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Neutrality of an increase in the price of natural resources to the level of technology☆

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ABSTRACT

In this paper, to investigate how an increase in the price of natural resources affects the level of technology, we develop an endogenous variety expansion model of a small open economy based on that of Grossman and Helpman (1991, Ch. 3). We conclude that an increase in the price of natural resources has a neutral effect on the level of technology in the long run.

1. Introduction

In developed countries, the production of energy depends mainly on fossil fuel. Data from the International Energy Agency reveal that, in 2009, 37% of US output was dependent on petroleum oil and 84% was dependent on fossil fuel; corresponding figures for Japan are 43% and 81%, respectively. Because oil reserves are scarce, almost all developed countries import fossil fuel. In 2009, the US imported about 45% of its oil, and Japan imported 99.6%. The price of oil has risen dramatically. Up until the 1970s, the price of oil was stable at between $10 and $20 per barrel (in 2007 US dollars). The price of oil rose dramatically during the 1973 oil price shock, but by 2000–2004, it had stabilized at around $30 per barrel. The price of oil per barrel rose sharply again in July 2008 to $145, but by 2012, it had fallen to around $95.

An increase in the price of oil influences not only the economies of countries that import crude oil, but also manufacturing firms. For example, Toyota, a leading Japanese automobile company, recently improved the fuel economy of the Prius, its full hybrid car. Whereas the second generation Prius—produced between 2004 and 2009—covered 29.6 km per liter, the third generation Prius—introduced in 2011—covers 32.6 km per liter.[1] Hence, rising oil prices induce firms to invent energy-saving goods. Recently, R&D investment has increased dramatically in OECD countries. The ratio of industrial R&D expenditure to GDP in the US rose from 2.60% in 2000 to 2.79% in 2008.

In this paper, we investigate how an increase in the price of natural resources affects the levels of R&D investment and technology. We develop an endogenous variety expansion model of a small open economy based on that of Grossman and Helpman (1991, Ch. 3). In our model, firms use an intermediate good and a natural resource to produce final goods. An innovator invents a new variety of intermediate good. When the price of the natural resource increases, firms will substitute the natural resource for the intermediate good, and then demand for the intermediate goods increases. This increases the incentive for firms to undertake R&D investment. In the short run, an increase in the price of the natural resource raises the level of R&D investment. However, in the long run, an increase in the price of the natural resource lowers expenditure and this reduces the demand for final goods. The level of R&D investment then declines. We show that these two effects cancel each other out in the long run. Therefore, in the long run, an increase in the price of the natural resource does not affect the level of technology. However, the increase in the price of the natural resource lowers the steady-state level of consumption.[2]

2. The model

We develop a dynamic general equilibrium model based on Grossman and Helpman (1991, Ch. 3). In this model, there are final

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[1] Fuel cost is measured by using the “JC08”method established in 2006 under new Japanese standards. For details, see http://toyota.jp/prius/.

[2] Many researchers investigate the relationship between the price of natural resources and economic growth. For instance, Peretto (2009) finds that an optimal tax rate on energy use exists that maximizes the welfare. In the short run, a tax on energy use then generates the temporary acceleration of total factor productivity growth.

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goods, intermediate goods, and a natural resource. Individuals consume only the final goods. Each individual lives forever and is endowed with one unit of labor services, which is inelastically supplied at each point of time. The population size in this economy is constant over time and normalized to unity. To produce the final goods, firms use the intermediate goods and the natural resource. This economy is a small open country that trades final goods and the natural resource at an exogenously given world price. We suppose that the final goods and the natural resource are tradable. In contrast, we assume that the intermediate goods are not tradable.

2.1. Production

Production of the final goods requires variety-specific intermediate goods and the natural resource. The production function is given by:

$$Y_t = \left[\gamma D_t^{\sigma} + (1-\gamma)G_t^{\sigma}\right]^{\frac{1}{\sigma}}, \tag{1}$$

where Y_t denotes the output of final goods at time t, G_t is the natural resource input at time t, and D_t denotes the composite input of the intermediate goods at time t. σ and γ are parameters. The composite of the intermediate goods is given by:

$$D_t \equiv \left(\int_0^{n_t} x_{it}{}^{\alpha} di\right)^{\frac{1}{\alpha}}, \tag{2}$$

where x_{it} denotes the intermediate goods produced by firm i at time t and n_t denotes the level of technology at time t. α is the elasticity of substitution between any two varieties in a given sector. If α is close to one, the goods are nearly perfect substitutes. The final goods firms sell their output to their own country and abroad. The final goods is chosen to be the numeraire and the price index of the composite intermediate goods is as follows:

$$P_{Dt} \equiv \left(\int_0^{n} p_{it}{}^{\frac{\alpha}{\alpha-1}} dj\right)^{\frac{\alpha-1}{\alpha}}, \tag{3}$$

