

Energy, the Stock Market, and the Putty-Clay Investment Model

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The energy crisis of 1973–1974 coincided with a dramatic decline in U.S. stock market capitalization. Real energy prices jumped by 80 percent from 1973 to 1974. At the same time, the market value of nonfarm, nonfinancial corporations plunged by 40 percent. Because the two events coincided, the energy price hike is often considered a potential explanation for the stock market decline. One of the leading advocates of a causal link, Martin Neal Baily (1981), holds that the jump in energy prices made a substantial fraction of the capital stock obsolete. Energy inefficient machines were shut down, and expected profits of machines in operation declined. The value of existing capital decreased because it was not technologically suited to new economic conditions. This link between rising energy prices and capital obsolescence may explain the low level of stock market prices during that period.

Despite the link, there has been no modern general-equilibrium evaluation of the extent to which the energy price shock was responsible for the dramatic drop in the market value of firms in 1974. I construct a dynamic general-equilibrium model with production and capital accumulation to examine the magnitude of the energy price effect. Contrary to the conventional wisdom, I find that an 80-percent increase in the real energy price causes the stock market

value to decline by only 2 percent. Labor compensation, not claims to the capital stock, bears the brunt of the energy cost increase.

The key element of the model is a putty-clay production technology. The neoclassical production function allows for smooth substitutability between factors after installation and conversion of capital to consumption goods at little cost. By contrast, the putty-clay production technology features *ex ante* substitutability of production factors, while there is no substitutability across them after machines are installed. Melvyn A. Fuss (1977) provides empirical evidence supporting the notion that capital and energy are complementary in the short run and substitutable in the long run. Because the technology is embodied in the capital stock in a putty-clay framework, changes in factor prices cause capital obsolescence and a decline in the value of capital. As a result, the putty-clay model is particularly suitable for studying the hypothesis put forward by Baily (1981).

This paper adapts the putty-clay model developed by Simon Gilchrist and John C. Williams (2000) to include energy as a factor of production. I take the production technology *ex ante* to be Cobb-Douglas with constant returns to scale, but for capital goods already installed, production possibilities take the Leontief form: there is no substitutability of capital, energy, and labor *ex post*. An energy price shock affects the market value of firms through three channels. The first channel is the endogenous depreciation of the old vintage machines from both decreases in capacity utilization and declines in expected profits; the second channel is the effect of the energy price shock on investment; and the third channel is the effect on the interest rate. The impact of the fundamental shocks on the securities market depends on the resulting movement of price variables, such as the wage and the interest rate. Only a full general-equilibrium model can sort out all the interactions.

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As a thought-experiment, I derive an upper bound on the impact of the energy price shock in a partial-equilibrium putty-clay model, where the real wage and interest rate are fixed exogenously. In such a setting, the magnitude of the energy price effect depends upon the ratio of the shares of production costs due to energy and capital. Since energy expenses make up only 4 percent of total production costs, an 80-percent permanent increase in the real energy price leads to a 10-percent decline in the market value of previously installed machines. The putty-clay structure, by capturing frictions in factor adjustment, allows the energy price shock to have a limited but noticeable impact on the securities market.

In a general-equilibrium putty-clay model, where the real wage and interest rate respond endogenously, the impact of the energy price shock turns out to be even smaller. An 80-percent increase in the real energy price causes the stock market value to decline by only 2 percent. This is because the energy price increase causes the real wage to decline by around 3.8 percent. The decline in the real wage is large enough to remove most of the increase in cost that depresses the value of capital in the partial-equilibrium calculation.

The reason for the real wage decrease is intuitive. In the putty-clay model, each machine has a fixed capital–energy ratio and energy–labor ratio and thus both the output and variable costs from running the machine are linear in labor. The firm weighs the variable costs from operating the machine against the output from it and chooses either to operate it at full capacity or to shut it down. The variable costs of running the machines are the labor costs and the energy costs. The rising energy price pushes up the variable cost of operating existing machines. The relatively inefficient machines face the prospect of being shut down. With *ex post* Leontief technology, labor cannot be reallocated to relatively efficient machines. Thus an energy price increase reduces labor demand. On the labor supply side, an increase in energy expenditure has a wealth effect which leads to lower consumption and lower leisure. The real wage has to decline to clear the labor market.

Since the labor demand is determined by the cost of operating previously installed machines,

the real wage stays low while these machines remain in operation. As a result, the impact of a persistent increase in the energy price on the market value are mostly negated by the persistent decrease in the real wage.

One might suppose that the model was unrealistic because wages are more rigid in the real world than in the model. But in fact the real wage dropped 3.4 percent below trend in 1974, a magnitude comparable to that predicted by the model. The analysis suggests that a broader set of forces was at work in causing the market downfall in 1974 than the energy cost increase alone.

A vast literature examines the relationship between the energy price shock and macroeconomic performance. Most of them feature the neoclassical production function, including In-Moo Kim and Prakash Loungani (1992). Andrew Atkeson and Patrick J. Kehoe (1999) use a putty-clay framework to model the relationship between the energy use and energy prices. Their dynamic analysis focuses on the case in which capital is always fully utilized, while in my model the variations in the capacity utilization is an important component of the endogenous obsolescence hypothesis. Mary G. Finn (1995) incorporates endogenous capacity utilization as a transmission mechanism from the energy price to the observed Solow residual. The capacity utilization in her model, however, only depends upon energy usage, not labor and energy costs of operating existing machines.

The paper is organized as follows. Section I presents the financial and macroeconomic data. Section II describes the general-equilibrium putty-clay model. In Section III, a simple partial-equilibrium putty-clay model is used to provide an upper bound on the energy price effect. Section IV describes the equilibrium dynamics of asset prices under a benchmark calibration. Section V concludes.

