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ABSTRACT

The Response of Business Fixed Investment to Changes in Energy Prices: A Test of Some Hypotheses About the Transmission of Energy Price Shocks

Changes in firms' investment expenditures are considered one of the primary channels through which energy price shocks are transmitted to the economy. It is widely believed that the response of business fixed investment to energy price increases differs from its response to energy price decreases. We show that the apparent asymmetry in the estimated responses of business fixed investment in equipment and structures cannot be reconciled with standard theoretical explanations of asymmetric responses. Rather this evidence is an artifact (1) of the aggregation of mining-related expenditures by the oil, natural gas, and coal mining industry and all other expenditures, and (2) of ignoring an exogenous shift in investment caused by the 1986 Tax Reform Act. After controlling for these factors, formal statistical tests are unable to reject the assumption of symmetric responses to energy price shocks for all components of investment in structures. For nonresidential equipment there is weak statistical evidence of classical asymmetries in some components, but not in the aggregate. Once symmetry is imposed and mining-related expenditures are excluded, the estimated response of business fixed investment in equipment and structures tends to be small and mostly statistically insignificant. Historical decompositions show that energy price shocks have played a minor role in driving fluctuations in nonresidential fixed investment other than investment in mining. Our conclusions are largely robust to defining energy price shocks in terms of percent changes, large percent changes or net percent changes of energy prices; they are also robust to using alternative measures of energy prices and to weighting energy prices by the energy share in value added.

JEL Classification: E22, E32 and Q43
Keywords: 1986 tax reform act, asymmetric responses, equipment, nonresidential fixed investment, oil price shocks and structures

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1 Introduction

It is widely accepted that in the absence of a major disruption in consumers' and firms' expenditures, the effects of energy price shocks on the U.S. economy are bound to be small (see Hamilton 2005). In related work, Edelstein and Kilian (2007) have investigated the response of consumers' expenditures to changes in energy prices, including the response of residential fixed investment. Little is known, however, about the response of firms' investment expenditures with the notable exception of Herrera's (2006) work on inventory adjustments in response to energy price shocks. This paper will investigate in detail how nonresidential fixed investment in structures and in equipment responds to changes in energy prices.

There are two main channels by which energy price shocks may affect nonresidential fixed investment. One channel is the increase in the marginal cost of production associated with an increase in the price of energy. This cost channel depends on the cost share of energy. A second channel operates through reduced demand for the firm's output, as consumer expenditures fall in response to rising energy prices (see Edelstein and Kilian 2007). The response of nonresidential fixed investment need not be symmetric in energy price changes. For example, changes in energy prices are thought to create uncertainty about future energy prices, causing firms to postpone irreversible investment decisions (see Bernanke 1983 and Pindyck 1991). This uncertainty effect has implications for both supply-side and demand-side accounts of the transmission of energy price shocks. Specifically, firms may respond to uncertainty about future production costs or to uncertainty about future sales and revenue. In either case, when energy prices rise, the uncertainty effect will reinforce the decline in firms' investment expenditures due to reduced consumer demand and higher energy costs. When energy prices fall, in contrast, the uncertainty effect counteracts the increase in investment expenditures driven by lower costs and increased consumer demand, dampening the increase in investment spending.

Models of asymmetric transmission mechanisms such as the uncertainty effect have been widely used in the empirical literature on oil prices to explain the apparent breakdown of the linear relationship between real GDP growth and oil prices in the mid-1980s (see, e.g., Mork 1989, Hooker 1996). This breakdown became apparent after the collapse of OPEC in late 1985, when crude oil prices plummeted, yet the U.S. economy failed to boom. As Edelstein and Kilian (2007) show, the weak economic growth of 1986 was not caused by weak growth in household consumption or residential fixed investment. Rather it can be traced to an unprecedented drop in the growth rate of firms' fixed investment. Thus, it is natural to investigate the possibility that nonresidential fixed investment may respond asymmetrically to energy price shocks.

In this paper, we allow for a variety of different measures of energy price shocks including percent changes in energy prices, large percent changes and net percent changes. We perform formal statistical tests for the presence of asymmetry in the response of nonresidential fixed investment to energy price shocks of different sign, but the same magnitude. Symmetry in this context means that the sum of the impulse response function to energy price increases and of the impulse response function to energy price decreases is jointly equal to zero at all horizons. The existing literature has not assessed the evidence for asymmetries by formal statistical tests of the symmetry assumption. One common approach is to include oil price increases and decreases as separate variables in a single-equation model for output growth, and to perform a Wald test for the equality of the coefficients on the lags of these variables (see, e.g., Mork 1989, Dotsey and Reid 1992, Hooker 1996, and Hooker 2002). A drawback of this approach is that this test only alerts us to differences in the slope coefficients, whereas we are really interested in whether the impulse responses to positive and negative energy price shocks are different. Another common approach has been simply to inspect the point estimates of the impulse response functions without formal testing (see, e.g., Davis and Haltiwanger 2001). That comparison, however, tells us nothing about the statistical significance of the difference. Nor do tests for pointwise statistical significance of the differences in the impulse response function constitute a formal test of the symmetry assumption.

The question of whether nonresidential fixed investment responds symmetrically to energy prices increases and decreases has not been addressed in the literature. Our study is the first to provide a detailed examination of the components of nonresidential fixed investment in structures and equipment. Using the BEA's National Income and Product Account data, we study the responses of nonresidential investment in structures (including commercial and health care, manufacturing, power and communication, mining and other structures) and in equipment (including information processing, industrial, and transportation equipment, mining and oil field machinery, and all other equipment). Special attention is given to mining and oil field machinery and to mining structures devoted to petroleum, coal and natural gas exploration and extraction.

We show that the apparent asymmetry in the estimated responses of business fixed investment in equipment and structures cannot be reconciled with standard theoretical explanations of asymmetric responses. Rather this evidence is an artifact (1) of the aggregation of mining-related expenditures by the petroleum industry and all other expenditures, and (2) of ignoring an exogenous shift in investment mainly caused by the 1986 Tax Reform Act. After controlling for these factors, formal statistical tests are unable to reject the hypothesis of symmetric responses to energy price shocks for all components of investment in structures. For equipment there is weak statistical evidence of asymmetries in some components, but not in the total. Thus, there is no empirical support for theoretical models of the uncertainty effect on business fixed investment expenditures such as Bernanke (1983) or Pindyck (1991) nor is there support for the reallocation effect emphasized in Hamilton (1988), which stipulates frictional unemployment in response to any change in real energy prices, as resources are being shifted across industries.

Once symmetry is imposed and petroleum-industry related expenditures are excluded, the estimated response of business fixed investment in equipment and structures is small and statistically insignificant. Our conclusions are in most cases robust to defining energy price shocks in terms of percent changes, large percent changes or net percent changes in energy prices; they are also robust to using alternative measures of energy prices and to weighting energy prices by the energy share in value added. Historical decompositions show that for most forms of investment in structures and equipment, the contribution of energy price shocks historically has been negligible. For mining and oil field machinery the cumulative contribution of energy price shocks has been somewhat larger. An even larger cumulative effect is obtained for mining structures (which consist mainly of structures devoted to the exploration and extraction of petroleum, natural gas and coal).

The remainder of the paper is organized as follows. In section 2, we propose a measure of intermediate energy prices that forms the basis of our analysis. We further document the evolution of the share of energy inputs in U.S. value added, and we summarize the results of various sensitivity analyses we conducted. In section 3 we investigate the evidence for asymmetric responses of business fixed investment to energy price shocks. Building on the results of sections 3, in section 4 we impose symmetry in estimating the response of nonresidential fixed investment in structures and in equipment. That same model is also used to quantify the cumulative contribution of energy price shocks to fluctuations in real nonresidential fixed investment. We conclude in section 5.

2 Specification of the Energy Price Series

There is reason to believe that crude oil prices do not reflect the energy costs faced by firms. Few firms use crude oil as an input to production. Rather firms tend to purchase refined petroleum products such as gasoline or heating oil, or they rely on electricity and natural gas. Hence, we focus on a broad measure of energy prices in the form of the BLS producer price of processed fuels and lubricants. The choice of this index is not innocuous. Indeed, it is plausible that a given change in energy prices may affect firms differently from households. Whereas the latter's purchasing power depends primarily on the price of motor fuels such as gasoline, as documented in Edelstein and Kilian (2007), firms depend to a much greater extent on electric power and natural gas. Our approach differs from much of the earlier literature which has focused on shocks to crude oil prices (see, e.g., Davis and Haltiwanger 2001; Hamilton 2003; Lee and Ni 2002). By focusing on crude oil prices, these studies potentially omit important price shocks caused in the process of refining crude oil. For example, following Hurricanes Rita and Katrina in late 2005 crude oil prices declined, whereas gasoline prices skyrocketed, as refineries in the Gulf area were shut down. They also may dramatically overstate the magnitude of the energy price shocks faced by firms, as illustrated below.

2.1 The Baseline Energy Price Series

As the energy input price, we use the Bureau of Labor Statistic's Processed Fuels and Lubricants producer price index (PPI) which is available on a monthly basis for the 1973.1-2006.12 period. This price index includes the prices of all energy goods purchased by firms as inputs in production. Table 1 lists the components of this price series and each component's weight in the construction of the index in 2002. The largest component is electric power (40.3%), followed by natural gas (14.5%) and unleaded gasoline (14%). Given the lack of suitable data prior to January 1973, we extrapolate this price series back to January 1970 using the Fuels and Related Products and Power PPI. The latter PPI includes crude energy and residential energy prices in addition to intermediate energy inputs prices. Given the high correlation of the two series after 1973, the error is likely to be small. We obtain a measure of real energy prices by deflating the resulting index by the PPI for all commodities.

The upper panel of Figure 1 plots the real price of intermediate energy inputs for 1970.1-2006.12. It shows that the real price of energy in late 2005 briefly exceeded its 1981 peak and at the end of the sample is similar to its level in 1985, before the collapse of OPEC. Thus, the real energy prices faced by firms are considerably higher by historical standards than the corresponding real price of crude oil (see Figure 1 in Kilian 2007). Moreover, the magnitude of real energy price shocks faced by firms is much smaller in general than the corresponding shocks to crude oil prices, owing to the large share of electric power available at stable prices. For example, in 1974, crude oil prices rose twice as much as intermediate energy prices. Even more strikingly, in 1990, crude oil prices rose by 83%, whereas intermediate energy prices only rose by 12%. This evidence confirms the importance of distinguishing between crude oil prices and the energy prices faced by firms.

