Production, safety, exchange, and risk

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Abstract: Two agents convert resources into safety investment and production while exchanging goods voluntarily. Safety investment ensures reduction of costly risk. High unit cost of safety effort reduces both productive effort and safety effort, which reduces income.

Keywords: production; safety; exchange; risk; trade; price.

Classical exchange theory was developed by Smith (1776) and Ricardo (1817). More recent accounts are Allen (2000), Arrow et al. (1961), Hausken and Moxnes (2005a, 2005b) and Taylor (1993). Recently, exchange theory and conflict have been merged, accounting for production and fighting (see Anderton, 1999; Anderton et al., 1999; Bowles and Gintis, 1993; Hausken, 2004; Rider, 1999; Skaperdas and Syropoulos, 2001). This article makes one step further accounting for safety investment in an exchange model.

Safety risk has not received much attention in the economics literature.[1] Safety concerns are often considered as constraints imposed by law and regulations. Firms face risks due to internal factors related to production, equipment failure, human failure, due to interaction with other firms within the industry, or external factors. The latter can be societal changes in general, or targeted action such as crime, theft, espionage, hacking, blackmail, terrorism. Asche and Aven (2004) argue "that safety measures have a value in an economic sense", and consider for one firm "the business incentives for investing into safety". Similarly, Viscusi (1986) considers market incentives for safety.

Recent changes in US accounting laws have made CEOs liable to legal malpractice if accounting information is found to be fraudulent. This has caused a certain panic among firms as to whether they should invest more in information assurance technologies, given that an increase in such investments could lead to a decrease in firms' productivity. Firms, most of which have finite resource constraints, are thus naturally led to determine optimal investments in information assurance technologies versus production technologies. The former can be perceived as investment to reduce the risk of legal malpractice. This article intends to understand the factors that influence the trade-off between safety and productive investment during exchange.

Each agent i can produce one good i, but also attaches utility to another good j, $i, j = 1, 2$, $i \neq j$. Agent i has a resource R_i (e.g., a capital good, or labour) which can be converted with unit conversion cost a_i into productive effort E_i, and with unit cost b_i into safety effort S_i, where

$$R_i = a_i E_i + b_i S_i \Rightarrow S_i = \left(R_i - a_i E_i\right) / b_i \tag{1}$$

The production cost coefficient a_i, where $1/a_i$ is the productive efficiency, measures the resources required to maintain the agent and machinery he uses in production. Analogously, $1/b_i$ is the safety efficiency. As a practical aid, it may be convenient to think of good i as a consumption good such as oil, and the resource R_i as a capital good such as oil drilling equipment. Alternatively, the product may be a consumption good such as fish, and the resource R_i a capital good such as fishing nets. The productive effort E_i is designed to generate good i, i.e., extract income from resources currently employed. Without risk, the production function for good i or income Y_i takes the simple form $Y_i = E_i^h$, where h is the productivity parameter, with no need for safety effort [Hirshleifer, (1995), p.31]. With risk, the expected income is

$$Y_i = \left[E_i\left(1 - f\left(r_i, S_i\right)\right)\right]^h = \left[E_i\left(1 - \frac{r_i}{c_i S_i}\right)\right]^h, \quad 0 \leq f\left(r_i, S_i\right) \leq 1 \tag{2}$$

where c_i is a parameter that scales the safety effort relative to the risk r_i. A large c_i reduces the risk more efficiently. The risk function $f(r_i, S_i)$ increases in the risk r_i, $\partial f / \partial r_i > 0$, which reduces income, and decreases in the safety effort S_i, $\partial f / \partial S_i < 0$, which constrains risk. The functional form is chosen for convenient analytical solutions. The agent can invest heavily in safety effort, which reduces the risk considerably, but that also reduces the production due to the budget constraint in (1). Hence, the agent faces a trade-off between E_i and S_i.

