Working Papers in Economics

Further Results on "An Endogenous Growth Model with Embodied Energy-Saving Technical Change"

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Working Paper no: 07 / 01

October 2007

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Working Paper #07/01

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Abstract:
In this short paper we add a non-renewable resource sector to van Zon and Yetkiner (2003) that extended Romer (1990) by including energy consumption of intermediate goods in a context of endogenous and embodied technical change. Van Zon and Yetkiner (2003) showed that the growth rate depends negatively on the growth of exogenous real energy prices. In this paper, we endogenise the growth rate of real energy prices by introducing a non-renewable resource sector into the model. This allows us to study the comparative statics of the model. We show that changes in technology parameters promote growth, while others disfavour growth.

JEL Classification: O31; O41; Q43

Keywords: Endogenous growth; energy-saving technological change; Hotelling's rule

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1. Introduction

Van Zon and Yetkiner (2003), further called VZY for short, introduced energy use in the production of intermediate goods in the Romer (1990) model. VZY assumed that energy and raw capital are the factors of production that are used to produce intermediate goods. VZY also assumed that energy and raw capital become more efficient in time due to basic R&D. Hence, the intermediate sector produces intermediates that are heterogeneous on two accounts. While the 'normal' love-of-variety heterogeneity found in Romer (1990) is still present, VZY also allow for heterogeneity in terms of (embodied) unit production costs, as the latest intermediates are the most productive. VZY focused on technology and growth, and assumed that energy supply at any moment in time was available in any quantity at real energy prices that were growing at a given exogenous rate. In a closed economy with limited energy resources and where Hotelling's rule should apply, this is a *gross simplification* that this paper wants to cure. In their simplified set-up, VZY found that productivity growth at the aggregate level was the result of both love-of-variety and efficiency (quality) improvements. They further showed that (i) aggregate energy efficiency may be improved through stepping up basic research, (ii) increasing real energy prices lead to corresponding rises in the user costs of intermediates and hence to a fall in profits on those intermediates.

VZY can be considered to be incomplete in at least one respect: the model leaves the rate of growth of energy prices unexplained. This is a weakness on two accounts. First, the VZY paper fails to close the model, by leaving out an important feedback mechanism from scarcity to prices and then to endogenous technical reactions. Secondly, because of the exogeneity of real energy prices, the VZY model implicitly covers only the small country case, whereas a global perspective requires a 'big country view' where prices are determined through the interaction between supply and demand. In this short paper, we take a global perspective by explicitly introducing a non-renewable resource sector. In particular, we use Hotelling's rule in its simplest form to link the rate of growth of real energy prices to the real rate of interest. This closes the model in the sense that all variables can now be expressed in terms of the system parameters. This "finishing touch" permits us to disclose the exact effects of parameter changes on the variables. In section 2 we present the extended VZY model and the resulting comparative statics. We show that changes in technology parameters promote growth, while others disfavour growth. Section 3 provides some concluding remarks.

2. The Extended VZY Model

van Zon and Yetkiner (2003) use an Ethier (1982) production function for final output Y that is linear homogeneous in (skilled) labour and effective capital services:

$$Y = L_Y^{1-\alpha} \int_0^A (x_i^e)^\alpha di \tag{1}$$

where L_Y is labour input used in final-output production. x_i^e are the effective capital services obtained from using the i^{th} type of intermediate good, $1-\alpha$ is the partial output elasticity of labour, and A denotes the (real) number of blueprints invented up to the present time. The distinguishing feature of VZY is their introduction of energy into the intermediate good production in Romer (1990):

$$x_i^e = \lambda_i (x_i)^{\beta} (e_i)^{1-\beta} \tag{2}$$

Equation (2) assumes that effective capital services x_i^e produced by the *i-th* intermediate are a Cobb-Douglas aggregate of raw capital x_i and energy e_i, where β measures the partial elasticity of effective capital services with respect to raw capital services. λ_i is the 'total-factor' productivity of raw capital and energy, and it takes the form of Hicks-neutral technical change in the production of effective capital services. VZY assume that λ_i can only change over time for $i = A$, i.e., for the latest intermediate. They show that this assumption, together with the requirement that the model should be able to generate positive steady state growth, implies that $\lambda_A = \lambda_0 A^{\varsigma}$, where λ_0 is the 'total factor productivity' of the first intermediate and ς implicitly measures the quality improvements embodied in the latest intermediate.

As in Romer, the R&D production function is given by:

$$\hat{A} = \delta (L - L_Y) \tag{3}$$

where δ represents the productivity of the R&D process, while $L_A = L - L_Y$ is the amount of R&D labour and *L* is the total labour force.

The demand-side is represented by a standard constant intertemporal elasticity of substitution utility function. This results in the following upward sloping relation between output (and consumption) growth and the real interest rate *r*:

$$\hat{C} = \hat{Y} = (r - \rho)/\theta \tag{4}$$

where $1/\theta$ is the intertemporal elasticity of substitution and ρ is the rate of pure time preference, and *C* is private consumption, and where we have assumed that the labour force *L* is constant over time.

Assuming that the growth rate of real energy prices is constant, VZY find the steady state growth rate of output to be given by:

$$\hat{Y} = \left(\frac{\alpha}{\alpha + \theta} \right) \left(\delta z L - \rho / \alpha - \hat{q}(1-\beta)(1+\alpha)/(1-\alpha) \right) \tag{5}$$

where $z = (1-\alpha+\varsigma\alpha)/(1-\alpha)$. Equation (5) shows that if real energy prices q would be constant (i.e., $\hat{q} = 0$), then the steady state growth rate of output would exceed the growth rate of the number of blueprints, as $\varsigma \geq 0$. This is because in the VZY-model growth does not only come from an increase in the number of intermediates, but also from the intrinsic productivity improvements embodied in the latest intermediates.