The panel below shows the quarterly growth rate in real energy prices faced by firms for 1970.II - 2006.IV. The latter series will form the basis of the empirical analysis in the sections below. As expected, the series shows marked spikes in 1974, 1979/1980, 1981, 1986, 1990/91, and 2003, during times of major disturbances in crude oil markets, and in 2005, when U.S. refining capacity was sharply reduced in the wake of Hurricanes Rita and Katrina. In the sections below, we will treat innovations to the (suitably defined) percent change in real intermediate energy prices as predetermined with respect to nonresidential fixed investment. This assumption will allow us to estimate the response of investment expenditures to energy price shocks, while controlling for reverse causality.

2.2 To Weight or Not to Weight

It is a commonly held view that the share of energy in value added has declined over time, making changes in energy prices less important for the U.S. economy (see, e.g., Bernanke 2006). Such changes in the economy-wide energy share are important for empirical work since they may invalidate standard regression analysis based on unweighted energy price innovations. While estimates of this share have been constructed, for example, by Rotemberg and Woodford (1996), the evolution of this share over time does not appear to have been documented. Following Rotemberg and Woodford (1996), the share of energy inputs in GDP is taken to be the sum of nominal value added in oil and gas extraction and imports of petroleum and petroleum products, divided by nominal GDP. This definition is natural in our context since we are interested in economy-wide expenditures on fixed investment and are unable to break down the aggregates by industry.

Notwithstanding the common view that the energy share has declined since the first oil shock of 1973, there do not appear to be data available on this energy share prior to 1977.[1] The annual energy share in value added for 1977-2005 is plotted in the lower panel of Figure 1. The average share over our sample period is 2.3%. Starting at 3.3% in 1977, the energy share rises through the late 1970s, briefly reaching a maximum of 5% in 1981. The share then falls throughout the 1980s and 1990s, reaching a minimum of 1% in 1998 following the Asian crisis. Since this time, it has risen back to its 1977 level of 3.3% in 2005. Thus, the common view that the share of energy in GDP has fallen since the 1970s must be partially revised.

An important question is whether these changes in the energy share affect the main conclusions of this paper. In sensitivity analysis (not reported in this paper) we verified that this is not the case for the 1977-2005 period. In fact, weighting the change in intermediate energy prices by the energy share makes little difference.[2] As the weighted and unweighted quarterly energy price changes have a correlation of 99%, the estimated responses of different types of structures and equipment investment to weighted price shocks (properly scaled) are virtually identical to the responses to

[1] Nominal value added in oil and gas extraction is reported by the BEA on an annual basis from 1977 through 2005. Nominal imports of petroleum and petroleum products are also available from the BEA for 1978-2005. We extrapolate the latter series back to 1977 using the percent change in the dollar value of imported barrels of crude oil (defined as the number of barrels of crude oil imported into the U.S. times the refiner acquisition cost for imported crude oil per barrel of crude oil). Since year-over-year changes in nominal imports of petroleum and petroleum products and in nominal imports of crude oil are highly correlated over the 1977-2005 period, this is likely to be a good approximation.

[2] Since the data used in computing the energy share are only available at annual frequency, we use linear interpolation to generate quarterly weights for 1977.IV-2005.IV.

unweighted price shocks. We therefore abstract from the weighting issue altogether, which allows us to extend the sample back to 1970.II. This increase in sample size not only improves the accuracy and power of the statistical tests at the center of our analysis, but it also allows us to assess the role of energy during the two oil price shocks of the 1970s, which would not be possible using weighted energy price changes.

2.3 Other Energy Price Measures

While there are good reasons to treat intermediate energy prices as the relevant measure of energy prices for firms, as discussed above, other choices are possible and different measures of energy prices might produce different results. Firms may adjust their investment spending in response to changes in energy costs as well as to changes in revenues. If firms react primarily to production costs, then a measure of intermediate energy prices is most appropriate. On the other hand, if firms respond primarily to changes in consumer demand for their goods and services, then a measure of consumer energy prices is more appropriate. While all empirical results reported in the sections below are based on real energy input prices, we verified that our main conclusions are robust to alternative measures of energy prices. Notably, we experimented with the BEA's PCE price index for energy goods and services, which includes gasoline (and other motor fuels), natural gas, electricity, and all other energy goods (including heating oil, coal, and oil lubricants). This price index was deflated by the overall PCE price index. The primary difference between the real consumer energy price and the real intermediate energy inputs price is the weight devoted to different components of each index. The correlation between the two indices is quite high ($\rho = 0.97$). In sensitivity analysis (not reported in this paper), we found that our qualitative conclusions are unaffected whether we use the baseline measure of intermediate energy price changes, unweighted real consumer energy price changes or consumer price changes weighted by the energy share in consumption (see Edelstein and Kilian 2007).

3 Does Nonresidential Fixed Investment Respond Asymmetrically to Energy Price Increases and Decreases?

In this section, we study impulse response estimates based on a series of bivariate VAR models. Each VAR model includes a suitably defined transformation of the quarterly change in energy prices defined in section 2. It also includes the quarterly percent change of the component of real nonresidential fixed investment that is of interest, as reported by the BEA. The sample period is 1970.II-

2006.IV. The VAR models are identified recursively with energy prices ordered first, indicating that energy price innovations are not affected contemporaneously by innovations to real nonresidential fixed investment.[3] The advantage of using a VAR model is that it isolates the linearly unpredictable component of changes in energy prices and allows for reverse causality.[4]

Throughout this paper, we impose a VAR lag order of 4 quarters. This lag order tends to be larger than the lag order selected by the Akaike Information Criterion conditional on an upper bound of 12 quarterly lags, which in some cases selected an implausibly low lag order. We present point estimates of the cumulative response of real investment to a one-time, one standard deviation energy price shock. The maximum horizon of the impulse response function is six quarters. The 95% bootstrap confidence intervals are based on the bias-corrected method of Kilian (1998).

We investigate the evidence for asymmetries as follows: Our baseline approach is to split percent changes in the real price of energy into positive and negative changes. As is standard in the literature, we define $\Delta p_t^+ = \Delta p_t \cdot 1(\Delta p_t > 0)$ and $\Delta p_t^- = \Delta p_t \cdot 1(\Delta p_t < 0)$ where $1(\cdot)$ denotes the indicator function and Δp_t the percent change in energy prices (see, e.g., Mork 1989). We then run one bivariate linear VAR model in energy price increases and the percent change in investment, and a second linear VAR model in energy price decreases and the percent change in investment. Finally, we compare the resulting responses of investment (controlling for the magnitude of the shock). If the data are generated by a VAR model in Δp_t and in investment growth, then in population the two response functions will be exact mirror images of one another. Comparing the responses allows us to characterize the nature of the asymmetry in the point estimates, if any, as described further below. In addition, we conduct a formal Wald test of the symmetry of the response functions. This test is based on a modification of the residual-based bootstrap method of Kilian (1998) that takes proper account of the fact that the underlying VAR models are only seemingly unrelated and that preserves the contemporaneous correlations in the data across models.

The baseline approach assumes that firms respond proportionately to the magnitude of the shock. Alternatively, it is possible that firms only respond to large shocks. We allow for that possibility by alternatively defining energy price shocks as increases or decreases that exceed 4.04%, which corresponds to one standard deviation of the percent change in energy prices. A third possibility is that firms respond only to changes in energy prices that are unprecedented in recent history (see

[3] Under the assumption that energy price changes are predetermined, there is no loss in generality in restricting ourselves to bivariate models. As a practical matter, qualitatively similar results would be obtained if we added a third variable such as consumption growth to the VAR model.

[4] Our approach does not allow us to differentiate between energy price changes driven by demand and by supply shocks in energy markets. The distinction between demand and supply shocks can be important, as these shocks tend to have very different effects on macroeconomic aggregates (see Kilian 2007). Identifying these shocks is not straightforward when dealing with refined products. The impulse responses shown below hence are best viewed as an average reflecting the (unknown) composition of demand and supply shocks over our sample period.

Hamilton 1996, 2003). We address this possibility by using a measure of the net energy price increase, defined as the difference between the current price and the maximum price over the previous year if the current price is larger than the previous maximum, and zero otherwise. Edelstein and Kilian (2007) extend this measure to include net energy price declines that are constructed in a similar fashion.[5] All three measures of energy price shocks are shown in Figure 2. For each specification, increases in prices are represented by positive values and decreases by negative values, allowing both series to be shown in the same plot.

Since increases and decreases are mutually exclusive, the respective series for increases and for decreases are shown in the same plot. A natural starting point for the analysis is the full-sample impulse response estimates for 1970.II-2006.IV. Full-sample estimates are potentially misleading, however. As discussed in Edelstein and Kilian (2007), a complicating factor in testing for symmetric responses is the existence of exogenous shifts of nonresidential fixed investment spending during this sample period. The most prominent of these shifts is associated with the 1986 Tax Reform Act, which had a negative effect on investment spending at a time of rapidly falling energy prices precipitated by the collapse of the OPEC cartel in late 1985. Real nonresidential investment in equipment fell by 4.65% that year, while real investment in structures fell by 16.35% (relative to their respective means), as the investment tax credit was repealed in the first quarter of 1986 and real estate tax shelters were eliminated. Failing to account for this exogenous shift at a time of sharply declining energy prices will tend to bias the test results in favor of asymmetry.

We attempt to account for the effects of the 1986 Tax Reform Act in two alternative ways. The first approach is to split the sample and to focus on the 1988.I-2006.IV period. The break date of 1987.IV was chosen to exclude all short-run effects of the 1986 Tax Reform Act from the second part of the sample.[6] A drawback of this approach is that splitting the sample in half may undermine the power of the symmetry tests. On the other hand, this approach does not constrain any of the model parameters and, by eliminating all confounding influences that are associated with the 1970s and early 1980s, may provide the most accurate representation of the effects of energy price shocks on investment at the end of the sample. The second approach involves regressing the growth rate of real investment on a constant and a dummy for each of the four quarters of 1986 and using the residuals from this regression as the second variable in the recursively identified VAR model. This approach implicitly assumes that the 1986 Tax Reform Act only affected the mean growth rate of real investment and that the effects of the 1986 Tax Reform Act on investment were concentrated in 1986. This approach allows us to make use of the full sample, increasing the power of statistical

[5] Our results are qualitatively robust to considering the net change relative to the preceding three years.

