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A NOTE ON OIL DEPENDENCE AND ECONOMIC INSTABILITY

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We show that dependence on foreign energy can increase economic instability by raising the likelihood of equilibrium indeterminacy, hence making it easier for fluctuations driven by self-fulfilling expectations to occur. This is demonstrated in a standard neoclassical growth model. Calibration exercises, based on the estimated share of imported energy in production for several countries, show that the degree of reliance on foreign energy for many countries can easily make an otherwise determinate and stable economy indeterminate and unstable.

Keywords: Indeterminacy, Energy Imports, Externalities, Returns to Scale, Sunspots, Self-Fulfilling Expectations

1. INTRODUCTION

Sharp increases in the price of oil have triggered two significant worldwide recessions since World War II: one in 1974–1975 and another in 1979–1981. The underlying reason is that many industrial economies depend heavily on imported energy in production, making them vulnerable to changes in the price of oil in the world market. Although it is well known that increases in the price of foreign energy can act like adverse productivity shocks to a domestic economy, many economists also argue that energy price shocks by themselves are not sufficient to causing a massive recession as large as experienced in the 1970s and the early 1980s. For example, Bernanke et al. (1997), Barsky and Killian (2001), and Leduc and Sill (2004) argue that monetary policies significantly aggravated the negative impact of oil shocks; and Hamilton (2003) argues that a sharp decrease of aggregate

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TABLE 1. Cost share of imported energy in GDP

Country	Cost share	Country	Cost share
Lithuania	16.0%	Luxembourg	3.6%
Ukraine	15.7%	Austria	3.4%
Slovakia	12.1%	Portugal	3.5%
Latvia	8.3%	Greece	3.2%
Belgium	7.7%	Finland	2.9%
South Korea	7.6%	Sweden	2.8%
Netherlands	5.8%	Spain	2.8%
Estonia	5.5%	Germany	2.4%
Hungary	5.4%	France	2.3%
Czech Republic	5.2%	Italy	2.0%
Malta	4.9%	United States	1.8%
Cyprus	4.5%	Ireland	1.8%
Slovenia	4.0%	United Kingdom	1.4%
Poland	3.9%	Denmark	1.3%

demand due to pessimistic expectations for the future at the time of oil shocks exacerbated the negative impact of higher energy prices.

This paper claims that reliance on foreign energy has another potentially important effect on economic activity—it destabilizes the economy by increasing its likelihood of indeterminacy, hence making the economy more susceptible to fluctuations driven by self-fulfilling expectations. Economic data show that energy imports account for a significant fraction of total costs in domestic production for industrial countries. For example, Table 1 shows that the cost share of imported energy can be as high as 16% of a country's GDP.[1] We argue that cost share of foreign energy as high as indicated in Table 1 can easily make an otherwise stable economy susceptible to sunspots-driven fluctuations.

The framework we adopt to make our point is that of Aguiar-Conraria and Wen (2007), which introduced oil into an indeterminate RBC model similar to those of Benhabib and Farmer (1994) and Wen (1998). In that paper, we showed that the large negative impact of oil price shocks on GDP and investment in the 1970s can be better understood by a multiplier–accelerator mechanism based on indeterminacy. However, we did not formally and systematically investigate the relationship between the magnitude of foreign energy share in GDP and the conditions of indeterminacy.

In this note we formally prove that the dependence of production on imported energy (such as oil and natural gas) can make it easier for indeterminacy to arise. For example, the required returns to scale for indeterminacy in the model of Wen (1998) can be reduced by 50% when the share of imported energy reaches 15% of GDP. Based on realistic and conservative estimates of the aggregate returns to scale, a cost share even as low as 5% of GDP can subject an otherwise stable economy to sunspots-driven fluctuations.

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2. THE MODEL

A representative agent chooses a trajectory for consumption (c), hours (n), capacity utilization (u), energy demand (e), and capital accumulation ($\dot{k}$) to solve

$$\max \int_0^\infty \exp(-\rho t)\left[\log(c_t) - n_t^{1+\gamma}/(1+\gamma)\right] dt \tag{1}$$

subject to

$$\dot{k} = -\delta k + y(uk, n, e) - c - pe, \tag{2}$$

where p denotes the international energy price, which is exogenous to the economy. The agent pays the amount pe in terms of output to foreigners to receive energy imports. Note that trade is balanced in every period because the cost of energy imports is fully paid for with exports of output. Hence, national income is given by $y - pe$, which equals domestic consumption and capital investment ($\dot{k} + \delta k$).

