

How Resilient Is the Modern Economy to Energy Price Shocks?

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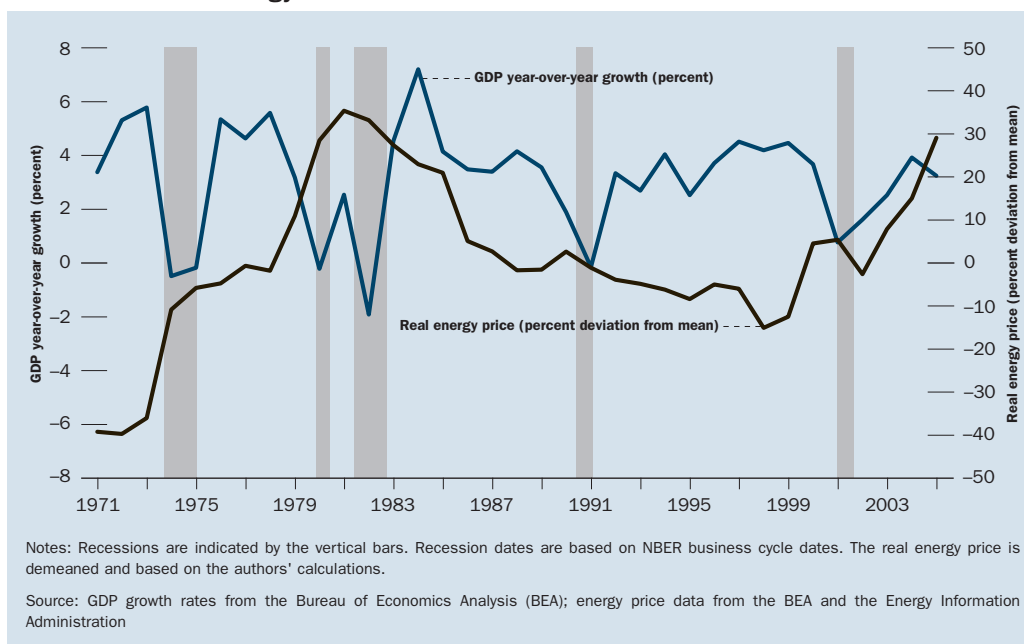
Economists and policymakers alike have noticed the striking correlation between energy prices and U.S. business cycles. Since 1973 every recession has been preceded by a rise in energy prices (see Figure 1). Conversely, almost every energy price hike has been followed by a recession. A large literature confirms this casual observation of energy prices driving business cycles with econometric methods, including Rasche and Tatom (1977), Hamilton (1983, 2003), Rotemberg and Woodford (1996), and Hamilton and Herrera (2004).¹

Despite the empirical link between energy prices and business cycles, the existing literature on dynamic stochastic general equilibrium (DSGE) models has either abstracted from modeling energy or found little effect of energy price shocks on the macroeconomy. Finn Kydland and Edward Prescott, who are the pioneers of studying business cycles in the DSGE framework, showed in their seminal paper (Kydland and Prescott 1982) that a large share of business cycle fluctuations is accounted for by using one single exogenous shock, total factor productivity. Given that they had abstracted from modeling energy use, Kim and Loungani (1992) add energy use on the firm side and a second exogenous shock, the energy price, to the Kydland and Prescott framework. They confirm the original finding that productivity shocks still explain a major portion of business cycle fluctuations.²

Both views—that of the DSGE-type researchers who claim that energy price shocks do not matter and that of the empiricists who claim that these shocks are the primary reason for business cycles in the United States—are not entirely convincing. On the one hand, it must have been a very unfortunate coincidence for theorists that the weak productivity observed in 1973–74 and 1979–82 occurred right after the energy price shock. On the other hand, the empiricists would have to address why in 1986, when energy prices declined sharply, we did not observe a major boom in the economy.

Mork (1989), who investigated the 1986 anomaly, shows that an asymmetric effect of energy price increases and decreases exists: The frictions in the economy

Figure 1
Growth Rates and Energy Prices



cause a negative effect on growth if energy prices go up but provide no benefit when energy prices decline.³ However, the empiricists still need to address why the recent run-up in energy prices has not caused a recession or even a slowdown so far. Real gross domestic product (GDP) has grown at a solid 3.5 percent rate since the end of 2002 whereas energy prices have risen by a magnitude similar to that observed in 1979.