[6] The results are similar if the sample is split at the 1987.I quarter.

tests of symmetry, but it abstracts from other forms of structural change.

3.1 Testing for Asymmetries in the Response of Nonresidential Fixed Investment

Tables 2a-2e summarize the pattern of impulse response estimates for various components of nonresidential fixed investment for the 1970.II-2006.IV period, the 1988.I-2006.IV period, the 1970.II-1987.IV period, the 1970.II-1987.IV period (including 1986 dummies), and the 1970.II-2006.IV period (including 1986 dummies), respectively. We show separate results for three specifications of energy price shocks: percent changes in energy prices (C), large percent changes in energy prices (LC) and net percent changes in energy prices relative to the preceding year (NC), as defined earlier. To conserve space the plots of the underlying impulse response estimates are collected in the Not-for-Publication Appendix.[7] Rather than present each of the 168 impulse response functions and the corresponding 168 Wald tests of the symmetry hypothesis, we summarize our findings succinctly in tables. We begin by classifying the response patterns. For a typical investment expenditure item such as manufacturing structures, one would expect one of the following response patterns:

> *No response*: The responses of investment to positive and negative energy price shocks are not statistically significant at the 95% confidence level.
>
> *Symmetry*: The negative response to positive energy price shocks and the positive response to negative price shocks are approximately equal in magnitude and at least one of the responses is statistically significant.
>
> *Classical asymmetry*: There is a statistically significant negative response of investment to positive energy price shocks and a response of investment to negative energy price shocks that is bounded above by the absolute magnitude of the response to a positive shock.
>
> *Perverse asymmetry*: Any asymmetry in the responses that departs from the classical asymmetry predicted by commonly used economic models of the transmission of energy price shocks.

As it turns out, these four patterns exhaust the possibilities encountered in our impulse response function estimates with one important exception. That exception is investment in *mining structures* and investment in *mining and oil field equipment*. Since crude oil, coal and natural gas producers

[7] Each row in Figures A.1a-A.1e shows the impulse response for a specific component of structures investment to a positive and negative energy price shock under each of the three energy price shock specifications.

account for 92.2% of all capital expenditures of the mining sector, energy price increases tend to stimulate investment in mining activities.[8] Hence, the notion of symmetry (or of classical asymmetry) for these mining-related expenditures is the mirror image of how these terms are defined for all other investment expenditures:

> *No response*: The responses of investment to positive and to negative energy price shocks are not statistically significant at the 95% significance level.
>
> *Symmetry*: The positive response to positive energy price shocks and the negative response to negative energy price shocks are approximately equal in magnitude and at least one of the responses is statistically significant.
>
> *Classical asymmetry*: There is a statistically significant negative response of investment to negative energy price shocks and a response of investment to positive energy price shocks that is bounded above by the absolute magnitude of the response to a negative shock.
>
> *Perverse asymmetry*: Any asymmetry in the responses that departs from the classical asymmetry predicted by commonly used economic models of the transmission of energy price shocks.

We use checkmarks in Tables 2a-2e in the appropriate columns to identify which responses follow which pattern. In addition, we use *, **, and ***, to indicate rejections of the symmetry hypothesis at the 10%, 5% and 1% level, respectively. It is possible for a response to be asymmetric in the sense that the Wald test rejects symmetry, yet be classified as *No response*, if the impulse response coefficients themselves are not statistically different from zero.

Under the null hypothesis of symmetry the response of investment to a positive energy price shock at each horizon is exactly the mirror image of the response to a negative energy price shock of the same magnitude. This hypothesis may be expressed as a Wald test statistic with an asymptotic χ^2_7-distribution, given our choice of impulse response horizon. We estimate the variance of the estimator based on a modification of the residual-based bootstrap method of Kilian (1998) that takes proper account of the fact that the underlying VAR models are only seemingly unrelated. The bootstrap algorithm is designed to preserve the contemporaneous correlations in the data across regression models.

It is useful to analyze separately the responses of nonresidential investment in structures and in equipment, which account for 32% and 68%, respectively, of total nonresidential fixed investment.

[8]See U.S. Census Bureau 2005, Table 1. Industry Statistics: 2002. We added capital expenditures for coal mining (5%) and for oil and gas extraction (78%), and the respective support activities (10%) including drilling.

We begin with nonresidential structures.

3.1.1 Asymmetries in Nonresidential Investment in Structures

A natural conjecture is that total nonresidential fixed investment in structures should decline, as energy prices rise, and increase, as energy prices fall. The results for structures are shown in the upper panel of Tables 2a-2e. We further differentiate between *mining structures*, *commercial and health care structures*, *manufacturing structures*, *power and communication structures* and *other structures.*

Full-Sample Analysis for 1970.II-2006.IV: The full-sample results in Table 2a show a perverse asymmetry for total nonresidential investment in structures reflecting the fact that these expenditures do not fall significantly in response to positive energy price shocks, but fall significantly in response to negative energy price shocks. This seemingly paradoxical result holds regardless of the specification of the energy price shocks. While not statistically significant at conventional significance levels, this evidence of asymmetry is clearly at odds with conventional explanations of asymmetries in the response of nonresidential investment expenditures.

It is useful to decompose structures investment further. The second row of Table 2a suggests that mining structures are characterized by highly significant classical asymmetries of the type anticipated based on conventional economic theories. Thus, one possible explanation of the perverse asymmetry in total structures investment is a simple *composition effect.* Total structures is the sum of investment in industries that use energy as an input (and that depend on consumer demand) and of investment by mining industries that produce energy in the form of crude oil, coal or natural gas. Thus, if the response of mining expenditures exhibits a classical asymmetry, as shown in Table 2a, and if nonresidential structures excluding mining do not, then aggregating these two components will by construction produce a perverse asymmetry.

This composition effect is illustrated in Figure 3 using a hypothetical example. For expository purposes, we postulated a small symmetric response of nonresidential structures excluding mining (upper panel). The panel below shows a classical asymmetry in the response of expenditures on mining structures. Such an asymmetry could arise for any number of reasons, including an uncertainty effect that dampens the positive response to higher energy prices and strengthens the negative response to falling energy prices. An alternative explanation could be that there were few domestic investment opportunities in response to rising energy prices in the United States during our sample period, making it difficult to invest in energy production domestically, while the option of cutting investment in mining in response to falling energy prices always has been available. For our purposes, the source of this classical asymmetry is immaterial. Assuming equal weights for expository purposes and summing the symmetric response in the first panel and the hypothesized asymmetric response of mining in the second panel, produces a response for total nonresidential structures that looks perverse from the point of view of conventional economic theories of the transmission of energy price shocks in that total investment rises somewhat in response to positive energy price shocks and falls strongly in response to negative energy price shocks.

The composition effect is quantitatively important in the data despite the relatively small share of mining structures in total structures, which ranges from under 10% to 30%, depending on the sample period. It can be shown that under the C specification, for example, the p-value of the symmetry test after excluding mining rises sharply from 0.20 to 0.48, indicating weakening evidence of perverse asymmetries. Similar results hold for the other two specifications of energy price shocks.

As Table 2a shows, in no case is there evidence of statistically significant asymmetries outside the mining industry. There is weak evidence of a perverse asymmetry even in *total nonresidential structures excluding mining*, however. That evidence cannot be explained based on the composition effect. Since no such evidence is found for any of the components of *total nonresidential structures excluding mining,* the apparent asymmetry in this point estimate is likely to be spurious. In fact, the only component of *total nonresidential structures excluding mining*, for which there is any evidence of asymmetries, is *other structures* and the asymmetry is of the classical rather than the perverse type.[9]

Split-sample Analysis for 1970.II-1987.IV and 1988.I-2006.IV: There has been much discussion of the proposition that the effect of energy price shocks has declined since the 1970s and early 1980s. It is therefore instructive to split our sample in half. We choose to break the sample in 1987.IV, for reasons discussed below. Table 2b focuses on the second half of the sample: 1988.I-2006.IV. Compared to the full sample, we see that none of the asymmetries remain statistically significant, and that the qualitative patterns of the responses change. Except under specification C, there is no evidence at all of an asymmetry in the response of *total structures.* The perverse asymmetry encountered under the first specification can be traced to the weak evidence of classical asymmetries in the response of *mining.* Excluding *mining*, there is no longer any evidence of perverse asymmetries in nonresidential structures investment. Under the C specification, for example, the p-value of the symmetry test rises slightly from 0.85 to 0.88 after excluding *mining*, consistent with the weak evidence of classical asymmetries in *mining.* None of the components of structures exhibits

[9] *Other structures* include religious structures, educational and vocational structures, lodging, amusement and recreation structures, farm structures, transportation structures, and other infrastructure.

statistically significant asymmetry in the second half of the sample. Thus, for 1988.I-2006.II, there seems to be little support for the classical asymmetries discussed in the literature.

In contrast, the results for the first half of the sample in Table 2c are far less clear-cut. Table 2c shows a clear pattern of classical asymmetries in mining structures. The only difference from the full sample is the lack of statistical significance. Using the percent change specification of energy price shocks (C), there is some evidence of a perverse asymmetry in total nonresidential structures (whether *mining* is excluded or not), but there is no such evidence for the other two specifications. Excluding *mining* sharply raises the p-value of the symmetry test from 0.51 to 0.84, again under the C specification. There also is systematic, if statistically insignificant, evidence of classical asymmetries in *other structures* and under the LC specification for *total structures*.

1970.II-1987.IV and 1988.I-2006.IV Revisited: Why are the results for the two subsamples so different? As discussed in Edelstein and Kilian (2007), there is reason to believe that the results for the first half of the sample are distorted. The distortion arises because we do not control for exogenous shifts in investment that occurred at the same time as the sharp decline in energy prices in the mid-1980s. Perhaps the most important candidate for such an exogenous shift in nonresidential investment is the 1986 Tax Reform Act. Investment in commercial structures including office buildings often served as a tax shelter prior to 1986. By removing the real estate tax shelter, the 1986 Tax Reform Act caused a sharp exogenous drop in investment in commercial and office space in 1986 that may easily be mistaken for an asymmetry (see *Survey of Current Business* 1987, p. 4). The fact that the only evidence for perverse asymmetries in Table 2c arises for commercial and health care structures is consistent with this view.[10]

In addition, Edelstein and Kilian (2007) have suggested that the seemingly asymmetric response of investment in the mining sector in 1986 may have been driven by the mining industry's reaction to the collapse of OPEC in late 1985. That response far transcended the response that one would have expected based on the decline in energy prices in 1986 alone, suggesting that the sudden collapse of OPEC was viewed as an exogenous shock by the mining industry over and above the decline in energy prices.