The production technology is given by

$$y(uk, n, e) = \Phi(uk)^{\alpha_k} n^{\alpha_n} e^{\alpha_e}, \tag{3}$$

where $\alpha_k + \alpha_n + \alpha_e = 1$ and Φ is a measure of production externalities and is defined as a function of average aggregate output, which individual firms take as parametric:

$$\Phi = [(uk)^{\alpha_k} n^{\alpha_n} (e)^{\alpha_e}]^{\eta}, \quad \eta \geq 0. \tag{4}$$

The rate of capital depreciation, δ, is time-varying and is endogenously determined in the model by the relationship

$$\delta = \frac{1}{\theta} u^{\theta}, \tag{5}$$

which states that capital depreciates faster if used more intensively. We require that $\theta > 1$, which imposes a convex cost structure on capital utilization.

To see the effects of foreign energy on the economy, we can substitute out Φ and the optimal demand for e in the production function to obtain the reduced-form production function in equilibrium

$$y = A(uk)^{\frac{(1+\eta)\alpha_k}{1-(1+\eta)\alpha_e}} n^{\frac{(1+\eta)\alpha_n}{1-(1+\eta)\alpha_e}}, \tag{6}$$

where $A = (\frac{\alpha_e}{p})^{(1+\eta)\alpha_e/[1-(1+\eta)\alpha_e]}$ is a Solow residual, which is inversely related to the energy price.[2] In this reduced-form production function, the effective returns to scale are measured by

$$\frac{(1+\eta)\alpha_k}{1-(1+\eta)\alpha_e} + \frac{(1+\eta)\alpha_n}{1-(1+\eta)\alpha_e}, \tag{7}$$

which increases with α_e under the constraint $(\alpha_k + \alpha_n + \alpha_e) = 1$, provided that $\eta > 0$. Hence, the reliance on imported energy amplifies the true returns to scale

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TABLE 2. The effect of factor shares on indeterminacy

Energy imports share (α_o)	Required externality	Reduction of η^*
0.00	0.094	0
0.04	0.083	14%
0.08	0.067	28%
0.12	0.054	42%
0.16	0.042	56%

when there are externalities. The following proposition shows formally that it is easier for indeterminacy to arise when α_e increases.

PROPOSITION 1. *The necessary and sufficient conditions for indeterminacy are given by*

$$\frac{\alpha_n}{(1-\alpha_n)} > \eta > \frac{\theta[(1+\gamma)(1-\alpha_e)-\alpha_n]-(1+\gamma)\alpha_k}{\theta\alpha_n+(1+\gamma)(\alpha_k+\alpha_e\theta)}. \tag{8}$$

Proof. See the Appendix. ■

It is clear from condition (8) that an increase in α_e, either holding α_n constant or holding $(\alpha_e+\alpha_n)$ constant, will decrease the term on the right-hand side, making it easier for indeterminacy to arise. Note that for realistic parameter values the inequality on the left-hand side does not bind.

We calibrate the model's structural parameters following Aguiar-Conraria and Wen (2007). Namely, we equate one unit of time to a quarter, and we set the inverse labor supply elasticity $\gamma = 0$ (Hansen's indivisible labor), the rate of time preference $\rho = 0.01$ (analogous to the discount factor of 0.99 in a discrete-time model), $\theta = 1.4$ (implying a steady-state rate of $\delta = 0.025$; see the Appendix), and the labor elasticity of output $\alpha_n = 0.7$.

Given these parameter values, Table 2 shows the relationship between the share of foreign energy in GDP and the threshold value of the production externality (η^*) for inducing indeterminacy.