One potential explanation for this lack of energy effects would be the low energy intensity of the modern economy. For example, energy use measured in British thermal units (BTU) per dollar of real GDP in 2005 is about half of the value observed in the 1970s. But this share argument is still unsatisfactory: If the impact of an energy price shock is proportional to the energy intensity, we should still have observed half of the drop observed in the 1970s, which certainly would have made for a severe growth slowdown, if not a recession. It is difficult to characterize growth of 3.5 percent over the past few years as being below trend by any metric.

Who is right—the empiricists who claim that energy price hikes have strong and significant effects on business cycles or the DSGE economists who claim that it is mostly productivity that matters? This article will reconcile the two competing views in the following manner. The DSGE-type explanation remains intact if we construct a “proper” series for productivity or Solow residuals by explicitly taking into account energy use in the production function, which has been absent from standard productivity accounting exercises done before. In particular, these productivity shocks continue to be the prominent force behind business cycles. However, during the years 1970 to 1985, productivity itself was negatively affected by energy price hikes. In the model constructed here, a Kim and Loungani-type economy, we allow for a negative correlation between energy price shocks and productivity based on our empirical evidence from 1970 to 1985. This simulation experiment confirms the findings of the econometric literature that energy price shocks reduced real output

growth prior to 1985. The correlation between energy price shocks and productivity disappeared completely after 1985. Our model simulation incorporating this lack of correlation explains why in 1986 there was no major increase in growth rates and, most important, why there was no recession in 2005. Therefore, we conclude that the modern economy, represented by the period after 1985, is very resilient to energy price increases.

Constructing the Model

The model used here is based on a version of the DSGE model in Kim and Loungani (1992) that incorporates energy use on the firm side as well as a stochastic process for energy prices.

Throughout the article, the term “energy price” refers to the price of energy relative to other goods. The process for the price of energy P varies exogenously over time. Specifically, we assume that energy prices follow an autoregressive moving average (ARMA) process of the following form:

$$(1) \log P_t = \rho_p \log P_{t-1} + \varepsilon_{p,t} + \rho_\varepsilon \varepsilon_{p,t-1},$$

where the shocks $\varepsilon_{p,t}$ are normally distributed with mean zero and standard deviation σ_p . This specification is standard in the literature.⁴

The model economy has a representative household that obtains utility from consuming C and disutility from working H hours. Specifically, we assume that at any time t the household obtains period utility,

$$(2) u(C_t, H_t) = \phi \log C_t + (1 - \phi) \log(1 - H_t),$$

where ϕ is the weight the household puts on consumption. Over time the household discounts period utility at a constant rate β , with $0 < \beta < 1$. Thus, the household maximizes expected discounted utility:

$$(3) U = E \sum_{t=0}^{\infty} \beta^t u(C_t, H_t).$$

The model economy also has a representative firm that has three inputs, labor H , the service flow from physical capital K , and energy E_f . The firm purchases its energy input at relative price P . We choose the following form for the production function:

$$(4) Y_t = Z_t H_t^{1-\alpha} \left[\eta K_{t-1}^\psi + (1-\eta) E_{f,t}^\psi \right]^{\alpha/\psi},$$

which is standard in the literature (see Kim and Loungani 1992 and Dhawan and Jeske 2006). Our functional form implies that the elasticity of substitution between capital and energy is $1/(1 - \psi)$. Thus, if we choose $\psi < 0$, capital and energy will be

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1. See Hamilton (2005) for an exhaustive list of references.
 2. Dhawan and Jeske (2006) include household energy use and durable goods consumption and confirm the Kim and Loungani results. Leduc and Sill (2004) add monetary shocks and nominal wage and price rigidities but find that energy price shocks still do not play a major role.
 3. Mork conjectures that a model like Hamilton's (1988) can produce an asymmetry in the energy price response.
 4. The following section will elaborate on the time series properties of energy prices that justify this particular functional form.

complements. In addition, the firm is subject to an exogenous productivity shock Z , also called total factor productivity (TFP), as is the norm in the literature. Kydland and Prescott's (1982) seminal research views business cycle fluctuations as the result of movements in TFP. We assume that the Z evolves according to

$$(5) \log Z_t = \rho_z \log Z_{t-1} + \varepsilon_{z,t},$$

where the shocks $\varepsilon_{z,t}$ are normally distributed with mean zero and standard deviation σ_p . We do not include a constant term because we assume that the model is scaled in such a way as to make log productivity equal to zero on average.