where p_{it} denotes the price of the intermediate goods produced by firm i at time t. We then obtain the profit-maximization conditions as follows:

$$P_{Dt} = \gamma^{\frac{1}{\sigma}}\left[1-(1-\gamma)^{-\frac{1}{\sigma-1}} P_g^{\frac{\sigma}{\sigma-1}}\right]^{\frac{\sigma-1}{\sigma}}, \tag{4}$$

$$D_t = \left(\frac{P_{Dt}}{\gamma}\right)^{\frac{1}{\sigma-1}} Y_t, \tag{5}$$

$$G_t = \left(\frac{P_g}{1-\gamma}\right)^{\frac{1}{\sigma-1}} Y_t, \tag{6}$$

$$x_{it} = \left(\frac{P_{Dt}}{p_{it}}\right)^{\frac{1}{1-\alpha}} D_t, \tag{7}$$

where P_g denotes the world price of the natural resource and P_g is given.

The intermediate goods firms buy a patent from the R&D sector and sell the intermediate goods exclusively to the final goods firm. The production of one unit of each intermediate good requires one unit of labor. Therefore, we can write the profit of the intermediate goods firm i as follows:

$$\pi_{it} = p_{it}x_{it} - w_t x_{it}, \tag{8}$$

where π_{it} denotes the profit of the intermediate goods firm i at time t and w_t denotes the wage rate of labor at time t. The monopoly price and the profit level are then:

$$p_{it} = \frac{w_t}{\alpha}, \tag{9}$$

$$\pi_{it} = (1-\alpha)\alpha^{\frac{-\sigma}{\sigma-1}}\gamma^{\frac{-1}{\sigma-1}} w_t^{\frac{\sigma}{\sigma-1}} n_t^{\frac{\alpha-\sigma}{\alpha(\sigma-1)}} Y_t \equiv \pi_t. \tag{10}$$

Consequently, we obtain the total output of intermediate goods and the price index of intermediate goods P_{Dt} as follows:

$$\chi_t \equiv n_t x_{it} = \left(\frac{w_t}{\alpha\gamma}\right)^{\frac{1}{\sigma-1}} n_t^{\frac{\sigma(\alpha-1)}{\alpha(\sigma-1)}} Y_t, \tag{11}$$

$$P_{Dt} = \frac{w_t}{\alpha} n_t^{\frac{\alpha-1}{\alpha}}, \tag{12}$$

where χ_t denotes the total output of intermediate goods at time t.

2.2. R&D sector

The R&D activities of the present model follow Grossman and Helpman (1991, Ch. 3). The intermediate goods producers enter into the R&D race and finance the cost of R&D by issuing equity in the stock market. The equity is bought by individuals. The stock value of the intermediate goods producers at time t is equal to the present discounted sum of its profit stream subsequent to t. Then, the stock value of the intermediate goods producers at time t is given by:

$$v_t = \int_t^{\infty} e^{-\int_t^s r_v dv} \pi_s ds, \tag{13}$$

where r_v denotes the interest rate on a riskless loan at time s. Differentiating Eq. (13) with respect to time t yields the following no-arbitrage condition:

$$\dot{v}_t = -\pi_t + r_t v_t. \tag{14}$$

The intermediate goods producers hire labor to develop blueprints. In this model, an increase in the number of intermediate goods implies an increase in the efficiency of the natural resource. We assume that L_{at} units of labor for R&D activity over a time interval dt produce a new variety of intermediate goods according to:

$$dn_t = \frac{L_{at}}{a} dt, \tag{15}$$

where a^{-1} denotes the productivity of R&D. The cost of R&D activities is $w_t L_{at} dt$. The blueprints create value for the intermediate goods producers of $v_t dn_t$ as each blueprint has a market value of v_t. We assume that there is free entry into the R&D race. Therefore, the following free-entry condition must hold:

$$v_t \le a w_t \quad \text{with equality whenever } \dot{n} \equiv \frac{dn_t}{dt} > 0. \tag{16}$$

2.3. Consumers

A representative agent has the following preference:

$$U_0 = \int_0^{\infty} e^{-\rho t} \log c_t dt, \tag{17}$$

where c_t stands for the consumption of the final goods at time t and $\rho > 0$ is the constant subjective discount rate. The budget constraint is represented by

$$\int_0^{\infty} E_t e^{-\int_0^t r_s ds} dt = a_0 + \int_0^{\infty} w_t e^{-\int_0^t r_s ds} dt, \tag{18}$$

where E_t denotes expenditure at time t, and $a_0 \equiv n_0 v_0$ denotes the economy's aggregate equity value at time 0. Then, from the first-order conditions of the maximization problem, we obtain the following