I. Historical Facts

The real energy price was fairly stable prior to 1972, due to the specific regulatory structure of the U.S. oil industry. Much of the cyclically endogenous component of petroleum demand showed up as a regulatory shift in quantities, not prices. In early 1971, the power to control crude

TABLE 1—PERCENTAGE OF DEVIATION RELATIVE TO THE TREND-ADJUSTED 1973 LEVEL

Year	1974	1975	1976
Real wage	-3.43	-4.79	-4.52
Consumption	-3.49	-5.46	-5.38
Investment	-6.48	-18.04	-19.40

Notes: All variables are measured relative to their trend-adjusted 1973 level. I detrend the variables by the average growth rate from 1959 to 1973. Real consumption and investment are divided by the adult (aged 16 and over) population. The variables are deflated by the personal consumption expenditure implicit price deflator.

oil prices shifted to Organization of the Petroleum Exporting Countries (OPEC). In October 1973, OPEC imposed an oil embargo on the United States and cut production. The real energy price jumped by 80 percent from 1973 to 1974. During the same period, the market value of nonfarm, nonfinancial corporations¹ dropped by 40 percent in real terms. The real energy price remained at the high level until the second energy crisis in 1979 pushed it even higher. The real market value of firms returned to its 1972 level only in the mid-1980's.

Table 1 describes real wages, real consumption of nondurables and services, and real investment between 1974 and 1976. I interpret the putty-clay model as covering the private nonenergy production sector of the economy. As a result, consumption is personal consumption expenditure on nondurables and services minus that on housing services and energy goods. Investment is gross private domestic fixed investment in nonresidential capital, excluding that component for the energy sector. Three patterns are revealed in Table 1: (1) the real wage decreased by 3.4 percent in 1974 and continued to decline in the following years; (2) real consumption dropped below trend; and (3) real investment dropped by around 6 percent in 1974 and the sharp decline continued in the following years.

¹ The value of the financial securities is measured as the market value of outstanding equities plus the constructed market value of financial liabilities less financial assets, all divided by the implicit deflator for private fixed nonresidential investment. The calculation follows Robert E. Hall (2001).

I will show that a general-equilibrium putty-clay model captures the qualitative, and some important aspects of the quantitative, features of the equilibrium dynamics of the price and quantity variables.

II. The Model

The economy consists of many identical, infinitely lived households which derive utility from the consumption of goods and leisure. Firms own all of the capital stock and make all investments in capital. Households own all shares in firms. They receive their income from supplying labor services to firms, and from dividends on the shares they hold. The claims on the profit streams of firms are traded on the securities market.

Three factors are used for production: capital, labor, and energy. Energy is imported at an exogenously given price, and energy imports are paid for with exports of output, with trade balanced in every period.

The economy starts at a steady state. There is no growth in the economy. The energy price shock is a once-and-for-all shock unanticipated by the agents in the model. Afterwards, there is no more aggregate uncertainty.

A. Firms

The production technology of firms is adapted from the Gilchrist-Williams putty-clay framework, in which capital and labor are the only production factors. This subsection extends their framework to include energy as a factor of production. The salient features of Gilchrist-Williams framework adopted here are:

1. The *ex ante* production technology is assumed to be Cobb-Douglas with constant returns to scale, but for capital goods already installed, production possibilities take the Leontief form: there is no *ex post* substitutability of capital, energy, and labor.
2. Capital goods are heterogeneous and are characterized by three attributes: a capital-energy ratio and an energy-labor ratio chosen at the time of installation, and the value of the idiosyncratic productivity term.
3. Idiosyncratic productivity is lognormally

distributed. It is observed after the investment decisions on new capital have been made and is constant over the life of the machine. The introduction of heterogeneity within vintages allows the utilization rate to vary in response to the energy price shock.

4. Capital goods require one period for installation and are productive for the next M periods. Once installed, capital goods cannot be converted into consumption goods or capital goods with different embodied characteristics.

In this economy, firms combine capital of various vintages with labor and energy to produce a single good. Each period a set of new investment “projects” becomes available. *Ex ante* constant returns to scale implies an indeterminacy of scale at the level of projects. Without loss of generality, all projects can be normalized to employ one unit of labor at full capacity. These projects are referred to as “machines.”

Subject to the constraint that the labor employed at time t on machine i of vintage $t - j$, $L_{i,t,j}$, is nonnegative, and less than or equal to 1, final output produced in period t by machine i of vintage $t - j$ is²

$$(1) \quad Y_{i,t,j} = \theta_{i,t-j} k_{i,t-j}^{\lambda\alpha} e_{i,t-j}^{\alpha} L_{i,t,j},$$

where $k_{i,t-j}$ is the capital–energy ratio, $e_{i,t-j}$ is the energy–labor ratio, $\lambda\alpha$ is the capital share of income, and $1 - \alpha$ is the labor share of income. Both $k_{i,t-j}$ and $e_{i,t-j}$ are chosen at the time of installation. Since the idiosyncratic productivity term, $\theta_{i,t-j}$, is revealed after these decisions are made, all machines of vintage $t - j$ share the same k_{t-j} and e_{t-j} .

The labor productivity of machine i of vintage $t - j$ is denoted by³

$$(2) \quad X_{i,t-j} \equiv \theta_{i,t-j} k_{i,t-j}^{\lambda\alpha} e_{i,t-j}^{\alpha}.$$

²For notational convenience, vintage $t - j$ machines mean the machines installed at period $t - j$.