We make a distinction between the service flow of capital and the investment. The entire stock of capital K is used in the production function while investment shows up in the national income and product accounts as the spending on new capital stock. The stock K and capital investment I_k are related via the following equation:

$$(6) \bar{K}_t = (1 - \delta_k) \bar{K}_{t-1} + I_{k,t},$$

where δ_k is the annual depreciation rate of physical capital.

To close the model we assume investment in fixed capital I_k as well as consumption C , and energy expenditures $P \cdot E_f$ are all financed by current production Y . The numerical techniques involved in solving the model are beyond the scope of this paper. We refer the interested reader to Dhawan and Jeske (2006).

Calibration and Time Series Properties of Shocks

The next step is to calibrate this model economy to match data measured at an annual frequency. Calibration means matching the steady state ratios such as K/Y , I_d/Y , hours worked H , and so on to the characteristics in the U.S. data between 1970 and 2005.⁵ The specifics of the calibration exercise are in Dhawan and Jeske (2006), and the exercise produces the parameter values shown in Table 1.⁶

An integral part of this model is the calibration of the shock processes. We now study some time series properties of the two shock processes for energy prices P and productivity Z . This analysis will guide us in finding realistic specifications of the shock processes used to simulate the dynamic model. We start by estimating a stochastic process for energy prices. The series for annual energy prices comes from the Energy Information Administration (EIA). We take the total nominal energy spending (household plus firm level) and divide by the total energy consumption in BTUs to obtain a series for the nominal energy price per unit of energy for 1970–2005. We then divide this series by the GDP deflator to obtain the real relative energy price P .⁷

Estimating the ARMA(1,1) process in equation (1) via the maximum likelihood method, we find that

$$(7) \log P_t = 0.8784 \log P_{t-1} + \varepsilon_{p,t} + 0.5256 \varepsilon_{p,t-1}.$$

(9.6114) (2.6150)

The t -statistics are in parentheses below the point estimates, and $\varepsilon_{p,t}$ has a standard error of 0.0753. Finding a statistically significant parameter estimate on the lagged shock (the moving average part of the ARMA) is consistent with the findings in Kim and Loungani (1992) and Dhawan and Jeske (2006), who also use an ARMA process for their energy prices. One can show that estimating only an AR(1) process, thus dropping the regressor $\varepsilon_{p,t-1}$, generates serially correlated error terms.

For this estimated ARMA process, an innovation ε_p of one standard deviation would, all other things being equal, raise energy prices by 7.53 percent in the current year and by 10.6 percent in the following year before slowly decaying after that. The reason that energy prices rise for two periods in a row is that the moving average term $\rho \varepsilon_{p,t-1}$ also shocks next period's energy price, and that effect is stronger than the decay of the initial shock.

Another ingredient in the model is the stochastic process for productivity Z . From the production function above, we back out the values of Z from the following equation:

$$(8) \quad Z_t = \frac{Y_t}{H_t^{1-\alpha} [\eta K_{t-1}^\psi + (1-\eta) E_{f,t}^\psi]^{\alpha/\psi}},$$

where we use the time series for annual real GDP from the Bureau of Economic Analysis (BEA) for Y and the index for “Nonfarm Business Sector: Hours of All Persons” from the BLS for H . As a measure for the capital stock K , we use the BEA's estimate of the “Net Stock of Fixed Assets.” Moreover, we subtract the BEA series for household nominal energy expenditures from the EIA total nominal energy expenditures series. We then divide by the price per BTU to compute real firm energy usage. With this measure we generate a time series Z_t for productivity from 1970 to 2005.⁸

The essential points of this article will be made by emphasizing that slightly different formulations of the productivity process generate vastly different results in the response of output to an energy price shock. We start with the most basic specification in equation (5), using Z as measured in equation (8) and estimate it via ordinary least squares to obtain the following equation:

$$(9) \quad \log Z_t = 0.8083 \log Z_{t-1} + \varepsilon_{z,t},$$

(8.3768)

where the error terms $\varepsilon_{z,t}$ have a standard deviation of 0.0126.⁹

Typically, when simulating the model one assumes that the innovations to the two shocks P and Z are independent. To check whether this assumption is adequate, we back out the residuals necessary to generate the observed paths for energy prices and productivity. In specification A, the two residuals display a sizable negative correlation of about -0.5 , as shown in Figure 2. Thus, the independence assumption is clearly violated, and feeding these shock processes into the model will miss an important link between energy prices and productivity.