The corresponding equilibrium value of the real interest rate, obtained by combining (4) and (5), is given by:

$$r = \left(\frac{\alpha\theta}{\alpha+\theta}\right)\left(\delta z L - \hat{q}(1-\beta)(1+\alpha)/(1-\alpha) + \rho/\theta\right) \qquad (6)$$

By using (6), VZY obtain the corresponding equilibrium allocation of labour to final output production:[†]

$$L_Y = \frac{1}{\delta(1-\alpha)z(\alpha+\theta)}\left(\delta z(1-\alpha)\theta L + \rho(1-\alpha) + \hat{q}\alpha(1-\beta)(1-\theta)\right) \qquad (7)$$

It follows from combining (3) and (7) that the growth rate depends in an ambiguous way on the intertemporal elasticity of substitution. However, in a global (and therefore closed) economy, $\hat{q}$ itself would depend on θ, possibly in a way that removes the ambiguity. By extending the model with a non-renewable resource sector that provides the endogenous link between r and $\hat{q}$, we will show below that L_Y does indeed depend positively on θ, and so causes the growth rate to depend positively on the intertemporal elasticity of substitution.

The Non-renewable Resource Sector

In a classic article, Hotelling (1931) introduced the notion of "the social value of" an exhaustible resource to determine the desirability of any extraction pattern. Hotelling (1931)

[†] The labour market arbitrage condition is $L_y = r/\alpha\delta z + ((1-\beta)\hat{q})/((1-\alpha)\delta z)$. It shows that continuously rising real energy prices will change the allocation of labour in favour of final output generation, ceteris paribus.

also showed that pure competition could yield an extraction path identical to the socially optimal one.

Hotelling's optimal extraction path can be represented in a somewhat condensed way using the Hotelling's rule, which states that along the optimum resource extraction path, the real price of the extracted resource should grow at a proportional rate equal to the real rate of interest. In the context of the VZY-model, this gives rise to:

$$\dot{q}/q = r \,. \tag{8}$$

Equation (8) is the well-known Hotelling's non-arbitrage condition saying that the non-renewable is essentially an asset and therefore its real price must grow at the real interest rate. The use of this finding in equations (3) and (5)-(7) allows one to obtain the full general equilibrium solution of the VZY-model.

Comparative Statics

In Table 1 below we present comparative statics results of the model.[‡]

Table is about here

[‡] All derivations are available from the authors on request.

Table 1 shows that an increase in β would lower the growth rate of output (and hence that of the physical capital stock and of consumption). An increase in β represents an increase in the weight of the reproducible factor of material production. This positively influences the amount of labour allocated to final good production and reduces the amount of human capital allocated to R&D. As a result, the growth rate of output (and capital) falls, while the long-run equilibrium interest rate rises due to the increase in the marginal product of capital following the rise in L_Y.

Table 1 demonstrates that an exogenous increase in θ has unambiguously negative effects on the growth rate of output. Recall that the higher θ is, the lower is the willingness of households to deviate from a uniform pattern of consumption over time. On the one hand, such a desire forces households to increase the share of labour allocated to final output production in the initial periods, which increases current levels of production (and hence also current consumption and investment) possibilities. On the other hand, such an increase in L_Y also implies a fall in L_A, which lowers the growth rate of knowledge accumulation and hence reduces future levels of production (and again of future consumption and investment possibilities).

Table 1 shows that an exogenous increase in the subjective rate of discount ρ works very much like θ in the model. This is due to the fact that a positive change in both parameters implies a smoother consumption, which forces the model economy to raise consumption and hence necessarily output in the beginning by increasing L_Y. The latter has negative effects on the long run growth rate for the same reasons that we discussed above.

An increase in ς leads to a rise in the total factor productivity of effective capital services. Such a rise accelerates output growth, as expected, but it also raises the "productivity return" to R&D and so L_Y falls while L_A rises. Consequently the rate of knowledge accumulation rises, which generates further output growth. The rise in productivity further enables a rise in the steady state value of the real rate of interest.

Table 1 also shows that an exogenous increase in R&D productivity δ speeds up the rate of knowledge accumulation and hence the rate of output growth. Note that the effects of ς and δ are identical in sign. This is not surprising, as both parameters are intimately and positively linked to the role played by technology in output growth. Finally, the marginal benefits of using human capital for R&D purposes are positively affected, and so L_A rises while L_Y falls.

3. Concluding Remarks

In this short paper, we closed VZY-model through Hotelling's rule, which establishes how real energy prices would grow in a limited non-renewable resource setting. We showed that once-and-for-all changes in the "non-technology parameters" β, θ, ρ rather lower the rate of growth of output, while once-and-for-all rises in the "technology parameters" ς, δ enhance growth. This underlines the importance of technology in energy conversion. Furthermore, the "old" VZY result that rising real energy prices *do not* invoke increased energy saving R&D

activity still stands. This in turn stresses the importance of active government policies aimed at mitigating the negative growth effects of rising real energy prices.

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Table 1. Comparative statics

	β	θ	ρ	ς	δ
$\hat{Y}$	-	-	-	+	+
$\hat{A}$	-[b]	-	-	+	+
r	+	+	+	+	+
L_Y	+[a]	+	+	-	-
L_A	+[b]	-	-	+	+

a: only if $\theta > 1$; ***b***: only if *a* does hold.