We observe in Table 2 that as the share of foreign factors in domestic production increases, the threshold value of the production externality for inducing indeterminacy (η^*) decreases significantly. For example, when we increase the share parameter of imported energy α_e from 0 percent to 8 percent, the reduction in the externality is 28%. And if we increase the share parameter to 16 percent, then the reduction in the externality is 56%.[3]

If we compare the values of Table 1 with those of Table 2, we see that the required returns to scale for indeterminacy may vary between 1.04 and 1.10 in the presence of foreign energy imports. These values imply that many industrial countries are in the dangerous zone of indeterminacy. For example, Laitner and

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Stolyarov (2004) found that the estimated returns to scale were around 1.09–1.11 for the U.S. economy. Inklaar (2007) found that the estimated returns to scale were around 1.16 for Germany and 1.12 for France. Hansen and Knowles (1998) found that the average estimated returns to scale were around 1.105 for high-income OECD countries (including Australia, Belgium, Canada, Finland, France, West Germany, Japan, Norway, Sweden, the United Kingdom, and the United States). Miyagawa et al. (2006) found that estimated returns to scale in Japan were about 1.075, and Kwack and Sun (2005) found them to be around 1.1 for South Korea. With these numbers in mind, it is clear that dependence on imported energy can significantly increase a country's risk of indeterminacy, thereby making the country more susceptible to sunspots-driven fluctuations.

3. CONCLUSION

The impact of oil price shocks on economic fluctuations has been widely recognized. But the relationship between economic stability and reliance on foreign energy has not been fully investigated in the literature. This paper shows that dependence of domestic production on imported energy, such as oil or natural gas, can significantly increase the economy's instability in the presence of externalities or increasing returns to scale, because it reduces the required degree of returns to scale for indeterminacy. As a result, the economy is more susceptible to endogenous fluctuations driven by self-fulfilling expectations.

NOTES

1. The data for all EU-25 countries are taken from Eurostat (2006). The energy shares for the EU-15 countries are easy to estimate based on the database. But to estimate the energy share of the remaining 10 countries, the Czech Republic, Estónia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, and Slovakia, we assume that the unit import cost of oil or oil equivalent is the same as for the other EU-15 countries. The figure for Ukraine is from Davis et al. (2005). For the United States, we use data from the Energy Information Administration. Finally, information for South Korea was found in Rabobank (2006). All data refer to the year 2004, except for South Korea, which refers to 2005.

2. This negative relationship substantiates the claim that oil price shocks act like adverse productivity shocks.

3. Table 2 is computed under the assumption that the foreign import factor is mainly a substitute for capital; hence when α_e increases, α_n remains constant, but α_k decreases so that $\alpha_k + \alpha_e$ remains constant (assuming constant returns to scale at the firm level). If we assume imported energy is mainly a substitute for labor instead (i.e., $\alpha_n + \alpha_e$ is fixed), then a larger α_e has the same qualitative consequences, although they are less dramatic.

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APPENDIX

Let $\lambda \exp(-\rho t)$ be the Lagrangian multiplier for the household's budget constraint. The first-order conditions with respect to $\{c, n, e, u, k\}$ are given respectively by $\lambda = \frac{1}{c}$, $n^{\gamma} = \lambda \alpha_n \frac{y}{n}$, $p = \alpha_e \frac{y}{e}$, $u^{\theta-1}k = \alpha_k \frac{y}{u}$, and $\frac{\dot{\lambda}}{\lambda} = -\alpha_k \frac{y}{k} + \frac{1}{\theta}u^{\theta} + \rho$. To simplify the analysis, we utilize the reduced-form production function (which is obtained by substituting out the optimal demand for energy and the capacity utilization rate in the production function in equilibrium)

$$y = \tilde{A} k^{\frac{\alpha_k(1+\eta)(\theta-1)}{\theta-(1+\eta)(\alpha_k+\theta\alpha_e)}} n^{\frac{\alpha_n(1+\eta)\theta}{\theta-(1+\eta)(\alpha_k+\theta\alpha_e)}}, \tag{9}$$

where $\tilde{A} \equiv (\alpha_k)^{\frac{(1+\eta)\alpha_k}{\theta-(1+\eta)(\alpha_k+\theta\alpha_e)}} (\frac{\alpha_e}{p})^{\frac{\theta(1+\eta)\alpha_e}{\theta-(1+\eta)(\alpha_k+\theta\alpha_e)}}$.