Table 1
Calibrated Parameters

α	0.3600
β	0.9606
ϕ	0.3382
η	0.9940
ψ	-0.7000
δ_k	0.0656

5. For a formal exposition of a calibration process, see Cooley and Prescott (1995).

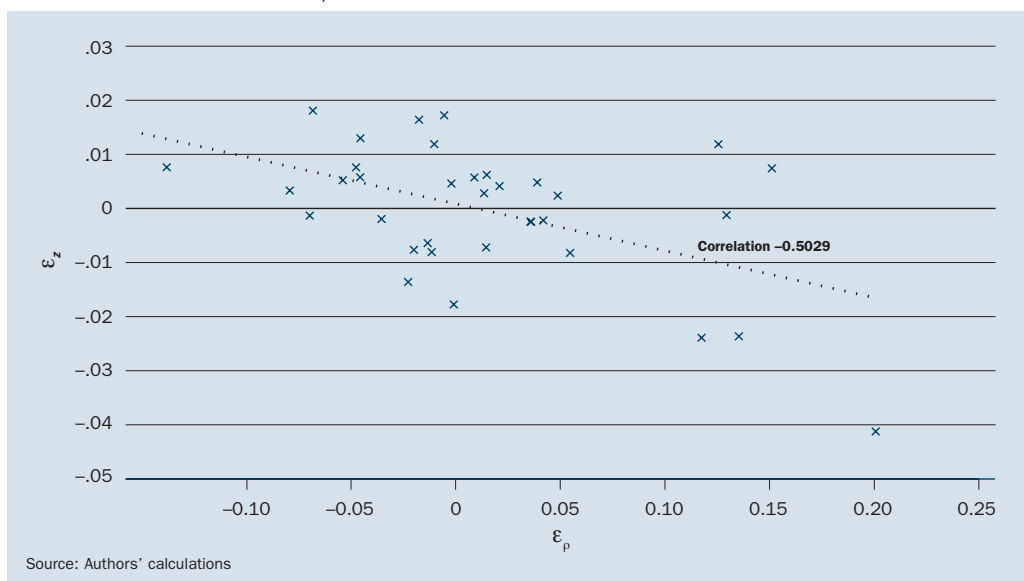
6. This model corresponds to model E-I in Dhawan and Jeske (2006), though on an annual basis. We also performed a sensitivity analysis along the energy share in the economy, which declined over the 1970–2005 period. We find that the numerical results are robust to this decline in energy share.

7. This is the series plotted in Figure 1.

8. This exercise also requires knowledge of the parameters α and ψ . We use the values as specified in the calibration above.

9. Cooley and Prescott (1995), using quarterly data, find $\rho_z = 0.95$, $\sigma_z = 0.007$, which corresponds to $\rho_z = 0.81$, $\sigma_z = 0.014$ on an annual basis, almost identical to our results.

Figure 2
Scatter Plot for Error Terms, 1970–2005



What is the source of the negative correlation between shocks? To investigate this question, we first plot the error terms for the two different subsamples (1970–85 and 1986–2005) in Figure 3. Notice that in the pre-1985 subsample the two error terms display an almost perfect negative correlation (−0.8618) while in the second subsample the correlation is essentially zero (0.0039). Consequently, we estimate another specification in which shocks in the energy price process are allowed also to spill over to the productivity process. Specifically, we regress current productivity not just on lagged productivity but also on the current shock from the energy price equation, multiplied by an indicator variable for the years before 1985. In other words, $\epsilon_{p,t}$ is included as an additional regressor, which is the error from the price equation times an indicator variable $I(t \leq 1985)$:

$$(10) \log Z_t = 0.8238 \log Z_{t-1} - 0.1915 \epsilon_{p,t} I(t \leq 1985) + \epsilon_{z,t}.$$