In Table 2d we control for both of these effects by specifying four intercept dummies in the VAR model, one for each quarter of 1986. Note that we do not include dummy variables for any other tax reform, but the Tax Reform Act of 1986. While there have been other tax bills over the course of our sample period (1970.II-2006.IV), the 1986 Tax Reform Act among major tax reforms stands out as specifically targeting fixed investment in structures and equipment. What distinguishes the 1986

[10] Data limitations prevent us from disentangling commerical and office space from health care structures.

Tax Reform Act even further from other tax reforms is that it occurred at the same time as a major decline in energy prices. In fact, the 1986 decline in energy prices is the only major decline in energy prices in the first part of the sample. It is this coincidence of these two unique events that is likely to cause a spurious correlation in our sample and requires the inclusion of a dummy variable. Put differently, if the 1986 Tax Reform Act had occurred in some other year, it would not be necessary to control for it in estimating the correlation of investment growth and energy price decreases.

Table 2d shows that the addition of time dummies for 1986 eliminates all evidence of perverse asymmetries in structures for the 1970.II-1987.IV period. With the exception of *other structures* which appear to exhibit a classical asymmetry, none of the components of structures nor *total structures* show a statistically significant response to energy price shocks. These results are the same across all three specifications.

One drawback of the evidence in Tables 2b and 2d is that the reduction in sample size associated with sample-splitting may render some results statistically insignificant merely because of lower power. There is also a greater chance of obtaining an apparent asymmetric pattern merely by chance. Table 2e therefore revisits the full-sample analysis with 1986 dummies.

The results are stronger than for the second half of the sample in that there is no evidence of asymmetries in *total structures*. The results in Tables 2b, 2d, and 2e also agree in that there is no significant asymmetry in total nonresidential *structures excluding mining*. Unlike in Table 2b, there is no evidence of asymmetry in the response of *mining structures* in Table 2e. Unlike in Table 2d there is evidence of a symmetric response of *mining structures*. The classical asymmetry in *other structures* in Table 2e is not statistically significant. No evidence at all remains of the perverse asymmetries that plagued the earlier analysis, which raises our confidence in the results. This result illustrates the importance of controlling for exogenous shifts in nonresidential investment in 1986.

We conclude that nonresidential investment in structures does not respond asymmetrically to energy price shocks. That result is robust to alternative specifications of energy price shocks. There is no statistically significant evidence of the asymmetric patterns suggested by various economic models of the transmission of energy price shocks (or of any other asymmetric patterns).

3.1.2 Asymmetries in Nonresidential Investment in Equipment

Having found no compelling statistical evidence of asymmetries in structures investment, we now turn to the evidence for nonresidential investment in equipment. The results for equipment are shown in the bottom panels of Tables 2a-2e. We distinguish between *mining and oil field machinery*, *equipment for information processing*, *industrial equipment*, *transportation equipment*, and all *other equipment*.

Table 2a shows that in the full sample, there is no evidence of perverse asymmetries in equipment, but a robust pattern of classical asymmetries with the exception of *information processing*. Only after excluding *mining and oil field machinery* is that pattern marginally statistically significant, and even in that case the rejection occurs only under one of three specifications. In contrast, if we focus on the results for 1988.I-2006.IV in Table 2b, much of the evidence of classical asymmetries vanishes. An exception is *mining and oil field machinery*. There is also some evidence of a perverse, but statistically insignificant asymmetry in the response of *industrial equipment*.

The results for 1970.II-1987.IV in Table 2c are closer to those for the full sample; the only difference being some evidence of perverse asymmetries in the response of *mining and oil field machinery*. That evidence weakens considerably in Table 2d, once we include the 1986 dummies. The 1986 Tax Reform Act sharply raised the effective tax rate for many corporations by severely curtailing deductions for capital expenditures and by eliminating the investment tax credit. For most types of equipment, the repeal of the investment tax credit, which became effective in the first quarter of 1986, amounted to the elimination of a 10% subsidy on investment. This fact helps explain the sharp drop in nonresidential fixed investment expenditures on equipment in 1986.[11] After controlling for these effects, all of the perverse responses for *mining equipment* become statistically insignificant. There is now a clear pattern of classical asymmetries in most components of equipment, but none of the patterns are statistically significant.

Moving to the full-sample results for the model with 1986 dummies in Table 2e, all of the perverse responses vanish and a very clear picture emerges. With the exception of *information processing* all forms of nonresidential investment in equipment appear to exhibit classical asymmetries. The strongest evidence against symmetry is obtained for the LC specification, including a 10% rejection of symmetry for *total equipment*. In contrast, under the NC specification, symmetry is never rejected, and under the C specification symmetry is rejected only for two disaggregates.

While it is difficult to compare formally the NC specification with the other two, we can test the support for the LC specification against the C specification, since one specification is nested in the other. This fact allows us to test formally the hypothesis that firms only respond to large percent changes in energy prices as opposed to responding to all percent changes in energy prices. Wald tests for the equality of the impulse responses to large percent changes in energy prices and the responses to percent changes in energy prices generate p-values of 0.63 for total equipment and of 0.67 for total equipment excluding mining and oil field machinery. Thus, there is no reason to reject the C specification which makes efficient use of all data on energy price changes in favor of the more limited LC specification. Whereas we cannot reject symmetry for the response of

[11] For details of the timing of the 1986 Tax Reform Act see Wakefield (1987).

total nonresidential equipment or for *mining and oil field machinery* under the C specification, we marginally reject symmetry at the 10% level for *total nonresidential equipment excluding mining and oil field machinery*. The latter rejection appears to be driven by *industrial equipment*. Thus, there is weak evidence for classical asymmetries in some forms of equipment investment under the C specification, but none under the NC specification. There is no evidence against symmetry in *total investment in equipment* for either specification, suggesting that there is not enough evidence to abandon the standard linear VAR model framework for investment.

3.1.3 Revisiting the Specification of the Energy Price Series

The results in Tables 2a-2e illustrate the importance of distinguishing investment in mining-related structures and equipment from other nonresidential investment. This distinction is all the more important, as the rationale for using intermediate energy prices for expenditures related to mining activities is questionable. A case can be made that investment expenditures on mining structures and on mining and oil field machinery should depend on the output price of primary energy goods more than on the input price of refined energy goods. We therefore computed an alternative set of results for mining structures and equipment based on the producer price index for crude oil (as a proxy for all primary energy goods). The results are similar to those in Table 2a in that for 1970.II-2006.IV there is statistically significant evidence of classical asymmetries in *mining structures*. Qualitatively similar results are obtained for the subsamples, but the statistical significance is lost in all cases. As in Table 2d, once we control for the 1986 dummies, the evidence for asymmetries in the first half of the sample weakens. For the full sample with 1986 dummies, we find impulse response patterns consistent with classical asymmetries, but none that are statistically significant.

For *mining and oil field machinery*, the results are more sensitive to the choice of the energy price series and more erratic under the crude oil price specification than the intermediate energy goods specification. There is weak evidence of asymmetries under the LC specification for the second part of the sample, but the C specification cannot be statistically rejected in favor of the LC specification. Likewise, the qualitative results for the full sample with 1986 dummies remain unchanged in that there is no evidence of statistically significant asymmetries. Thus, the choice of the energy price series does not affect our conclusions.

4 Quantifying the Effect of Energy Price Shocks on Real Nonresidential Fixed Investment

Given the lack of evidence for asymmetries in the responses of structures as well as equipment to energy price shocks, in this section our objective is to quantify these responses based on models that impose symmetry. Apart from the imposition of symmetry, our estimation methodology is the same as in the previous section. A positive one standard deviation shock amounts to a 3.9% quarterly increase in energy prices. We present results only for percent changes in energy prices. The estimated responses to large price changes and net price changes are qualitatively similar. We focus on the results for 1970.II-2006.IV (including 1986 dummies), 1970.II-1987.IV (including 1986 dummies) and 1988.I-2006.IV, so that we can assess the extent to which the estimates have declined over time. The 95% bootstrap confidence intervals are again based on the bias-corrected method of Kilian (1998).

4.1 The Response of Nonresidential Investment in Structures to Energy Price Shocks

Figure 4a focuses on the results for nonresidential investment in structures. The response of *total structures* is flat, if not positive, and never statistically significant, whether in the full sample or in the subsamples. Investment in *mining structures* increases by 5.1% after six quarters. The response is highly statistically significant. Interestingly, the response estimate for the second half of the sample is even more statistically significant, but that for the first half is statistically insignificant. Excluding *mining structures* does not alter the responses much; they remain statistically insignificant and close to zero. The same is true for the disaggregates. With the exception of *other structures*, the disaggregates tend to have flat responses. The response of *manufacturing structures* is associated with noticeably larger sampling uncertainty than the other responses.

4.2 The Response of Nonresidential Investment in Equipment to Energy Price Shocks

Figure 4b shows an insignificant decline in *total equipment* investment. In the full sample, a one-standard deviation shock lowers *total equipment* investment by -1.61%. The point estimate is dominated by the data for the first half of the sample. In the second half, the estimated response is virtually flat. In contrast, *mining and oil field machinery* shows a highly statistically significant increase in the full sample. The point estimate is 7.4% after six quarters and quite similar to the split-sample results, except that the split-sample results are not statistically significant. Excluding *mining and oil field machinery* from total investment in equipment makes little difference for the response estimates or their statistical significance.

Of the remaining forms of equipment investment, only the responses of *transportation* and of *other equipment excluding mining* are statistically significant. They also show the largest responses. Investment in *transportation equipment* drops by -3.7% after six quarters. The point estimate for 1970.II-1987.IV is -5.8% (yet only partially significant), whereas the point estimate for 1988.I-2006.IV is only -1.7% (and statistically insignificant). These results indicate that the response of investment in *transportation equipment* (unlike that of *total equipment excluding mining and oil field machinery*) has become less responsive to energy price shocks, a result that mirrors similar findings for motor vehicle consumption in Edelstein and Kilian (2007). *Other equipment excluding mining* drops by -3.1% in the full sample, and by -5.8% and -0.9% in the respective subsamples.