³To incorporate growth in the model, one can multiply the right-hand side of equation (2) with a scalar variable that represents the overall level of technology for each period.

The idiosyncratic productivity term, $\theta_{i,t-j}$, is lognormally distributed:

$$(3) \quad \log \theta_{i,t-j} \sim N\left(-\frac{1}{2}\sigma^2, \sigma^2\right),$$

where the mean correction term $-\frac{1}{2}\sigma^2$ implies that the average productivity of the vintage $t - j$ capital, X_{t-j} , is $k_{t-j}^{\lambda\alpha} e_{t-j}^{\alpha}$.

Each period the firm decides how much of its capacity to use and what investment to undertake.

B. Capacity Utilization Decision

There are no costs for taking machines or workers on- or off-line. At each period, the only variable costs to operate one unit of vintage $t - j$ machines are the labor cost (real wage) W_t and energy expenses $P_t e_{t-j}$, where P_t is the real energy price.

The net income of running each machine is linear in labor employed. There exists a cutoff value for the minimum productivity level of machines used in production: those with productivity $X_{i,t-j} \geq W_t + P_t e_{t-j}$ are run at full capacity at period t , while those less productive are left idle.

Given that the idiosyncratic shock $\theta_{i,t-j}$ is lognormally distributed, the proportion of machines of vintage $t - j$ in use at time t can be summarized as

$$(4) \quad \Pr[X_{i,t-j} > (P_t e_{t-j} + W_t) | W_t, P_t] \\ = 1 - \Phi(z_t^{t-j}),$$

where $\Phi(\cdot)$ is the cumulative distribution function of the standard normal random variable and

$$(5) \quad z_t^{t-j} = \frac{1}{\sigma} \left[\log(P_t e_{t-j} + W_t) \right. \\ \left. - \log X_{t-j} + \frac{1}{2}\sigma^2 \right].$$

Total labor inputs, L_t , total energy inputs, En_t , and aggregate final output, Y_t , are:

$$(6) \quad L_t = \sum_{j=1}^M \{[1 - \Phi(z_t^{t-j})](1 - \delta)^{j-1} Q_{t-j}\},$$

$$(7) \quad En_t = \sum_{j=1}^M \{[1 - \Phi(z_t^{t-j})]$$

$$\times (1 - \delta)^{j-1} Q_{t-j} e_{t-j}\},$$

$$(8) \quad Y_t = \sum_{j=1}^M \{[1 - \Phi(z_t^{t-j} - \sigma)]$$

$$\times (1 - \delta)^{j-1} Q_{t-j} X_{t-j}\},$$

where Q_{t-j} is the quantity of new machines started in period $t - j$, and δ reflects the fact that a subset of machines has failed completely each period. The summation of labor inputs uses the fact that in equilibrium each machine in operation employs one unit of labor. In equation (8), $1 - \Phi(z_t^{t-j} - \sigma)$ is the ratio of actual output produced from vintage $t - j$ capital to the level of output that could be produced at full capacity utilization.⁴

C. The Firm's Problem

At the beginning of period t , there are M vintages of capital in existence. Each vintage is identified by the capital–energy ratio, k_{t-j} ; the energy–labor ratio, e_{t-j} ; and the quantity of machines installed per vintage, Q_{t-j} , $j = 1, \dots, M$.

The firm takes the vintage structure, the owners' (representative households) marginal rate of substitution, $\{m_{t,t+s}\}_{s=0}^{\infty}$, the real energy price $\{P_{t+s}\}_{s=0}^{\infty}$, and the real wage rate, $\{W_{t+s}\}_{s=0}^{\infty}$, as given. The decisions on $\{z_{t+s}^{t-j}\}_{s=0}^{\infty}$, $j = 1, \dots, M$ are made according to equation (5). The firm chooses $\{Q_{t+s}, k_{t+s}, e_{t+s}\}_{s=0}^{\infty}$ to maximize its net present value, which is equal to the present discounted value of all current and future cash flows.⁵

⁴ The proof is contained in Gilchrist and Williams (2000, footnote 10).

⁵ Since Q_{t+s} is the quantity of machines with each machine hiring one unit of labor, and $k_{t+s}e_{t+s}$ is the

$$(9) \quad \sum_{s=0}^{\infty} [m_{t,t+s}(Y_{t+s} - W_{t+s}L_{t+s} - P_{t+s}En_{t+s} - Q_{t+s}k_{t+s}e_{t+s})],$$

subject to equations (6), (7), (8), and

$$(10) \quad P_{t+s} = 1 + \rho(P_{t+s-1} - 1),$$

where ρ is the persistence parameter of the energy price process.

Define d_{t+s}^{t-j} as the average net income per vintage $t - j$ machine at period $t + s$:

$$(11)$$

$$d_{t+s}^{t-j} = (1 - \delta)^{j+s-1} \{X_{t-j}[1 - \Phi(z_{t+s}^{t-j} - \sigma)] - (P_{t+s}e_{t-j} + W_{t+s})[1 - \Phi(z_{t+s}^{t-j})]\}.$$

The first and second terms in the bracket represent respectively the average output and cost of operating one unit of vintage $t - j$ machines. Since the average labor productivity, X_{t-j} , is predetermined, the variable cost of operation, $P_{t+s}e_{t-j} + W_{t+s}$, determines the capacity utilization rate and expected income of machines in operation.

