

## **Induced Innovation: Evidence from China's Secondary Industry**

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### **Abstract**

We investigate the effect of rising labor costs on induced technological change in China's secondary industry. Building on insights developed in a rich literature, we propose a model linking changes in labor productivity to changes in labor costs and the predetermined availability of physical capital. Importantly, we derive testable hypotheses to distinguish induced innovation from standard substitution of capital for labor under fixed technology. Our empirical results support the hypothesis that rising wages have induced labor-saving innovation in China, at least in the decade of the 1990s, but less so or not at all after the middle of the next decade.

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## Technical Appendix

### Setup:

- A representative firm produces the final good using two factors of production, labor and capital. The price of the final good is normalized to one.
- Technologies are created and supplied by a profit-maximizing monopolist.
- In Acemoglu's (2010) M economy, the supplies of the productive factors are assumed to be given. We adopt a similar setup, except that the wage ( $W$ ) instead of the labor supply is given. The goal is to examine how rising wages affect the advancement of induced technological changes. The supply of  $K$  is fixed at  $\bar{K}$  in the short run.

### Final-Good Producer

The objective function of the final-good producer:

$$\max_{K,L,q(\theta)} \alpha^{-\alpha}(1-\alpha)^{-1}(K^\theta(AL)^{1-\theta})^\alpha q(\theta)^{1-\alpha} - W \cdot L - R \cdot K - \chi q(\theta)$$

$\theta$ : technology

$q(\theta)$ : quantity of an intermediate good embodying technology  $\theta$

$\chi$ : price of the intermediate good

$A$ : labor augmenting technology

$\alpha^{-\alpha}(1-\alpha)^{-1}$ : a convenient normalization used in Acemoglu (2010);  $\alpha \in (0,1)$ .

FOCs:

$$[L]: W = \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)(K^\theta(AL)^{1-\theta})^{\alpha-1} K^\theta A^{1-\theta} L^{-\theta} q(\theta)^{1-\alpha}$$

$$[K]: R = \alpha^{1-\alpha}(1-\alpha)^{-1}\theta(K^\theta(AL)^{1-\theta})^{\alpha-1} K^{\theta-1}(AL)^{1-\theta} q(\theta)^{1-\alpha}$$

$$[q(\theta)]: \alpha^{-\alpha}(1-\alpha)^{-1}(1-\alpha)(K^\theta(AL)^{1-\theta})^\alpha q(\theta)^{-\alpha} = \chi$$

$$\Rightarrow q(\theta) = \alpha^{-1}\chi^{-1/\alpha}(K^\theta(AL)^{1-\theta})$$

$$W = \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)(K^\theta(AL)^{1-\theta})^{\alpha-1} K^\theta A^{1-\theta} L^{-\theta} q(\theta)^{1-\alpha}$$

$$\begin{aligned}
&= \alpha^{1-\alpha}(1-\alpha)^{-1}(1-\theta)(K^\theta(AL)^{1-\theta})^{\alpha-1}K^\theta A^{1-\theta}L^{-\theta}[\alpha^{-1}\chi^{-1/\alpha}(K^\theta(AL)^{1-\theta})]^{1-\alpha} \\
&= (1-\alpha)^{-1}(1-\theta)K^\theta A^{1-\theta}L^{-\theta}\chi^{(\alpha-1)/\alpha}
\end{aligned}$$

$$\Leftrightarrow L = KA^{\frac{1-\theta}{\theta}} \left( \frac{1-\theta}{1-\alpha} \frac{1}{W} \right)^{\frac{1}{\theta}} \chi^{\frac{\alpha-1}{\alpha\theta}}$$

At the equilibrium,  $K = \bar{K}$ . Then  $L = \bar{K}A^{\frac{1-\theta}{\theta}} \left( \frac{1-\theta}{1-\alpha} \frac{1}{W} \right)^{\frac{1}{\theta}} \chi^{\frac{\alpha-1}{\alpha\theta}}$ , and  $q(\theta) =$

$$\alpha^{-1}\bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{\frac{1-\theta}{\theta}} \chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}}.$$

### The Profit-Maximizing Monopolist

Assumptions:

(1) A technology  $\theta$  is created at a cost  $C(\theta)$ .

$$\theta = \frac{1}{1+e^\phi} \rightarrow \phi = \ln\left(\frac{1}{\theta} - 1\right)$$

$$\text{Assume } C(\theta) = \left[ \ln\left(\frac{1}{\theta} - 1\right) \right]^2.$$

(2) Once the technology  $\theta$  is created, the unit production cost is assumed to be  $\frac{1-\alpha}{1-\alpha+\alpha\theta}$  units of the final good. Since the price of the final good is normalized to 1, the unit production cost of the intermediate good is  $\frac{1-\alpha}{1-\alpha+\alpha\theta}$ .