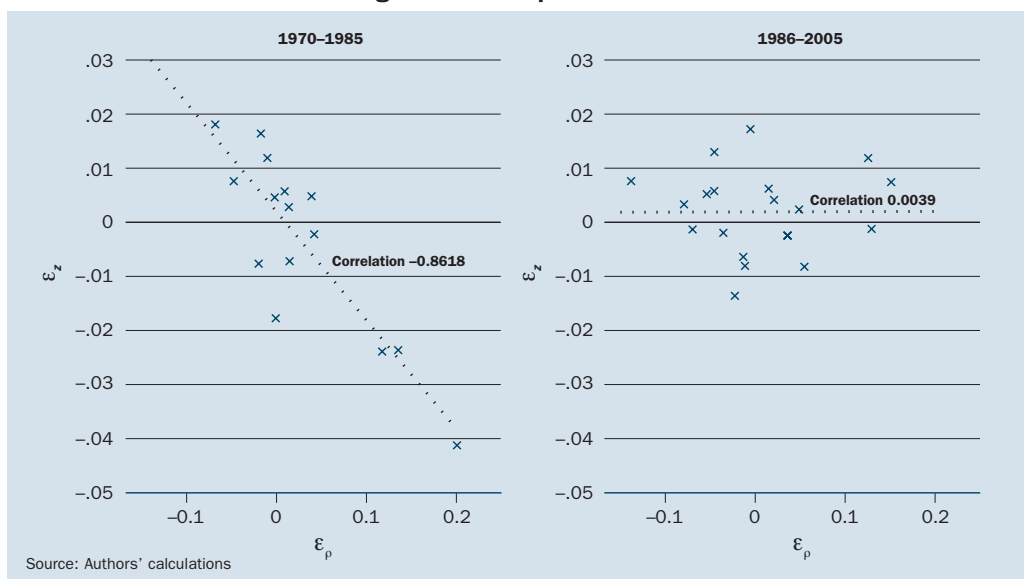
(12.8555)
(-6.6480)

According to our estimates, the coefficient on the spillover term is significantly negative; that is, a rise in energy prices was associated with lower productivity before 1985. Even though the coefficient may appear to be small in absolute value, the spillover effect from energy prices to productivity is substantial. To see this effect, consider the following example. A positive innovation to energy prices by one standard deviation reduces productivity by about 1.5 percent, or about 1.76 times a standard deviation of the productivity shock. Thus, according to our estimates, energy price shocks determine most of the fluctuations prior to 1985.

A Discussion of the Results

The model is simulated by feeding in the shock processes for energy prices and TFP. Specifically, we perform experiments for two alternative specifications of the TFP process. Specification A uses the estimated process above without the correlation term while specification B includes the correlation term. The specifications are as follows:

Figure 3
Scatter Plot of Error Terms during Two Subsamples



Specification A: $\log Z_t = 0.8238 \log Z_{t-1} + \varepsilon_{z,t}$ (post-1985);

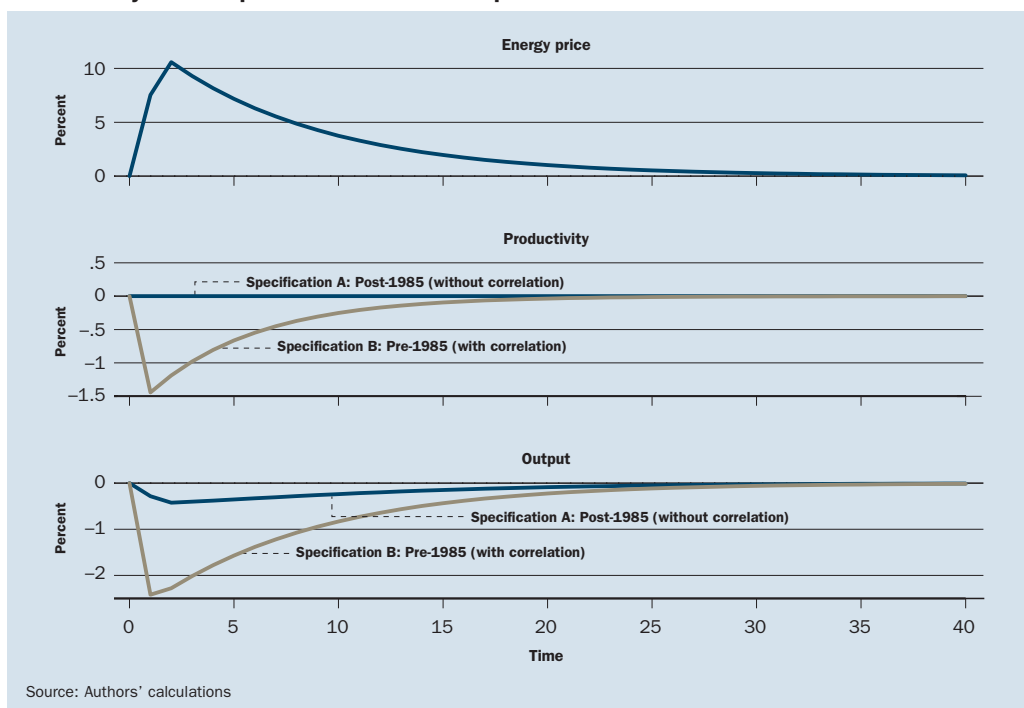
Specification B: $\log Z_t = 0.8238 \log Z_{t-1} - 0.1915 \varepsilon_{p,t} + \varepsilon_{z,t}$ (pre-1985).