The first-order conditions with respect to Q_t , k_t , and e_t are:

$$(12) \quad k_t e_t = \sum_{s=1}^M m_{t,t+s} d_{t+s}^{t+s},$$

$$(13) \quad e_t = \sum_{s=1}^M m_{t,t+s} (1 - \delta)^{s-1} \times \{\lambda \alpha k_t^{\lambda \alpha - 1} e_t^{\alpha} [1 - \Phi(z_{t+s}^{t+s} - \sigma)]\},$$

$$(14) \quad k_t = \sum_{s=1}^M m_{t,t+s} (1 - \delta)^{s-1} \times \{\alpha k_t^{\lambda \alpha} e_t^{\alpha - 1} [1 - \Phi(z_{t+s}^{t+s} - \sigma)] - P_{t+s} [1 - \Phi(z_{t+s}^{t+s})]\}.$$

capital–labor ratio for newly installed machines, $Q_{t+s}k_{t+s}e_{t+s}$ is the gross investment in the new capital.

The left-hand sides of the above equations are respectively the marginal costs of increasing the quantity, the capital–energy ratio and energy–labor ratio of the newly installed machines. The right-hand sides are the corresponding marginal benefits.

D. The Household's Problem

The representative household maximizes the lifetime utility of consumption and leisure:

$$(15) \quad \max \sum_{s=0}^{\infty} \left\{ \beta^s \frac{1}{1-\gamma} \times [C_{t+s}(1-L_{t+s})^\varphi]^{1-\gamma} \right\},$$

$$0 < \beta < 1,$$

where $\gamma > 0$ is the coefficient of relative risk aversion and $\varphi > 0$ indexes the consumer's preferences for leisure. The maximization is subject to a standard sequential budget constraint.

The household side of the model determines the real wage and the marginal rate of substitution through optimal decisions on the labor supply and consumption:

$$(16) \quad W_t = \varphi \frac{C_t}{1-L_t},$$

$$(17) \quad m_{t,t+1} = \beta \frac{U_1(C_{t+1}, L_{t+1})}{U_1(C_t, L_t)}.$$

The definition of a perfect-foresight competitive equilibrium in this setting is standard. In equilibrium, all produced goods are either consumed, invested, or paid for energy expenses:

$$(18) \quad Y_t = C_t + Q_t k_t e_t + P_t E n_t, \quad \forall t.$$

E. Asset-Pricing Implications

The market value of the firm at time t , V_t , is the value of the firm after the current period payout is distributed and investment is made:

$$(19) \quad V_t = \sum_{s=1}^{\infty} [m_{t,t+s}(Y_{t+s} - W_{t+s}L_{t+s} - P_{t+s}E n_{t+s} - Q_{t+s}k_{t+s}e_{t+s})] \\ = \sum_{j=0}^M \left[Q_{t-j} \left(\sum_{s=1}^{M-j} m_{t,t+s} d_{t+s}^{t-j} \right) \right].$$

The last equality is obtained using equation (12), which states that future investments have zero economic rent. The above equation can be further simplified if we define

$$(20) \quad q_t^{t-j} = \sum_{s=1}^{M-j} m_{t,t+s} d_{t+s}^{t-j}, \quad j = 0, \dots, M.$$

Using standard pricing formulas, we can recognize that q_t^{t-j} is the average price of one unit of vintage $t-j$ machines at time t .⁶ From equation (12), the price of one unit of machines installed at period t , q_t^t , is equal to $k_t e_t$. The market value of the firm, V_t , now equals the market value of the capital installed between periods $t-M$ and $t-1$ plus the investment made at time t , with the former being the dominant component:

$$(21) \quad V_t = \sum_{j=1}^{M-1} Q_{t-j} q_t^{t-j} + Q_t k_t e_t.$$

Consider a sharp increase in energy prices. Each machine installed before the energy price increase has a fixed capital–energy ratio and energy–labor ratio. As indicated in equation (11), the variable costs of operation determine the capacity utilization rate and the expected profits of machines in operation. As a result, the market value of the previously installed machines depends upon the variable cost of operation over the remaining life span. The variable costs of running the machine are the labor costs

⁶ Since $\theta_{i,t-j}$ is idiosyncratic across vintage $t-j$ machines, it is easy to show that the aggregated values of vintage $t-j$ machines are equal to the total amount of vintage $t-j$ machines, Q_{t-j} , multiplied by the average price of vintage $t-j$ machines at time t , which is q_t^{t-j} .

and the energy costs. Since the real wage is endogenously determined in the model, the cross-price elasticity of labor and energy is important in assessing the effects of energy price shocks.

III. A Partial-Equilibrium Calculation

This section presents a partial-equilibrium analysis as a useful benchmark.⁷ I make three strong assumptions to distinguish the partial-equilibrium setting from its general-equilibrium counterpart:

1. Machines of the same vintage are identical. All machines are in full operation.
2. The real interest rate is fixed and known with certainty.
3. The real wage remains at its pre-shock steady-state level after the energy price shock.

By assumption 1, I prevent firms from adjusting capacity utilization. The unprofitable machines will remain in operation. Moreover, since a real wage decrease would reverse the upward pressure on the variable cost brought by the energy price increase, fixing the real wage and interest rate puts an upper bound on the impact of the energy price shock.