$$\max_{\chi, \theta} \left( \chi - \frac{1-\alpha}{1-\alpha+\alpha\theta} \right) \cdot \alpha^{-1}\bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{\frac{1-\theta}{\theta}} \chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}} - C(\theta)$$

$$[\chi]: \chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}} + \left( \chi - \frac{1-\alpha}{1-\alpha+\alpha\theta} \right) \frac{\alpha-1-\alpha\theta}{\alpha\theta} \chi^{\frac{\alpha-1-\alpha\theta}{\alpha\theta}-1} = 0$$

$$\Leftrightarrow \chi = 1$$

Given  $\chi = 1$ , The problem of the monopolist can be simplified as follows:

$$\max_{\theta} \frac{\theta}{1-\alpha+\alpha\theta} \cdot \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{\frac{1-\theta}{\theta}} - \left[ \ln\left(\frac{1}{\theta} - 1\right) \right]^2$$

$$\text{FOC: } \frac{1}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{(1-\theta)/\theta} \left( \frac{-\alpha\theta}{1-\alpha+\alpha\theta} - \frac{1}{\theta} \ln\left(\frac{1-\theta}{1-\alpha} \frac{A}{W}\right) \right) = 2\ln\left(\frac{1}{\theta} - 1\right) \frac{1}{\theta^2-\theta}$$

For the existence of  $\theta^*$ , we require  $(1-\alpha)\frac{W}{A}$  to be greater than 1:

$$\lim_{\theta \rightarrow 0} \frac{\theta}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{\frac{1-\theta}{\theta}} = 0 < \lim_{\theta \rightarrow 0} \left[ \ln \left( \frac{1}{\theta} - 1 \right) \right]^2$$

$$\lim_{\theta \rightarrow 1} \frac{\theta}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{(1-\theta)/\theta} = \bar{K} < \lim_{\theta \rightarrow 1} \left[ \ln \left( \frac{1}{\theta} - 1 \right) \right]^2$$

It is easy to show that the LHS of the FOC is positive given  $(1-\alpha)\frac{W}{A} > 1$  and its RHS is positive only when  $\theta > 0.5$ , so  $\theta^*$  must be between 0.5 and 1.

The objective function of the monopolist has strictly increasing differences in  $(W, \theta)$  if and only

$$\text{if } \frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{(1-\theta)/\theta}}{\partial W \partial \theta} > 0.$$

$$\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{(1-\theta)/\theta}}{\partial W \partial \theta} = \frac{1}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{W} \right)^{1/\theta} \left( \frac{A}{1-\alpha} \right)^{(1-\theta)/\theta} \frac{1}{\theta^2} \left[ \frac{\alpha\theta^2}{1-\alpha+\alpha\theta} + \ln \left( \frac{1}{1-\alpha} \right) + \ln \left( \frac{(1-\theta)A}{W} \right) + \frac{\theta}{1-\theta} \right]$$

$$\frac{\partial^2 \frac{\theta}{1-\alpha+\alpha\theta} \bar{K} \left( \frac{1-\theta}{1-\alpha} \frac{A}{W} \right)^{(1-\theta)/\theta}}{\partial W \partial \theta} > 0 \text{ requires that } W < \frac{1-\theta}{1-\alpha} A e^{\frac{\alpha\theta^2}{1-\alpha+\alpha\theta} + \frac{\theta}{1-\theta}}. \text{ It is easy to show that}$$

$$\frac{1-\theta}{1-\alpha} A e^{\frac{\alpha\theta^2}{1-\alpha+\alpha\theta} + \frac{\theta}{1-\theta}} \text{ is strictly increasing in } \theta. \text{ Then, we define } W_{max} \text{ as } \frac{1-0.5}{1-\alpha} A e^{\frac{\alpha \times 0.5^2}{1-\alpha+\alpha \times 0.5} + \frac{0.5}{1-0.5}},$$

which should be larger than  $\frac{A}{1-\alpha}$ . Please note that  $W < W_{max}$  is only a sufficient condition to ensure the objective function of the monopolist has strictly increasing differences in  $(W, \theta)$ .

Given that (a) the objective function is continuously differentiable in  $\theta$ , (b)  $\frac{A}{1-\alpha} < W < W_{max}$

(which ensures that the existence of the solution and the objective function of the monopolist has strictly increasing differences in  $(W, \theta)$ ), and (c) the solution is strictly between 0.5 and 1,

Topkis's theorem implies that  $\frac{\partial \theta^*}{\partial W} > 0$ . In other words, an increase in  $W$  can encourage technological advancement, which we define as a wage-induced technical change.

### Output (Y) Per Worker

$$\frac{Y}{L} = \frac{\alpha^{-\alpha} (1-\alpha)^{-1} (\bar{K}^\theta (AL)^{1-\theta})^\alpha \left( \alpha^{-1} (\bar{K}^\theta (AL)^{1-\theta}) \right)^{1-\alpha}}{L}$$

$$= \alpha^{-1} (1-\alpha)^{-1} \left( \frac{\bar{K}}{L} \right)^\theta A^{1-\theta}$$

$$= \alpha^{-1} (1-\alpha)^{-1} \frac{W(1-\alpha)}{1-\theta}$$

$$= \frac{W}{\alpha(1 - \theta)}$$

If  $\theta$  is fixed, output per worker increases with  $W$ . An wage-induced technical change ( $W \uparrow \Rightarrow \theta \uparrow$ ) will further increase the output per worker.

#### Summary of the Model

- (i) Given  $\bar{K}$ ,  $\theta^*$  increases with  $W$ : an increase in  $W$  will encourage technological advancement, which we define as a wage-induced technical change.
- (ii) Under fixed technology, the output per worker will increase with  $W$  (holding  $\bar{K}$  fixed). Wage-induced technical change will increase output per worker more than what would be expected on the basis of a pure substitution of capital for labor under fixed technology.