The first-order conditions and the budget constraint can be simplified to the following system of equations: $\frac{\dot{c}}{c} = \frac{\theta-1}{\theta}\alpha_k \frac{y}{k} - \rho$, $\dot{k} = [\alpha_k(\frac{\theta-1}{\theta}) + \alpha_n]y - c$, and $c = \alpha_n \frac{y}{n^{1+\gamma}}$, where output is given by (9). In the steady state, we have $\frac{\bar{y}}{\bar{k}} = \frac{\rho}{\alpha_k}\frac{\theta}{\theta-1}$, $\frac{\bar{c}}{\bar{y}} = \alpha_k(\frac{\theta-1}{\theta}) + \alpha_n$, $\frac{\bar{c}}{\bar{k}} = \frac{\rho[(\theta-1)\alpha_k+\theta\alpha_n]}{(\theta-1)\alpha_k}$, and $\bar{n} = [\frac{\theta\alpha_n}{(\theta-1)\alpha_k+\theta\alpha_n}]^{1/(1+\gamma)}$. From the budget constraint and the Euler equation for consumption one can derive the steady state depreciation rate $\bar{\delta} = \frac{\rho}{\theta-1}$, which implies that $\theta = \rho/\bar{\delta} + 1$.

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Linearizing around the steady state, the dynamics of the model can be represented by a system of two linear differential equations,

$$\begin{bmatrix} \dot{c} \\ \dot{k} \end{bmatrix} = M \begin{bmatrix} c \\ k \end{bmatrix}, \tag{10}$$

where

$$M = \begin{bmatrix} \frac{\rho\alpha_n(1+\eta)\tau_n}{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)} & -\frac{\rho[(\theta-1)\alpha_k+\theta\alpha_n]}{(\theta-1)}\left\{\frac{(1+\eta)(1+\gamma)\tau_k\rho}{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)}+\frac{\rho}{\alpha_k}\right\} \\ \frac{\alpha_n(1+\eta)\tau_n}{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)}-1 & -\frac{(1+\eta)(1+\gamma)\tau_k\rho}{\{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)\}}\frac{[\alpha_k(\theta-1)+\theta\alpha_n]}{(\theta-1)} \end{bmatrix}.$$

The model exhibits local indeterminacy if and only if the eigenvalues of M are both negative. This is true if and only if the determinant of M is positive and the trace of M is negative. The determinant and trace of M are given, respectively, by

$$\det(M) = \left(-\alpha_n(1+\eta)\tau_n\tau_k + \left\{\tau_k + \frac{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)}{(1+\eta)(1+\gamma)\alpha_k}\right\} \times (1+\gamma)[1-\alpha_e(1+\eta)\tau_n]\right)\Omega,$$

$$\mathrm{Tr}(M) = \frac{(1+\eta)\rho[\alpha_n\theta-(1+\gamma)(\alpha_k(\theta-1)+\theta\alpha_n)]}{\{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)\}[\theta-\alpha_k(1+\eta)]},$$

where $\Omega = \frac{[\alpha_k(\theta-1)+\theta\alpha_n](1+\eta)(1+\gamma)}{(\theta-1)}\left(\frac{\rho}{\{[\alpha_n+\alpha_e(1+\gamma)](1+\eta)\tau_n-(1+\gamma)\}}\right)^2 > 0$.

The condition $\det(M) > 0$ implies that

$$\frac{(1-\alpha_e-\alpha_k)}{\alpha_e+\alpha_k} > \eta > \frac{\theta[(1+\gamma)(1-\alpha_e)-\alpha_n]-(1+\gamma)\alpha_k}{\theta\alpha_n+(1+\gamma)(\alpha_k+\alpha_e\theta)}. \tag{11}$$

Note that the numerator of $\mathrm{Tr}(M)$ is always negative, so the trace will be negative when the denominator is positive, which is equivalent to the condition

$$\eta > \frac{\theta[(1+\gamma)(1-\alpha_e)-\alpha_n]-(1+\gamma)\alpha_k}{\theta\alpha_n+(1+\gamma)(\alpha_k+\alpha_e\theta)}, \tag{12}$$

which is the same as the right-hand side of condition (11). ■

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