Under the assumptions above, equation (11) collapses to the following:

$$(22) \quad d_{t+s}^{t-j} = (1 - \delta)^{j+s-1} \\ \times [X_{t-j} - (P_{t+s}e_{t-j} + W_{t+s})].$$

The economy is in a steady state to start with. All steady-state variables will be denoted by an asterisk [*]. Suppose that at time t the real energy price jumps by 80 percent and is expected to stay at that level forever.⁸ Holding the

real wage fixed, the percentage decline in the net income per vintage $t - j$ machine compared to its steady-state counterpart is:⁹

$$(23) \quad \frac{P^*e^*}{X^* - (P^*e^* + W^*)} \left(\frac{P_t}{P^*} - 1 \right) \\ = \frac{(1 - \lambda)\alpha}{\lambda\alpha} \left(\frac{P_t}{P^*} - 1 \right).$$

In the partial-equilibrium setting, the effect of the energy price shock on the stock market depends upon the ratio of energy share to capital share of production costs. Since the energy share is just around 0.04 in the 1970's, under a fixed real wage rate, the net income of vintage $t - j$ machines falls by 10 percent each period in response to an 80-percent hike in the real energy price. Given a fixed real interest rate, the market value of previously installed capital also drops by 10 percent. By contrast, the market value of firms dropped by 40 percent in 1974. The simple computations show a limited, but noticeable, impact of the energy price shock.

Another way to measure the upper bound is to compute the decline in the real wage rate required to counter the effect of the energy price increase. Since labor costs account for 64 percent of total production costs, a 5-percent decrease in the real wage is sufficient to remove all the adverse impact of an 80-percent energy price hike on the market value of capital.

To determine whether the upper bound provides an accurate estimate of the magnitude of the energy price effect, one needs to calibrate the general-equilibrium model to examine the responses of the wage and interest rate, and determine whether they amplify or diminish the direct effect of the energy price shock.

⁹ Since the *ex ante* production technology is Cobb-Douglas with constant returns to scale, we have

$$\frac{P^*e^*}{X^*} = (1 - \lambda)\alpha,$$

$$1 - \frac{P^*e^* + W^*}{X^*} = \lambda\alpha,$$

where the left-hand sides are respectively the energy and the capital share of production costs.

⁷ Plutarchos Sakellaris (1997) developed a similar partial-equilibrium illustration of the impact of the energy price shock on the drop in market value.

⁸ I assume that the real energy price follows a persistent process with mean reversion in the general-equilibrium model. The upper bound derived under this alternative assumption in a partial-equilibrium setting is slightly smaller than the one obtained here.

IV. Model Dynamics

A. Calibration

A time period is taken to be one year. The calibrated preference parameters are $\beta = 0.97$, $\gamma = 1.5$, and $\varphi = 3$. The parameter φ is chosen so that households work about 23 percent of their time in the steady state. On the production side, λ and α are calibrated to imply a labor share of income of 0.64, and an energy share of income of 0.04. The depreciation rate δ is 0.084. The number of vintages, M , is set to be 25.¹⁰

The standard deviation of idiosyncratic uncertainty, σ , is set to 0.25. This benchmark calibration of σ implies a utilization ratio of 89 percent in the steady state, close to the 88-percent utilization rate among major industries in 1973.¹¹

The persistence of the energy price process, ρ , is set to 0.95.¹² The real energy price is set to 1 in the steady state.

The benchmark calibration implies a steady-state consumption–output ratio of 71 percent, an energy–capital ratio of 0.02 and energy–labor ratio of 0.05. All are within the acceptable region of their counterpart in the data. I combine the multidimensional perturbation and the Ray C. Fair and John B. Taylor (1983) methods to compute the responses of the economy to the energy price shock.

B. Equilibrium Paths After the Shock

Assume that the energy price shock arrives in period t in the sense that the energy price increases by 80 percent in that period. Afterwards, the energy price follows the process specified in equation (10). I assume that period t is 1974.

Figure 1 shows the equilibrium paths of the quantity and price variables following the en-

ergy price shock. Real income, $Y_t - P_t E n_t$, decreases by 3.9 percent on impact, mostly due to the increase in energy expenditure. Real consumption decreases by 3.5 percent in the first period and stays low in the following years.

On impact the real wage rate decreases by 3.8 percent, a magnitude comparable to that observed in the data.¹³ An energy price increase pushes up the variable cost of operating existing machines. The relatively inefficient machines face the prospect of being shut down. With *ex post* Leontief technology, labor cannot be reallocated to relatively efficient machines. The implied demand for labor falls and, in equilibrium, the real wage declines to clear the labor market. Since the labor demand is determined by the cost of operating previously installed machines, the real wage stays persistently below its steady-state value while these machines remain in operation. The persistence of the real wage indicates that its decrease has nontrivial effects on the market value of capital.

Holding the real wage fixed, an 80-percent increase in the energy price raises variable cost per machine by 4.7 percent. This implies a 3-percent reduction in capacity utilization. Allowing for the real wage decrease, the utilization rate declines by just 1 percent at period t , and by even less in the following periods. As a result, labor hours drop by only 1 percent in the initial period. By contrast, there was a 4-percent decline in the capacity utilization in 1974, and a further 10-percent reduction in 1975. Since the economy was in deep recession in 1975, it is not clear whether the large-scale machine shutdowns, and resulting sharp declines in labor hours, were entirely caused by the energy price shock.¹⁴ Given the real wage decrease of the observed magnitude, the model implies that there should not be a large-scale shutdown of machines.

In response to the energy price shock, the real

¹⁰ Williams C. Brainard et al. (1980) find that the average life span for equipment is 14.5 years in the 1970's. With $M = 25$ and $\delta = 0.084$, we approximately match this average life span.

¹¹ See Table B-52 in *Economic Report of the President* (Council of Economic Advisors, 2000).

¹² This persistence parameter is close to what Kim and Loungani (1992) obtained from the autoregression of the real energy price for the period from 1949 to 1987.

¹³ A real wage decrease of 3.8 percent is slightly larger than the 3.4-percent decrease observed in 1974. However, this small discrepancy makes at most a 1-percent difference in the eventual impact of the energy price shock on the securities market.

