty-induced welfare effect as well as an externality-induced welfare effect. The latter effect arises because better

[9]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.

[10]Further results which 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 modelled explicitly.

information influences the path of technological development in the economy.

Our analysis highlights the inherently ambiguous role of more reliable information for economic welfare in a dynamic context. The mechanisms through which information affects technological development and economic welfare depend critically on the risk sharing capacity of the economy's financial system. In the absence of any risk sharing arrangements, better information allows agents to improve their investment decisions without any adverse risk effects. As a consequence, the uncertainty-induced welfare effect is positive. At the same time, better information lowers the level of technological development if intertemporal substitution is convex. Under conditionally efficient risk sharing, by contrast, better information adversely affects the unconditional equilibrium risk allocation thereby producing a negative uncertainty-induced welfare effect. This mechanism shows up in combination with a positive externality-induced welfare effect which is caused by a higher standard of technological development.

Our theoretical study is subject to a number of limitations. First, we have chosen as simple a model as possible to combine aspects of welfare, technological development, and information. This approach allowed us to characterize in formal terms and to discuss in economic terms the main mechanisms through which information affects the economy. Due to its simplicity, though, the model permits little interaction among the economic agents. In the absence of risk sharing, agents are essentially autarkic and merely interact through the technological externality exerted on other generations. If risk sharing is possible, they also interact on the risk sharing markets. A richer structure of interactions between generations and among members of the same generation (which might include financial contracts) might yield further insights into the role of information for the dynamic evolution of production economies. This is left for future research.

Second, we have studied only the extreme cases where the financial system either allows fully efficient conditional risk sharing or no risk sharing at all. Is is an open question to ask whether specifications that allow some, but less than full, risk sharing would narrow the discrepancy between our results in section 3.1 and section 3.2. Finally, our study models technological progress in a rather crude way. Even though our modelling approach is standard in the literature, it would be desirable to have a theory that explains more explicitly the mechanisms by which the level of technological development evolves through time.

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 $\nu_y = \alpha\bar{\nu}_y + (1-\alpha)\hat{\nu}_y, \alpha \in [0,1]$.

$$\begin{aligned}
V(\nu_y, Q_{t-1}) &= \alpha\Big[-v(x(\nu_y), Q_{t-1}) + \int_{\mathcal{A}} u(x(\nu_y) + A)\bar{\nu}_y(A)\,\mathrm{d}A\Big] \\
&+ (1-\alpha)\Big[-v(x(\nu_y), Q_{t-1}) + \int_{\mathcal{A}} u(x(\nu_y) + A)\hat{\nu}_y(A)\,\mathrm{d}A\Big] \\
&\leq \alpha\Big[-v(x(\bar{\nu}_y), Q_{t-1}) + \int_{\mathcal{A}} u(x(\bar{\nu}_y) + A)\bar{\nu}_y(A)\,\mathrm{d}A\Big] \\
&+ (1-\alpha)\Big[-v(x(\hat{\nu}_y, Q_{t-1})) + \int_{\mathcal{A}} u(x(\hat{\nu}_y) + A)\hat{\nu}_y(A)\,\mathrm{d}A\Big] \\
&= \alpha V(\bar{\nu}_y, Q_{t-1}) + (1-\alpha)V(\hat{\nu}_y, Q_{t-1}).
\end{aligned}$$

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 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

$$
\begin{aligned}
1 &= \int_{\mathcal{A}} \frac{\rho(A)}{\pi(x(\nu_y))}\, \nu_y(A)\, \mathrm{d}A \\
&= \frac{1}{\pi(x(\nu_y))} \left[\alpha \int_{\mathcal{A}} \rho(A) \bar{\nu}_y(A)\, \mathrm{d}A + (1-\alpha) \int_{\mathcal{A}} \rho(A) \hat{\nu}_y(A)\, \mathrm{d}A \right] \\
&= \frac{1}{\pi(x(\nu_y))} \Big[\alpha \pi(x(\bar{\nu}_y)) + (1-\alpha) \pi(x(\hat{\nu}_y)) \Big]. \qquad (27)
\end{aligned}
$$

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

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

is satisfied. (17) and (18) imply

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

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

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

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

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

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). □

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