We then report impulse response functions to an energy price shock over a time horizon of forty years under the two alternative specifications. The philosophy behind impulse response functions is as follows. The model constructed earlier was calibrated to match steady state properties to those observed in the data. At the steady state, all disturbances or shocks to the system are set to zero by definition. From this equilibrium state, the model is subjected to a shock, in this case an energy price shock, and the model's response for key variables is tracked over time.¹⁰ One can view this exercise as an economic laboratory experiment, studying the response to one shock while switching off all other noise in the economy.

We are primarily interested in the response of output to an energy price increase and therefore report the output impulse response functions to a positive one-standard-deviation shock to energy prices. This shock translates into a 10.6 percent hike in the energy price. The top panel in Figure 4 displays the path for the energy price following this one-time shock. Notice that because of the ARMA(1,1) structure, the price increases for two periods before it decays toward its old value in steady state. The middle panel displays the effect on total factor productivity Z based on the two alternative specifications, as detailed in the previous section. Notice that the impulse response for Z is entirely due to the energy price shock and not its own innovation $\varepsilon_{z,t}$, which we set to zero along the transition path. Therefore, TFP (Z_t) stays at zero for specification A, where energy price innovations had no effect on productivity. In

10. Technically, this procedure means that one solves the first-order conditions to find the decision rules using an appropriate numerical approximation method. Iterating over the decision rules when given a shock generates the desired impulse response functions.

Figure 4
A One-Time Positive Energy Price Shock and Its Effect on Productivity and Output for Two Different Specifications of the TFP Process

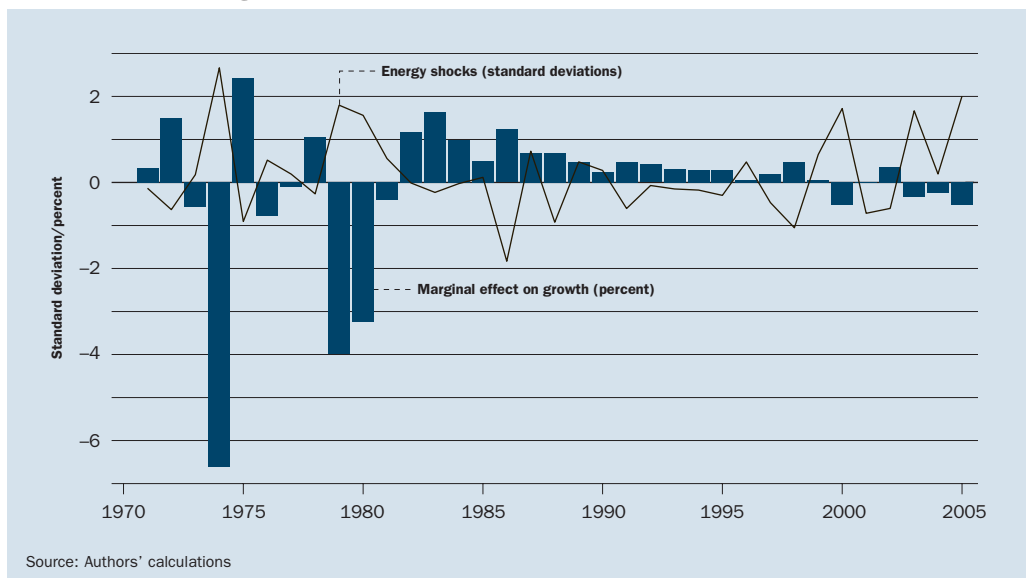


specification B, however, productivity drops dramatically because of the correlation and its negative implications on TFP, as described in the previous paragraph.