¹⁴ The model abstracts from unemployment. As a result, it is not equipped to capture the sharp reductions in labor hours caused by the unemployment.

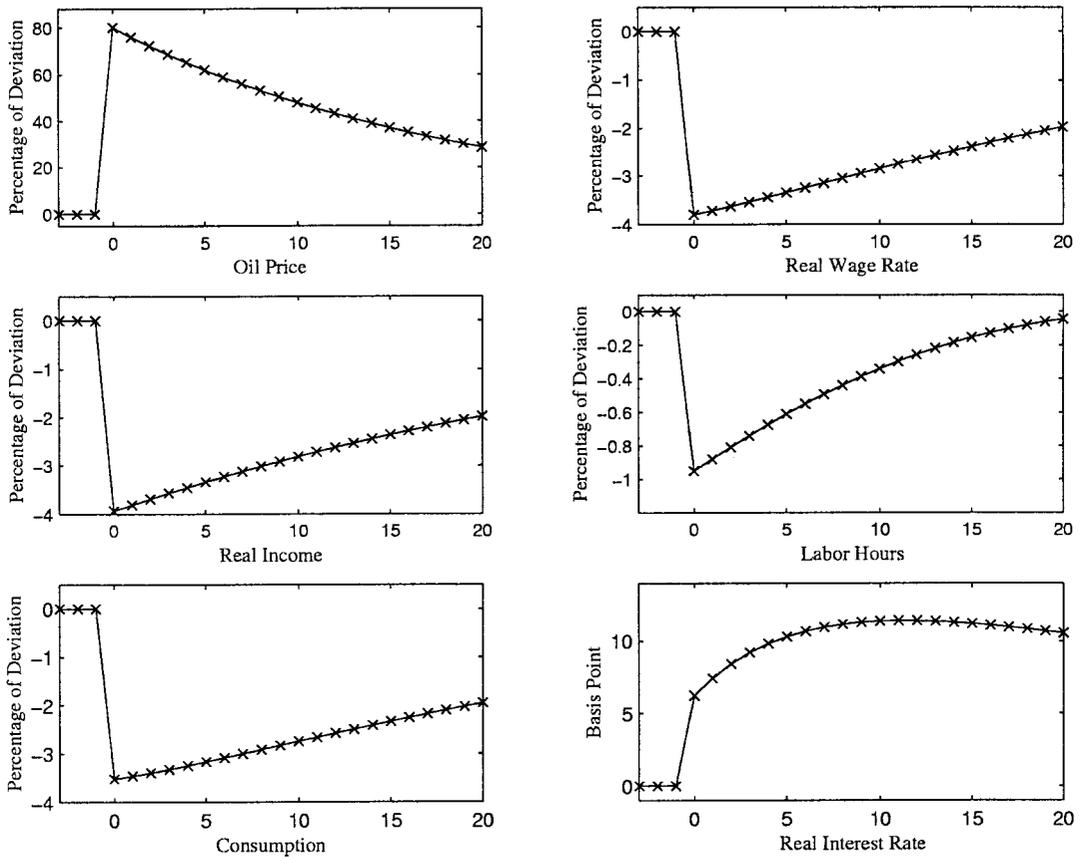


FIGURE 1. EQUILIBRIUM PATHS FOLLOWING THE ENERGY PRICE SHOCK (PERCENT)

Note: The x axis is the number of years after the energy price shock.

interest rate rises slightly above its steady-state level so that the agent consumes less in the current relative to the next period.

Now I turn to the dynamics of the asset prices. Based on equation (21), the market value of the firm at period t equals the market value of the capital installed between periods $t - M$ and $t - 1$ plus the investment made at time t . The next two subsections describe separately the changes in these two components.

C. The Market Value of Machines Installed Before Period t

The machines installed before period t are embodied with the technological choices made earlier. Their market value depends upon the variable

cost of operation over their remaining life span. The decrease in the real wage offsets the adverse impact of the energy cost increase on the capacity utilization and the expected earnings of the machines already installed. The decline in the market value of these machines turn out to be small.

For the more recently installed machines, the current losses from the higher energy price can be compensated with future reductions in the variable cost due to the real wage decrease. This pattern is reflected in Figure 2 in that the machines that are installed earlier lose more value than those installed more recently.¹⁵ At time t ,

¹⁵ Charles R. Hulten et al. (1989) take an empirical approach to examine the age-price profile for used capital

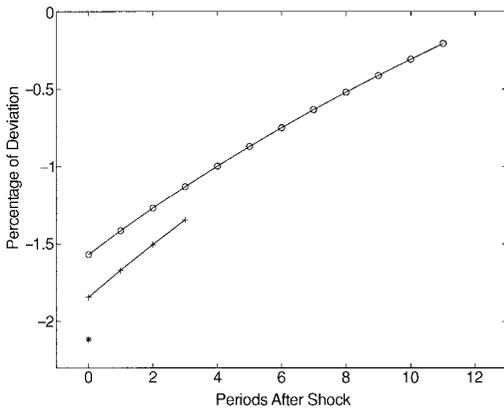


FIGURE 2. PERCENTAGE OF DEVIATION IN PRICES OF VINTAGE $t - j$ MACHINES

Notes: The x axis is the number of periods after t , the y axis is the percentage of deviation in the price of the vintage $t - j$ machines, q_{t+i}^{-j} , relative to the steady-state price of machines of the same age. Here i takes the value from 0 to $M - j$, the remaining life span of the machines. The symbol * denotes the machines installed at period $t - (M - 1)$. The symbols + and \circ respectively denote those installed at periods $t - 21$ (4 more years of operation) and $t - 13$ (12 more years of operation).

the machines installed $M - 1$ periods ago have only one period of production ahead. The variable cost of operating this vintage of machines in the next period is 1.1 percent above the steady state. As a result, the market value of this vintage of machines decreases by 2.1 percent.