4.3 Quantifying Historical Fluctuations in Nonresidential Fixed Investment due to Energy Price Shocks

It is useful to put the impulse response estimates in perspective. The magnitude of a one standard deviation shock to energy prices is 3.9%. The biggest shock in our sample occurred in 2003.I and amounted to a 15.7% increase in energy prices. A shock of this size would leave *total nonresidential investment in structures* virtually unchanged after six quarters. It would raise investment in *mining structures* by 20.5% and lower all other nonresidential investment in structures by -0.7%. If the same shock were applied to investment in equipment, we would observe a decline of -6.5% in *total equipment excluding mining and oil field machinery*, but a sharp increase in investment in *mining and oil field machinery* of 29.7%. Given the negligible share of the latter component in *total nonresidential equipment investment*, the overall decline in *total nonresidential equipment investment* of -6.5% equals the decline in non-energy related equipment. Of course, such large shocks are rare and this prediction presumes that no other shocks occurred subsequently, whereas in reality positive shocks are often followed by negative shocks, as was indeed the case after the 2003 spike (see Figure 2).

While the estimated impulse response functions provide a measure of the response of real business fixed investment to a hypothetical permanent shock to energy prices, an equally insightful question is how important energy prices have been overall in driving fluctuations in nonresidential fixed investment during the 1970.II-2006.IV period. The answer to the latter question may be obtained from historical decompositions of the data on the basis of the full-sample estimates of the bivariate VAR model of the previous section (including the 1986 dummies).

The uppermost panel of Figure 5 shows the actual (demeaned) growth rates for total real structures investment excluding mining structures. It also shows the growth rates predicted based on the cumulative effect of the energy price shocks alone. The difference between the two series measures the extent to which investment growth is not explained by energy price shocks. The panel below shows the corresponding results for mining structures.

It is evident that only a small part of the fluctuations in non-mining structures investment is accounted for by the cumulative effect of energy price shocks. There is some evidence of a decline in investment growth in non-mining structures in the second half of the 1970s and in the early 1980s, for example, that is driven by energy prices. There is also some evidence of increased investment in the mid- and late 1980s and the late 1990s, but all these effects are dwarfed by the large positive spikes in investment in non-mining structures in 1971-1973, 1976-1979, 1984-85, and the large negative spikes in 1975, 1980, and 1982/83. This evidence is important because it supports the view that not only the booms in investment of the 1970s and 1980s, but also the major declines in investment in 1975, 1980 and 1982-83, were not primarily driven by energy price shocks (see, e.g., Barsky and Kilian 2002, 2004).

Energy price shocks do a somewhat better job at tracking the growth in investment dedicated to mining structures, but there remain important exceptions. For example, the sharp increase in domestic investment in mining structures in 1978/79 (during the time of the Iranian Revolution) is not explained by the cumulative energy price shocks. Similarly, the drop in investment in 1985 and in 1986 (after the collapse of OPEC) far exceeds what the model predicts.

The remaining two panels deal with mining and oil field machinery and with all other forms of equipment investment, respectively. The results for the latter aggregate are very similar to those for structures excluding mining structures. Energy price shocks do a somewhat better job at explaining fluctuations in investment in mining and oil field machinery than in other equipment investment. Interestingly, the decline in investment in mining and oil field machinery in 1986 is much less pronounced than for mining structures and to some extent is explained by energy prices. On the other hand, there are some major spikes in 1992/93 (and to a lesser extent in 2002/2003) that are not explained by energy price shocks.

We conclude that, at least outside the mining sector, energy prices historically have had only a negligible effect on the growth rate of real nonresidential fixed investment. Only for mining structures and to a lesser extent for mining and oil field machinery, have energy prices played a somewhat more important role.

5 Conclusion

The response of firms' fixed investment expenditures is one of the main channels for the transmission of energy prices to the U.S. economy that have been discussed in the literature on oil and the macroeconomy (see, e.g., Hamilton 2005). There are two main mechanisms by which energy price shocks may affect nonresidential fixed investment. One mechanism is that an increase in the price of energy raises the marginal cost of production. This cost channel depends on the cost share of energy. A second mechanism is through reduced demand for the firm's output, as consumer expenditures fall in response to rising energy prices (see Edelstein and Kilian 2007).

The response of nonresidential fixed investment need not be symmetric in energy price increases and decreases. The absence of an economic boom in 1986 following the rapid fall in energy prices as a consequence of the OPEC collapse in 1985, has led a number of researchers to incorporate asymmetries into models of the transmission of energy price shocks to the economy such as the uncertainty effect on irreversible investment decisions described in Bernanke (1983) and Pindyck (1991). A common view is that positive energy price shocks will lower nonresidential fixed investment, while negative energy price shocks of the same magnitude will not increase investment to the same extent. We referred to this pattern as a *classical asymmetry*. In contrast, a more conventional symmetric response would involve a negative response to positive shocks and a positive response to negative shocks of the same magnitude that sum to zero. We referred to this pattern as *symmetry*.

Despite the prominence of classical asymmetries in policy discussions and in economic modeling, it remains an unresolved empirical question whether the nonresidential fixed investment responses actually are symmetric or not. Clearly, the absence of the expected asymmetric pattern in the data would have immediate implications for the credibility of economic models of the transmission of energy price shocks that appeal to classical asymmetries. Our analysis addressed this question by comparing the responses of nonresidential fixed investment to positive and to negative energy price shocks of the same magnitude under the assumption that energy price shocks may be treated as predetermined with respect to nonresidential investment at the quarterly frequency. We showed that uncritical application of the VAR methodology will result in spurious evidence of asymmetries in the responses of nonresidential fixed investment and in particular in evidence of *perverse asymmetries*, in the sense that these asymmetries are at odds with predictions of commonly used economic models of the transmission of energy price shocks.

We traced this evidence to two problems in particular. One problem is that the aggregation of mining-related investment by domestic producers of coal, natural gas and crude oil with other forms of investment expenditures may generate perverse asymmetries (in the sense that the observed asymmetries are seemingly at odds with the predictions of economic models). We showed that this problem can be quantitatively important. The other problem is that impulse response estimates tend to be highly sensitive in small samples to an exogenous shift in nonresidential investment that occurred in 1986 during a major decline in energy prices. This shift was related in large part to the 1986 Tax Reform Act. We controlled for this shift by introducing quarterly intercept dummies for 1986 and/or by splitting the sample in 1987.IV. Excluding investment in mining-related activities and including the 1986 dummies removed much of the evidence of asymmetries in the 1970.II-1987.IV and 1988.I-2006.IV subsamples. The little evidence that remained became statistically insignificant.

In addition, we illustrated the importance of relying on long samples when estimating the effect of energy price shocks on real nonresidential investment. We showed that using the full 1970.II-2006.IV period in conjunction with the 1986 dummies helps eliminate all evidence of asymmetries that are economically implausible. Results for this final specification are free of all perverse asymmetries and in general quite robust to alternative specifications of energy price shocks.

We concluded that there is no compelling evidence of asymmetries in the responses of aggregate nonresidential investment in structures and no compelling evidence of asymmetries in the response of aggregate nonresidential equipment investment. Only in two cases did we find a marginal rejection of symmetry at the 10% level for components of equipment investment. There is no significant rejection of symmetry at all for the components of structures investment. These results are qualitatively consistent with recent findings by Edelstein and Kilian (2007) for the response of consumer durables and residential fixed investment in structures. Our results are robust to weighting energy price changes by the share of energy in value added (the evolution of which we documented in the paper) and robust to alternative specifications of the energy price series.

Theoretical models that incorporate asymmetric effects of energy price changes have played an important role in the recent literature. While there are several potential sources of asymmetry in the responses of nonresidential investment, our evidence casts doubt, in particular, on the view that investment is subject to an uncertainty effect of the type described in Bernanke (1983) and Pindyck (1991). If there is such an effect, it seems too small or too imprecisely estimated to be detected by our statistical tools. Similarly, our results are inconsistent with the existence of a reallocation effect of the type emphasized in Hamilton (1988). Thus, there is no compelling reason to abandon the assumption of symmetric responses to energy price shocks in empirical work. Moreover, there is no reason to discard theoretical models of the transmission of energy price shocks that imply symmetric responses to energy price increases and decreases.

Our analysis of the evidence of asymmetries has been at the aggregate level in that we focused on economy-wide investment expenditures broken down by type of investment. An alternative approach would have been to focus on plant-level evidence, as has been done successfully in modeling employment flows in response to oil price shocks (see, e.g., Davis and Haltiwanger 2001). There are many plausible sources of asymmetric adjustment to energy price increases and decreases at the plant level. In addition to investment being irreversible, as discussed by Bernanke (1983) and Pindyck (1991), there could be nonconvex adjustment costs or borrowing constraints, for example. The work of Doms and Dunne (1998), however, suggests that nonconvexities that seem important at the plant level, may disappear when aggregating investment data to the firm level, industry level or national level. Thus, it is conceivable that there is evidence of asymmetric investment responses at the plant level that does not carry over to aggregate investment expenditures. Further research is required to explore this possibility.

Our analysis in the remainder of the paper aimed at quantifying the effect of energy price shocks on nonresidential investment based on linear models that impose symmetry. We showed that, in response to a one percent increase in energy prices, *real nonresidential investment in equipment* falls by a statistically insignificant -0.41% after six quarters, whether or not *mining and oil field machinery* is included. The largest responses are found in *transportation equipment* with a statistically significant -0.95% decline, and in *mining and oil field machinery* which rises by a statistically significant 1.90%. Other forms of real equipment investment are largely unresponsive to energy price shocks. Real investment in *total nonresidential structures* increases by a statistically insignificant 0.03%, while real investment in *mining structures* (used for petroleum, coal and natural gas exploration and extraction) increases by a statistically significant 1.31%. Other forms of real structures investment are unresponsive to energy price shocks. Excluding *mining structures*, the response of nonresidential structures is -0.04%, but remains statistically insignificant.

We found no compelling evidence that nonresidential fixed investment in structures has become less responsive to energy price shocks since the mid-1980s with the exception of *other structures* (including religious, educational, transportation, and farm structures, among others). We found some evidence of a decline in the responsiveness of nonresidential fixed investment in equipment, mainly in *transportation equipment* and in *other equipment*. The declining response of investment in *transportation equipment* is consistent with evidence of a decline in the response of real consumption of vehicles in Edelstein and Kilian (2007).