The lower panel in Figure 4 plots the drop in output caused by this energy price hike. Notice that the energy price hike does not cause any major output drop in specification A because there is no effect on the TFP process. The biggest drop occurs in the year after the initial energy price hike but amounts to only a 0.43 percent drop in output before converging back to zero. This result is consistent with previous research showing that DSGE models with energy use do not produce major output fluctuations if energy price shocks are uncorrelated with TFP.¹¹

Under specification B, however, output drops by almost 2.4 percent. Even eight years after the shock, output is still 1 percentage point below the level where it would have been without the energy price shock. The technical reason for this big and persistent effect is that the energy price shock substantially reduces TFP, which in turn affects output. Recall from the calibration section that for the 1970–85 period, a positive one-standard-deviation shock to the energy price equation, given the spillover effect, is equivalent to a -1.76 standard-deviation shock to TFP, which is big enough to drag down GDP substantially. Hence, the impulse response function in specification A can be interpreted as the outcome of energy price hikes in an economy set to match data characteristics after 1985; similarly, specification B is for an economy with characteristics from 1970 to 1985. The fact that energy price hikes were associated with major recessions in 1973 and 1980, but seemingly did not have any major output effect in the most recent episode from 2002 to 2005, is thus entirely consistent with our modeling structure.

Figure 5
**Estimated Standardized Energy Price Shocks and
 Their Estimated Marginal Effect on Growth Rates**



So what do these results mean in regard to the question posed in the article's title? In the context of our model, the economy today is far more resilient to energy price hikes than it was before 1985. Even a major energy price hike—caused by, say, a two-standard-deviation shock to the energy price process in equation (1)—represents a drag of a mere 0.8 percentage points in the second year of the impact in the modern era (defined as 1985 to 2005). If the negative correlation observed in the 1970s had prevailed, this price hike would have caused a precipitous 4.8 percent drop in output.

We can also use the model to determine the marginal impact energy prices had on growth between 1970 and 2005. In other words, how have the “observed” energy price shocks between 1971 and 2005 affected output growth in these thirty-five years? To answer this question, we generate a total impulse response function, that is, not with one single shock but with the thirty-five energy price shocks $\epsilon_{p,t}$ one after the other, as derived from our ARMA(1,1) estimation. Consequently, the impact of energy price changes in each year is the impact of the current year shock in addition to the impact from all lagged shocks. In this simulation we assume that specification B for the technology process prevails, that is, the pre-1985 era, when there is a negative spillover from energy price shocks to the technology. After 1985 technology is unaffected by energy prices because the indicator variable in the regression equation (10) is zero. Figure 5 plots the standardized energy price shocks $\epsilon_{p,t}$ and their marginal impact on output growth rates predicted by the model.

11. Specifically, Kim and Loungani (1992) show that energy price shocks do not produce a sizable fraction of business cycle fluctuations. Dhawan and Jeske (2006) show that modeling durable goods on the household side even softens the impact of energy price shocks because households have more margins to adjust their behavior. Particularly, households reduce new durable goods investment sharply to cushion the fall in fixed-capital investment, which mitigates future output losses.

Table 2
Growth Rates: Actual versus Counterfactual

	Actual (percent)	Counterfactual (percent) ^a
2003	2.51	-1.08
2004	3.91	3.98
2005	3.22	-0.64

^a For the counterfactual growth rate, energy price shocks affect TFP.

drop was 0.2 percent. The model simulation reveals that the growth rate that year would have been 3.2 percentage points higher, well outside of recession territory, if there had been no energy price shocks.

After 1985, however, energy price shocks had a much smaller effect on output growth rates. The simulation implies that energy prices did not play any role in the 1991 and 2001 recessions. The most recent run-up in energy prices, while quite dramatic, with three positive energy shocks in a row from 2003 to 2005, did not cause an obvious reduction in real GDP growth. The cumulative impact of energy price shocks on 2005 growth has been a mere 0.5 percentage points. The energy shock in 1980 (and 1979), about equal in magnitude to those observed in 2003 or 2005, did far more damage, as discussed previously.

We can also ask how much damage the energy price hike from 2002 to 2005 would have done had there still been the same type of negative correlation between TFP and energy price shocks as observed in the data before 1985. To answer this question we compute the marginal impact on output growth of energy price shocks, as discussed earlier, but assume that beginning in the year 2003 the economy reverts to the same shock process as observed in the pre-1985 era; namely, TFP is negatively affected by energy price shocks $\epsilon_{p,t}$. Table 2 reports growth rates for GDP for 2003 through 2005 under this scenario. The first column is the actual growth rate as reported by the BEA. The second column is the growth rate under the assumption that TFP is negatively affected by energy price shocks, the same way it had been before 1985.¹² Had the TFP process been of the same structure as before 1985, the recent energy price hikes would have dragged the economy into recession both in 2003 and 2005. Thus, the correlation between energy price shocks and TFP makes all the difference, and recessions would likely have occurred in 2003 and 2005, while without the correlation, the economy showed resilience to energy price shocks.