The rise in the interest rate depresses the value of capital stock, with a larger impact on younger machines. The rise in the interest rate accounts for one-twentieth of the simulated 2.1-percent decrease in the vintage $t - (M - 1)$ machines, versus one-third of the 1.6-percent decrease in the vintage $t - 1$ machines. Summing across different vintages, the market value of machines installed before the energy price shock decreases by only 1.6 percent on impact.

before and after 1973. They find no evidence for a systematic change in the profile. My model predicts that even though theoretically there are systematic changes in the age-price profiles, these changes can be very small and easily offset by other factors at work.

D. The Market Value of Machines Installed at Period t

This subsection describes the market value of machines installed at period t , which is equal to the investment made at that period, namely $Q_t k_t e_t$. Panels A to C in Figure 3 plot the percentage of deviations in the capital intensity, energy efficiency, and quantities of machines installed after the energy price shock relative to their steady-state values. The capital-energy ratio increases and the energy-labor ratio drops, showing a substitution of capital and labor away from energy. As a result, the labor productivity of new generations of machines, $k^{\lambda\alpha} e^{\alpha}$, declines.

Panel D shows investment decreases in response to the energy price shock and stays below the steady state during subsequent years for the following reasons. First, less resources are available for investment because of a decline in real income. Second, only a very small fraction of machines becomes obsolete as a result of the real wage decrease. The demand for replacing obsolete capital is weak. Third, the persistently low real wage rate encourages substitution of labor away from capital. As a result, the capital-labor ratio of machines installed at the period of the energy price shock decreases by 3.8 percent.

The energy price shock generates a 5.1-percent decline in investment at the period of the energy price shock, close to the 6-percent decline observed in 1974. Real private domestic fixed investment in nonresidential capital plunged by around 18 percent in 1975 and 1976, much sharper than predicted by the model. Since investment is part of the market value of firms, this discrepancy is consistent with the notion that the energy cost increase by itself is not able to account for the sharp decline in the market value.

E. Sensitivity Analysis

In the benchmark case, an 80-percent energy price increase leads to a 5.1-percent decline in investment, and a 1.6-percent decrease in the value of pre-installed machines. The rise in the interest rate depresses the value of capital stock. Of the three channels through which the energy price shock exerts its influence on the securities market, the interest rate channel is the weakest. In total, an 80-percent increase in energy prices

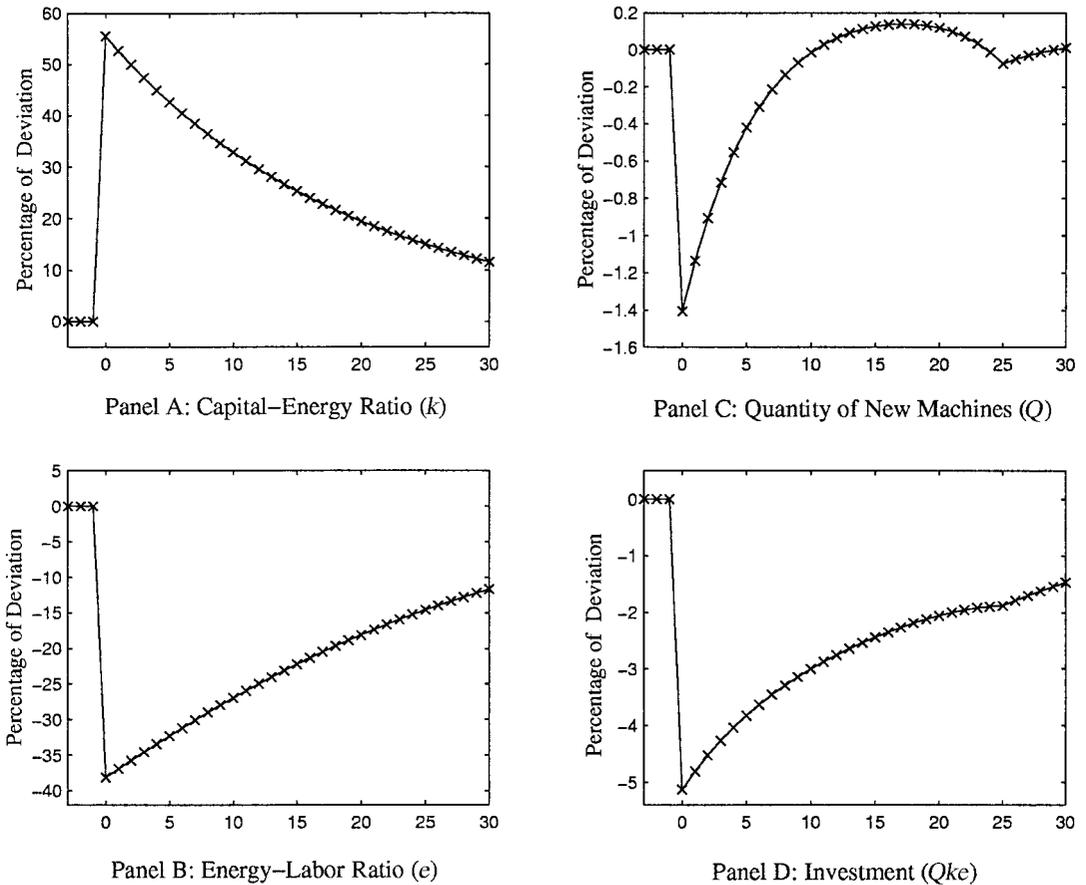


FIGURE 3. RESPONSES TO THE ENERGY PRICE SHOCK (PERCENT)

Notes: The x axis is the time period after the energy price shock, and the y axis represents the above attributes embodied in the machines installed in the corresponding time period. The kinks in Panels C and D reflect the replacement echo due to the finite life span of machines.

causes the market value to decline by only 2 percent, far short of the 40-percent decline observed in the data.