We also addressed the closely related question of how important energy price shocks have been overall for U.S. nonresidential fixed investment. Historical decompositions show only a negligible cumulative effect on investment in equipment and structures. A partial exception is investment in mining structures and to a lesser extent investment in mining and oil field machinery.

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Table 1: Components of Processed Fuels and Lubricants PPI

Component	Percent Share
Liquefied petroleum gas	2.40
Electric power	40.32
Natural gas	14.50
Unleaded gasoline	13.98
Aviation gasoline	0.57
Kerosene	0.16
Jet Fuel	9.73
Home heating oil	2.06
#2 diesel fuel	11.36
Residual Fuels	2.42
Lubricating grease	0.14
Lubricating and similar oils	1.29
Petroleum and coal products, n.e.c.	1.10

Notes: Based on 2002 weights in processed fuels and lubricants. Source: U.S. Bureau of Labor Statistics.

Table 2a: Classification of Responses to Innovations in Real Energy Prices
1970.II-2006.IV

	No Response			Symmetric Response			Classical Asymmetry			Perverse Asymmetry		
	C	LC	NC	C	LC	NC	C	LC	NC	C	LC	NC
Nonresidential Structures												
Total										✓	✓	✓
Mining							✓**	✓*	✓***			
Total Excluding Mining										✓	✓	✓
Commercial and Healthcare	✓	✓	✓									
Manufacturing	✓	✓	✓									
Power and Communication	✓	✓*	✓*									
Other	✓							✓	✓			
Nonresidential Equipment												
Total							✓	✓	✓			
Mining and Oil Field Machinery							✓	✓	✓			
Total Excluding Mining and Oil Field Machinery							✓	✓*	✓			
Information Processing	✓	✓	✓									
Industrial							✓	✓	✓			
Transportation							✓	✓	✓			
Other Excluding Mining and Oil Field Machinery							✓	✓	✓			

Note: C: Change in real energy price. LC: Large change in real energy price. NC: Net change in real energy price. ✓ indicates that the estimated responses follow the pattern indicated. A formal definition of these patterns can be found in the text.
* Symmetry rejected at 10% level. ** Symmetry rejected at 5% level. *** Symmetry rejected at 1% level.

Table 2b: Classification of Responses to Innovations in Real Energy Prices 1988.I-2006.IV

	No Response			Symmetric Response			Classical Asymmetry			Perverse Asymmetry		
	C	LC	NC	C	LC	NC	C	LC	NC	C	LC	NC
Nonresidential Structures												
Total		✓	✓							✓		
Mining							✓	✓	✓			
Total Excluding Mining	✓	✓	✓									
Commercial and Healthcare	✓	✓	✓									
Manufacturing	✓	✓	✓									
Power and Communication	✓	✓	✓									
Other		✓	✓							✓		
Nonresidential Equipment												
Total	✓	✓	✓									
Mining and Oil Field Machinery							✓	✓	✓			
Total Excluding Mining and Oil Field Machinery	✓	✓	✓									
Information Processing	✓	✓	✓									
Industrial	✓										✓	✓
Transportation	✓	✓	✓									
Other Excluding Mining and Oil Field Machinery	✓	✓	✓									

Note: C: Change in real energy price. LC: Large change in real energy price. NC: Net change in real energy price. ✓ indicates that the estimated responses follow the pattern indicated. A formal definition of these patterns can be found in the text.
* Symmetry rejected at 10% level. ** Symmetry rejected at 5% level. *** Symmetry rejected at 1% level.

Table 2c: Classification of Responses to Innovations in Real Energy Prices
1970.II-1987.IV

	No Response			Symmetric Response			Classical Asymmetry			Perverse Asymmetry		
	C	LC	NC	C	LC	NC	C	LC	NC	C	LC	NC
Nonresidential Structures												
Total			✓					✓		✓		
Mining							✓	✓	✓			
Total Excluding Mining	✓	✓	✓									
Commercial and Healthcare		✓	✓							✓		
Manufacturing	✓	✓	✓									
Power and Communication	✓	✓	✓									
Other							✓	✓	✓			
Nonresidential Equipment												
Total							✓	✓	✓			
Mining and Oil Field Machinery		✓**								✓		✓**
Total Excluding Mining and Oil Field Machinery							✓	✓	✓			
Information Processing	✓	✓	✓									
Industrial							✓	✓	✓			
Transportation							✓	✓	✓			
Other Excluding Mining and Oil Field Machinery							✓	✓	✓			

Note: C: Change in real energy price. LC: Large change in real energy price. NC: Net change in real energy price. ✓ indicates that the estimated responses follow the pattern indicated. A formal definition of these patterns can be found in the text.
* Symmetry rejected at 10% level. ** Symmetry rejected at 5% level. *** Symmetry rejected at 1% level.

Table 2d: Classification of Responses to Innovations in Real Energy Prices
1970.II-1987.IV with 1986 Dummies

	No Response			Symmetric Response			Classical Asymmetry			Perverse Asymmetry		
	C	LC	NC	C	LC	NC	C	LC	NC	C	LC	NC
Nonresidential Structures												
Total	✓	✓	✓									
Mining	✓	✓	✓									
Total Excluding Mining	✓	✓	✓									
Commercial and Healthcare	✓	✓	✓									
Manufacturing	✓	✓	✓									
Power and Communication	✓	✓	✓									
Other							✓	✓	✓			
Nonresidential Equipment												
Total							✓	✓	✓			
Mining and Oil Field Machinery		✓								✓		✓
Total Excluding Mining and Oil Field Machinery							✓	✓	✓			
Information Processing	✓	✓	✓									
Industrial							✓	✓	✓			
Transportation							✓	✓	✓			
Other Excluding Mining and Oil Field Machinery							✓	✓	✓			

Note: C: Change in real energy price. LC: Large change in real energy price. NC: Net change in real energy price. ✓ indicates that the estimated responses follow the pattern indicated. A formal definition of these patterns can be found in the text.
* Symmetry rejected at 10% level. ** Symmetry rejected at 5% level. *** Symmetry rejected at 1% level.

Table 2e: Classification of Responses to Innovations in Real Energy Prices
1970.II-2006.IV with 1986 Dummies

	No Response			Symmetric Response			Classical Asymmetry			Perverse Asymmetry		
	C	LC	NC	C	LC	NC	C	LC	NC	C	LC	NC
Nonresidential Structures												
Total	✓	✓	✓									
Mining				✓	✓	✓						
Total Excluding Mining	✓	✓	✓									
Commercial and Healthcare	✓	✓	✓									
Manufacturing	✓	✓	✓									
Power and Communication	✓	✓	✓									
Other							✓	✓	✓			
Nonresidential Equipment												
Total							✓	✓*	✓			
Mining and Oil Field Machinery							✓	✓	✓			
Total Excluding Mining and Oil Field Machinery							✓*	✓**	✓			
Information Processing	✓	✓*	✓									
Industrial							✓*	✓	✓			
Transportation							✓	✓	✓			
Other Excluding Mining and Oil Field Machinery							✓	✓	✓			

Note: C: Change in real energy price. LC: Large change in real energy price. NC: Net change in real energy price. ✓ indicates that the estimated responses follow the pattern indicated. A formal definition of these patterns can be found in the text.
* Symmetry rejected at 10% level. ** Symmetry rejected at 5% level. *** Symmetry rejected at 1% level.