Agent 1 exports an amount X_1 of good 1 to agent 2 in exchange for an amount X_2 in return. The agents have equivalent Cobb-Douglas preferences for the two goods, with utilities

$$U_1 = \left(Y_1 - X_1\right)^\alpha X_2{}^{1-\alpha}, \quad U_2 = X_1{}^\alpha \left(Y_2 - X_2\right)^{1-\alpha}, \quad X_1 = P_2 X_2, \quad \alpha \in [0,1] \tag{3}$$

where α is the relative preference parameter for good 1 for both agents, and P_2 is an interior terms-of-exchange price denoting the price of good 2 in terms of good 1. To determine the first order conditions, we let agent 1 choose E_1 and X_1, and agent 2 choose E_2 and X_2, simultaneously and independently, to maximise utility. This gives

$$
\begin{aligned}
&\frac{\partial U_i}{\partial E_i}=0 \Rightarrow E_i=\frac{R_i-\sqrt{R_i b_i r_i / c_i}}{a_i}, \quad S_i=\frac{\sqrt{R_i r_i}}{\sqrt{b_i c_i}}, \\
&Y_i=\frac{\left(\sqrt{R_i c_i}-\sqrt{b_i r_i}\right)^{2h}}{\left(a_i c_i\right)^{h}}, \quad \sqrt{R_i c_i} \geq \sqrt{b_i r_i}
\end{aligned} \tag{4}
$$

Proposition 1: The productive effort E_i increases in the resource R_i and in the risk reduction efficiency c_i, and decreases in both unit costs a_i and b_i, and in the risk r_i.

Proposition 2: The safety effort S_i increases in the resource R_i and risk r_i, and decreases in the unit cost b_i of safety effort, and in c_i.

Proposition 3: The income Y_i increases in the resource R_i and in c_i, and decreases in both unit costs a_i and b_i, and in the risk r_i.

Especially interesting among these results is that high unit cost of safety effort reduces both productive effort and safety effort, and thus of course reduces income. Focusing on reducing b_i is thus beneficial. We next insert $X_2 = P_2^{-1} X_1$ into the first equation in (3) and differentiate U_1 with respect to X_1, and thereafter insert $X_1 = P_2 X_2$ into the second equation in (3) and differentiate U_2 with respect to X_2. This gives

$$
\frac{\partial U_1}{\partial X_1}=0 \Rightarrow X_1=Y_1(1-\alpha), \quad \frac{\partial U_2}{\partial X_2}=0 \Rightarrow X_2=Y_2 \alpha \tag{5}
$$

To determine the market equilibrium condition, inserting (5) into (3) gives the price equation

$$
P_2=\frac{X_1}{X_2}=\frac{Y_1(1-\alpha)}{Y_2 \alpha} \tag{6}
$$

The price P_2 of good 2 in terms of good 1 is determined endogenously on a supply-demand basis. When agent 1 acquires more resources (R_1 increases), he produces more (Y_1 increases), exports more (X_1 increases), and the price $P_2 = X_1/X_2$ increases. Conversely, when the relative preference parameter α for good 1 increases so that both agents attach higher utility to good 1 than to good 2, the demand for good 1 increases, causing a lower price P_2 of the less valuable good 2 in terms of the more valuable good 1.

Inserting (5) into (3) gives the utilities

$$
U_1=Y_1^{\alpha} Y_2^{1-\alpha} \alpha, \quad U_2=Y_1^{\alpha} Y_2^{1-\alpha}(1-\alpha) \tag{7}
$$

Essential for the utilities is the agents' preference α for goods. Agent 1 does better if good 1 is more preferred, and conversely if good 2 is preferred.

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Notes

1 See Calow (1998), Fischoff et al. (1981), and Jones-Lee (1989) for economic approaches to safety. Much literature focuses on public safety. See Feber et al. (2003) for the economic effects of road safety improvements, Swinbank (1993) for the economics of food safety, Thomas (1999) for economic and safety pressures on nuclear power, Rose (1990) for economic determinants of airline safety, Oi (1974, 1995) for the economics of product safety, Kotz and Schafer (1993) for economic incentives to accident prevention.