So far we have stated only statistical facts about a spillover from energy price hikes into reduction of TFP. We have not developed any theory about the causes for a negative correlation between technology and energy price shocks before 1985. One can view this negative correlation as a reduced form representation for other omitted factors in the model. For example, Hamilton (1988) develops a model with multiple sectors in the presence of frictions for reallocating production inputs, primarily labor, between sectors. If energy prices have a differential effect on sectors, the economy has to spend a sizable amount of resources to overcome these frictions. This explanation, of course, raises a question about why these frictions suddenly disappeared after 1985.

An alternative explanation for energy price hikes having vastly differential effects on growth in the two subperiods is that different policies were in place to address the price hikes. Most notably, the 1970s were marked by price controls on energy from 1973 to 1981 and wage controls during the Nixon era. Not surprisingly, during the oil

Evidently, energy price hikes had very adverse effects on growth in 1974, 1979, and 1980, knocking multiple percentage points off output growth rates. For example, energy price shocks reduced output growth in 1974 by an estimated 6.6 percent, meaning that in the absence of energy price shocks, output growth would have been more than 6 percent instead of the actual 0.5 percent decline. Likewise, in the recession year 1980, the actual output

shocks in both 1973 and 1979, gasoline was rationed, while after 1985 prices were allowed to move more freely. Evans (1982) studies the impact of general price and wage controls (not during the 1970s but during World War II) and finds that they caused a substantial output loss.

One can see how price controls have negative effects on productivity. In a market without price controls and any other frictions, the price of a good like oil or a service like labor provides an efficient way of rationing scarce resources because the market allocates them to the most productive use. Specifically, only those firms with the highest productivity are willing to hire workers and purchase energy at a given market price. If, by contrast, the price is not allowed to work as an allocation mechanism, inputs may be used by inefficient firms. For example, if there are lines at the gas pumps, those agents who are the most patient or just plain lucky get the gasoline, while the most productive agents may either get no gasoline or waste precious time and resources while waiting in line. This situation affects businesses directly if they purchase gasoline but also indirectly if it creates uncertainty about whether employees arrive at work on time. If the rules of supply and demand are suspended, then idled resources and misallocation of energy lead to less productive use of energy, which shows up as lower productivity or TFP.

If indeed all of the differential impact on growth is due to price controls, an implication from our model is that price controls not only harm output growth, but their indirect impact on growth (measured as the difference between the impulse response functions from specifications A and B) is larger than the direct effect of energy price hikes (the impulse response function of specification A).

Conclusions

The general equilibrium analysis in this study shows that energy price shocks can cause a large drop in output if and only if they also affect the underlying productivity (TFP) trend. Thus, today's economy is very resilient because the TFP process is not being affected by energy price shocks, as it was from 1970 to 1985. Even the major energy price increases of 2003 and 2005, which are comparable in magnitude to those in 1974 and 1979, did not cause a recession as the underlying trend in TFP has been positive since there were no negative spillovers from energy prices to TFP like those experienced before 1985.

The article discusses that a possible reason for this negative correlation was the energy price controls observed in the 1970s in response to energy price shocks. Thus, if the drop in TFP is due to a bad policy, then the implication from our analysis is that energy price shocks themselves are far less damaging than the policies that may be implemented to address them. This is an example of the medicine likely doing more harm than the condition it was supposed to cure.

Do we believe that the U.S. economy is shielded from any future recessions? Certainly not! While the economy is more resilient to energy price shocks than before 1985, it is still subject to fluctuations in TFP unrelated to energy price hikes. In addition, if policies were to be implemented that inhibit the functioning of free markets, say, through price controls or other measures that lead to energy rationing, the economy will again be susceptible to energy price-induced recessions.

12. This figure is computed by first subtracting the marginal impact as reported in Figure 5 from the observed annual GDP growth rates, as reported by the BEA. This result can be viewed as a model estimate for the growth rate that would have prevailed in the absence of all energy price shocks. Then we add to that number the marginal impact computed under the counterfactual assumption of a negative correlation between $\varepsilon_{p,t}$ and TFP in 2003–05.

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