Figure 1: Intermediate Energy Prices and Energy Share in Value Added

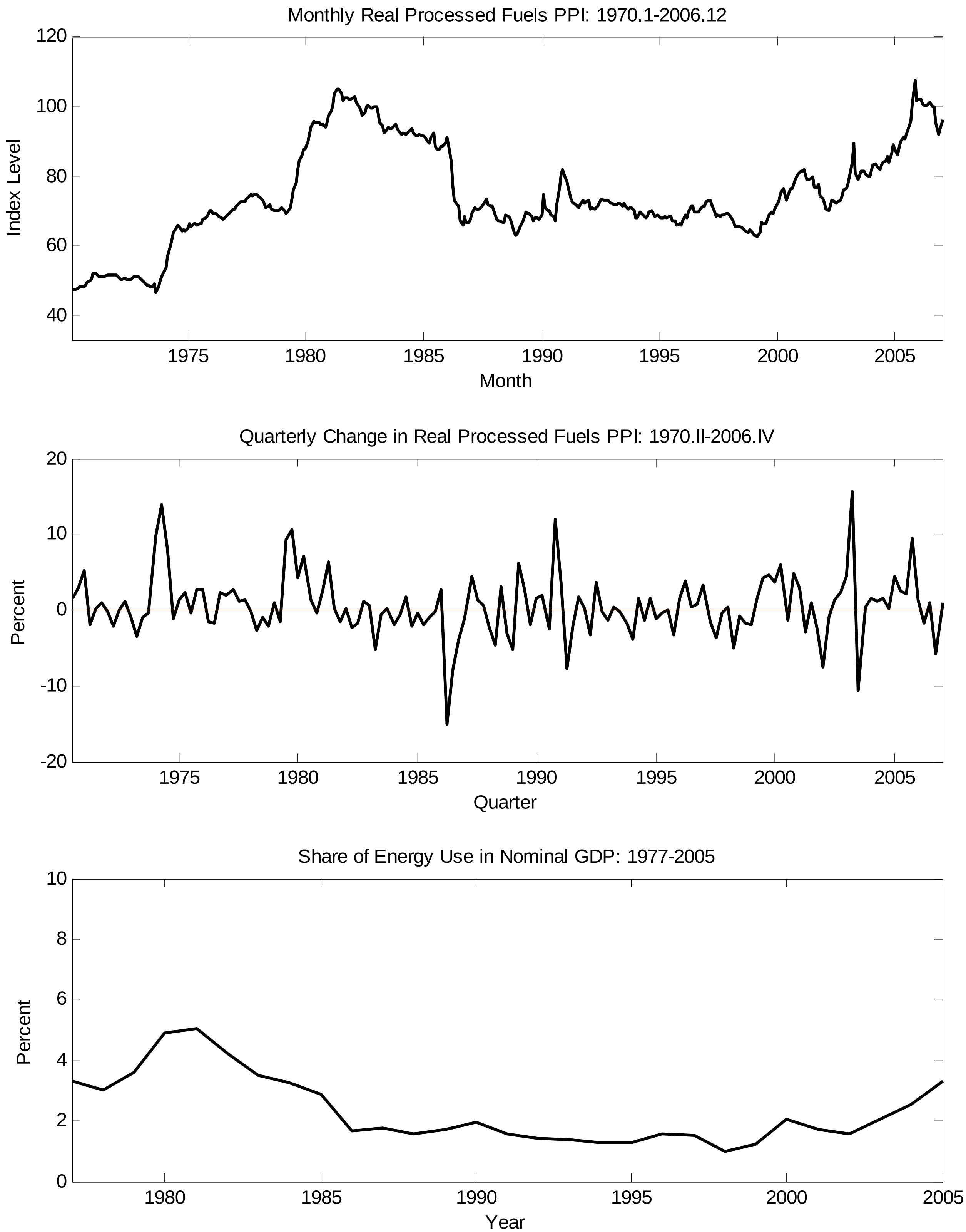


Figure 2: Alternative Measures of Energy Price Shocks
1970.II-2006.IV

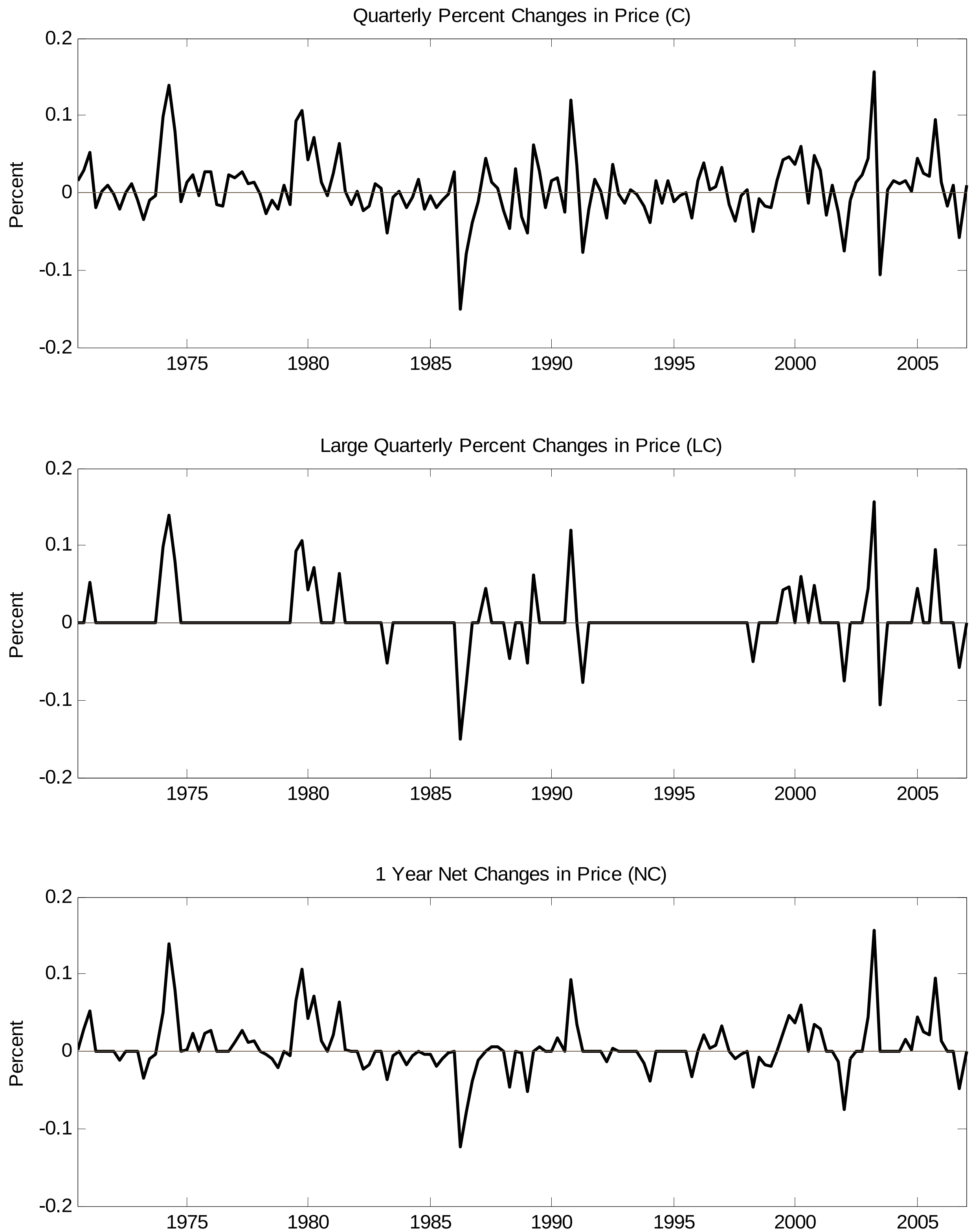


Figure 3: Illustration of the Composition Effect

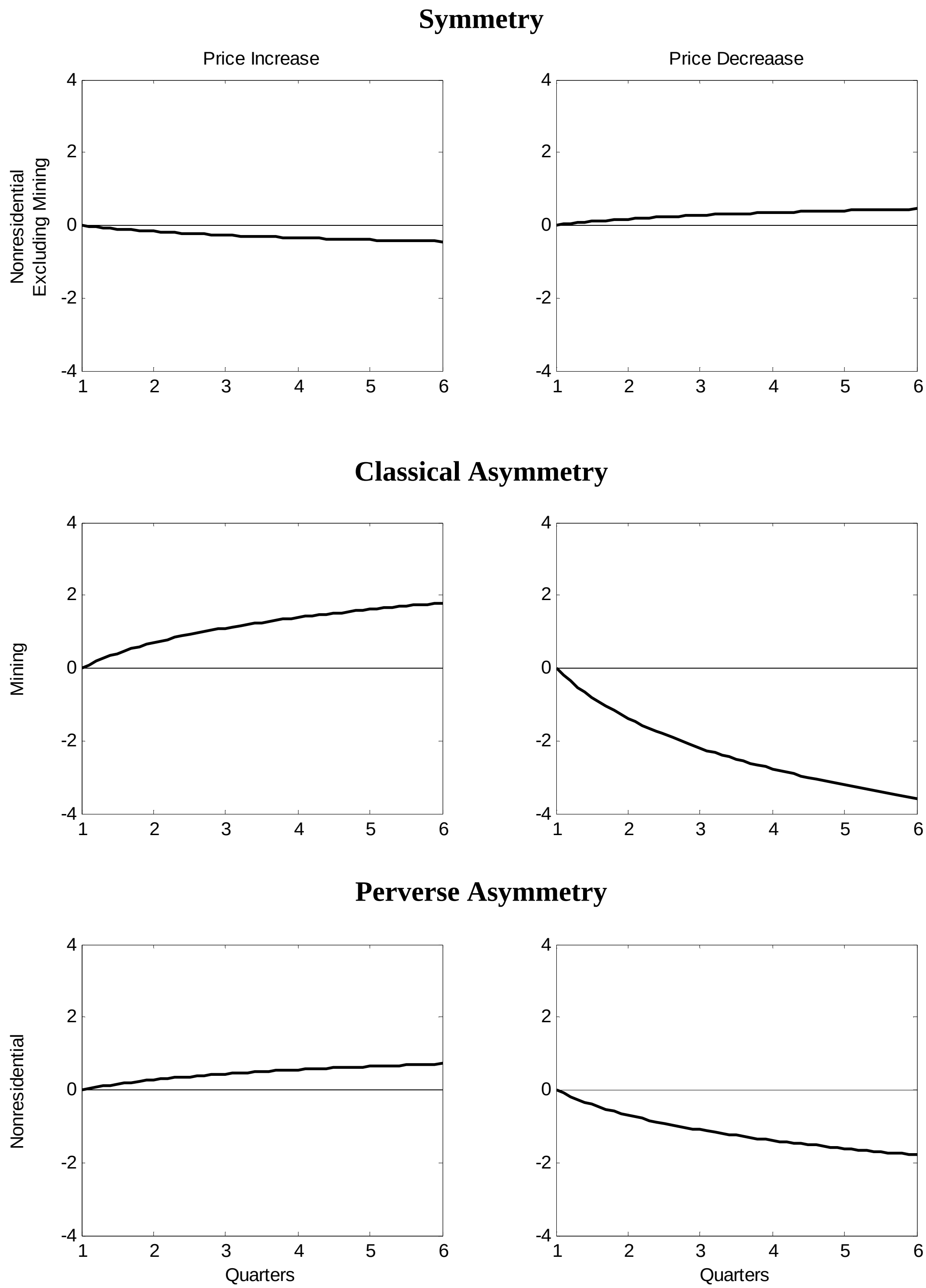


Figure 4a: Response of Real Structures Investment to Energy Price Shock

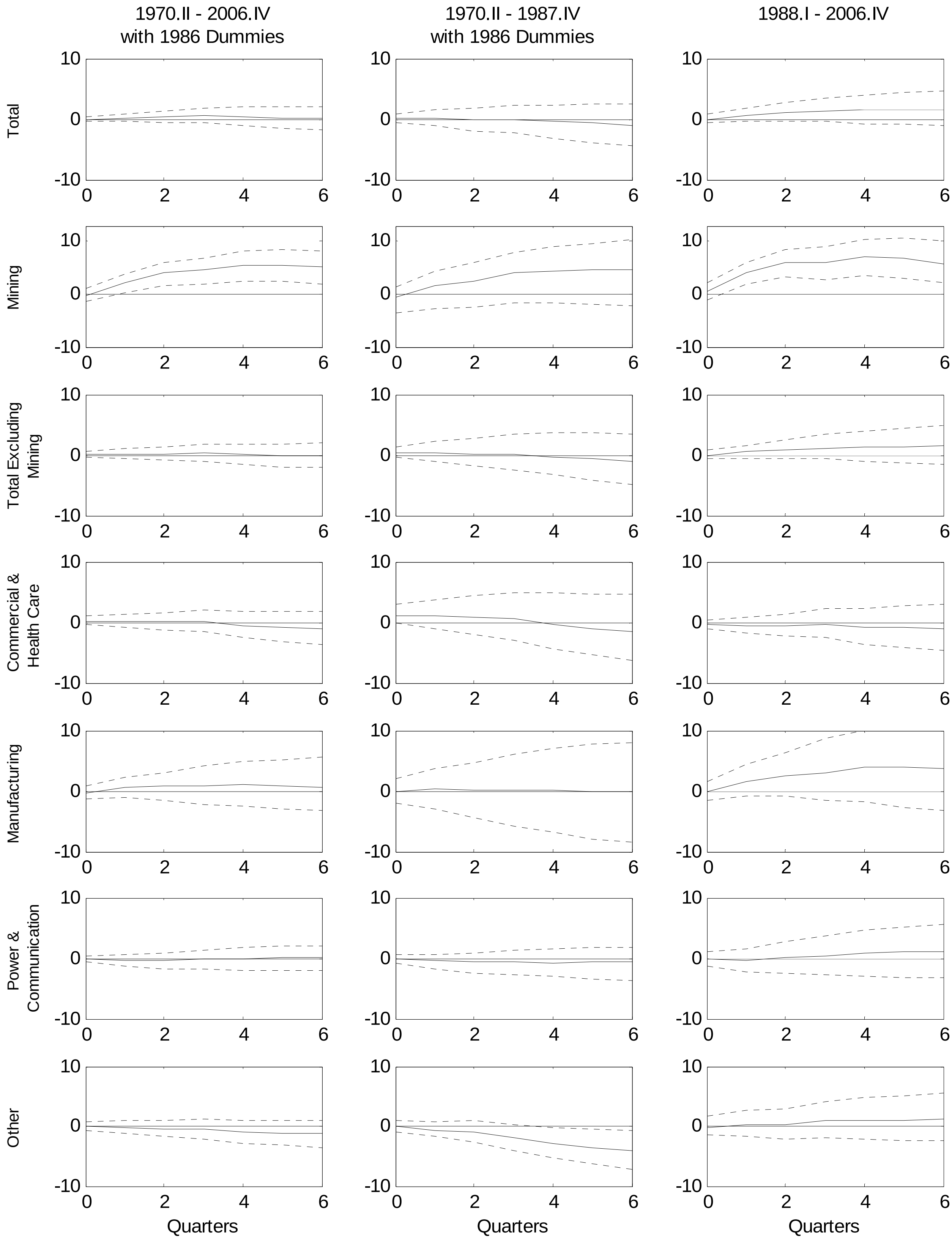