In this subsection, I explore the sensitivity of the model solutions to alternative specifications of energy price expectations and reasonable variations in model parameters.

In the benchmark case, I assume that the real energy price follows a mean-reverting autoregressive process after the shock. Suppose, instead, that the agents expect more energy price hikes ahead after observing the 80-percent energy price increase. The expectation of higher energy prices in the future increases marginal utility even further, and leads households to

work more at a given wage compared to the benchmark case. The real wage decreases more as a result of a more pessimistic view of future energy prices. For example, assuming the energy price increase to be permanent results in a decline in the market value of 2.5 percent, slightly higher than the benchmark case. Alternatively one might assume that the expectation of energy prices are the same as the observed energy prices after 1974.¹⁶ Even with such

¹⁶ This assumption is unrealistic because it is hard to believe that people could have anticipated the 1979 energy crisis back in 1974. This expectation also implies radical

expectations, the market value of capital only declines by around 5.8 percent.

The standard deviation of idiosyncratic productivity, σ , affects the slope of the labor demand curve and the extent of shifts in the labor demand and supply schedules. Lowering σ to 0.15, while holding other parameters fixed, leads to a decrease in the real wage of around 3.1 percent, and a slightly larger decline in the market value compared to the benchmark case.

My conclusions are also robust to other reasonable variations, such as altering the preference parameters, extending the life span of machines, or varying the initial distribution of the capital and energy efficiency.¹⁷

V. Conclusion

In this paper, I use a putty-clay model to evaluate the effect of the 1973–1974 energy cost increase on the market value of firms through capital obsolescence. The putty-clay model represents an extreme case of rigidity in the adjustment of capital *ex post*. Even in this extreme case, the energy price effect on the market value of capital is very small. Holding the real wage fixed, an 80-percent permanent increase in the real energy price can explain a 10-percent decline in the market value of previously installed machines. Allowing for general-equilibrium effects including a decline in the real wage, the value of capital declines by only 2 percent. The model has generated movements of the real wage, income, and consumption in the right direction and of comparable magnitude to those observed in the data. The fact that the real wage did decline by the amount implied by the model lends credibility to the analysis.

The model permits the energy price to affect the economy through the production function. It implies that given the real wage decrease, the large-scale machine shutdown is as much a puzzle as the sharp decline in the market value of firms. Timothy F. Bresnahan and Valerie A. Ramey (1993) document the lower capacity uti-

lization of automobile producers due to the rapidly changing composition of desired sales. James D. Hamilton (1988, 1999) suggests that energy price increases can lead to a sharp dispersion in relative demand and, with frictions in allocating factors, a relatively large drop in output. Quantifying these demand composition effects in a dynamic general-equilibrium model will be pursued in future research.

The paper studies the impact of the energy price shock in isolation. It is possible that the energy price shock, combined with other shocks, might have had a different effect on the securities market in 1974. There are also other possible explanations for the 1974 market decline, including the tightening of the monetary policy, the arrival of information technology, the rise in uncertainty, and so forth. The quantitative relevance of these explanations in a general-equilibrium environment remains to be judged in a calibrated model. More work is under way to uncover the mysteries behind the massive market decline in 1974.

APPENDIX A: CONSTRUCT THE REAL ENERGY PRICE

The series used to construct the real energy price are taken from *Annual Energy Review*, Energy Information Administration, 1999. The data are downloaded from the web site <http://www.eia.doe.gov/emeu/aer/contents.html>.

Energy Prices (dollar prices per million Btus in chained 1992 dollars, calculated by using personal consumption expenditure implicit price deflators):

pdmoil: domestic first purchase price of crude oil, series in Table 3.1.

pimpoi: imported cost of crude oil, dollars per barrel, series in Table 5.19, converted into Btu units using the thermal conversion factors in Table 13.2.

pnatgs: domestic price of natural gas, series in Table 3.1.

pcoal: domestic price of coal, series in Table 3.1.

changes in investment in 1974, which is not observed in the data.

¹⁷ The details of the comparative dynamics are available from the author.

The Btu content of the above energy sources are obtained from Table 1.2, 5.2, 5.3, and 5.5. The domestic price of crude oil is weighted by

the share of Btu content of the domestically produced crude oil minus the export. All other prices are weighted by their respective shares in total Btu content. The weighted energy price is the composite real energy price.

Using 1987 as base year, the energy price deflator can be constructed from the composite real energy price. The percentage change in the energy price deflator from 1973 to 1974 is also around 80 percent.

APPENDIX B: OTHER DATA

Real Wage (Table 1): *DRI, LBCPU7*, real compensation per hour, nonfarm business (1982 = 100, SA, quarterly).

Real Consumption (Table 1): personal consumption expenditure of nondurable goods and services minus that on housing services and energy goods: *National Income and Products Accounts*.

Real Investment (Table 1): real gross private domestic fixed investment in nonresidential capital excluding the purchase of the structures in the petroleum and natural gas sectors (*GANMG*), *National Income and Products Accounts*.

Adult (aged 16 and over) Population (Table 1): Department of Commerce, Bureau of the Census.

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