Figure 4b: Response of Real Equipment Investment to Energy Price Shock

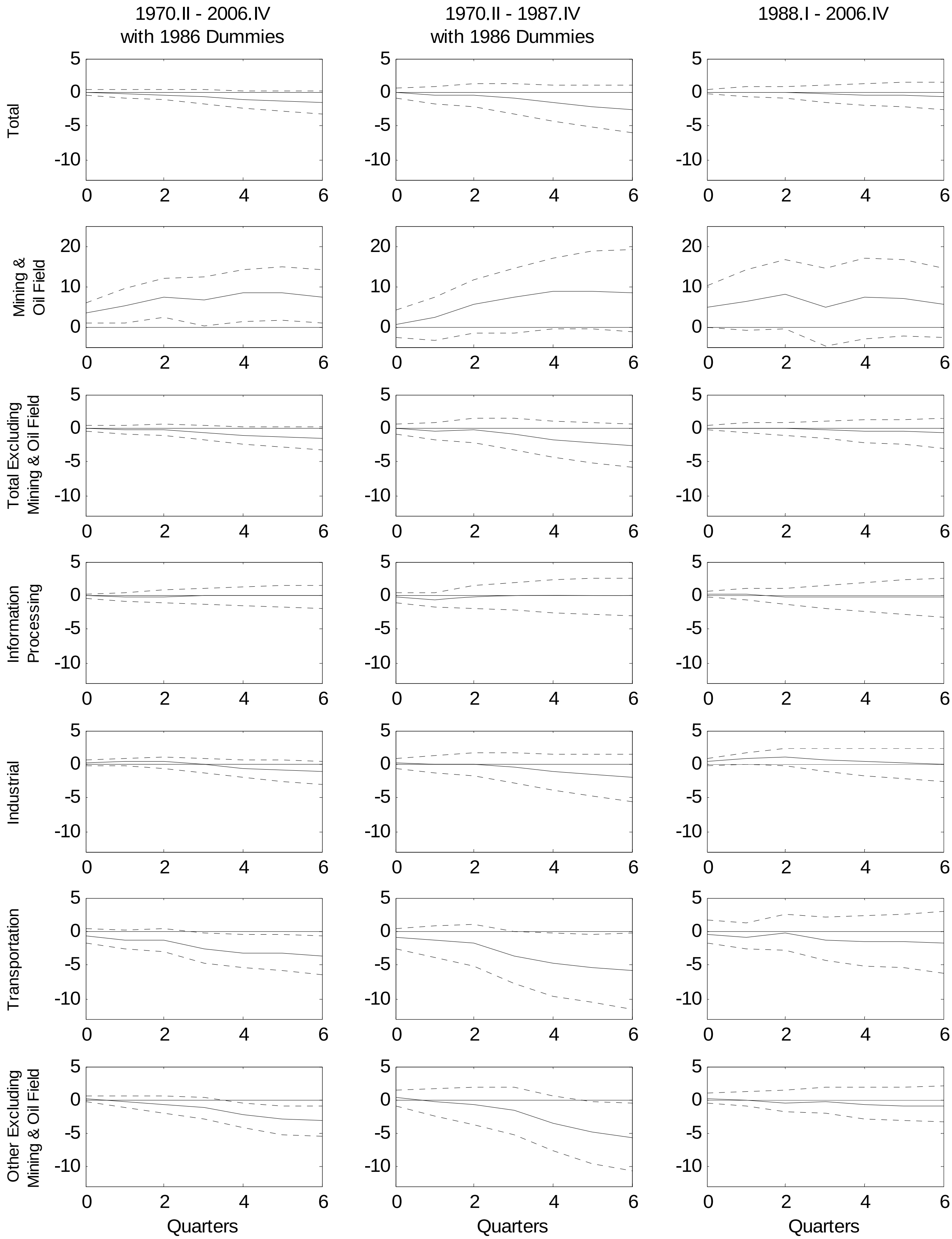
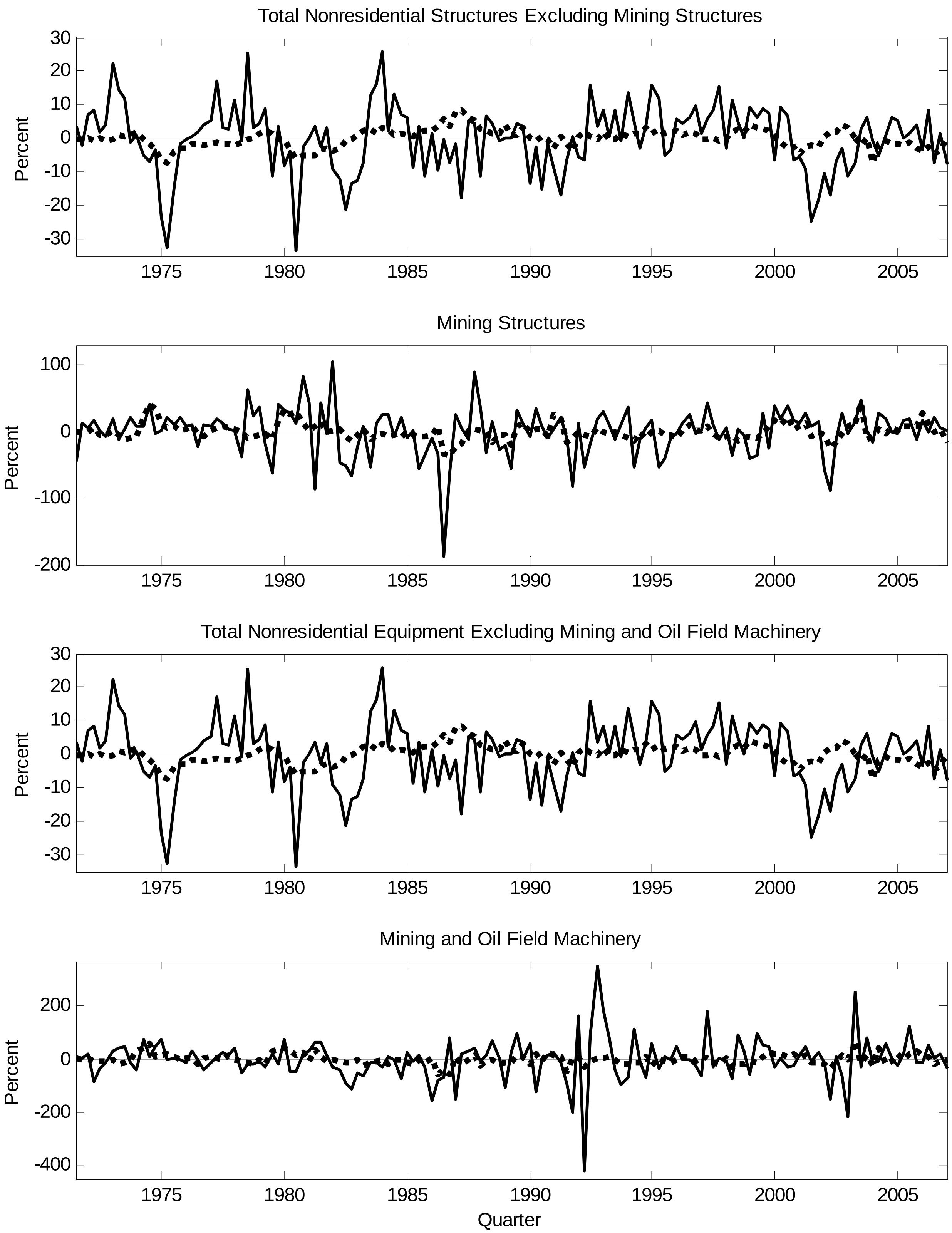


Figure 5: Contribution of Energy Price Shocks to Quarterly Change in Real Investment: 1970.II – 2006.IV



Not-for-Publication Appendix

Table A.1: Symmetry Tests
***C* Specification**

	1970.II – 2006.IV	1988.I – 2006.IV	1970.II – 1987.IV	1970.II – 1987.IV with ’86 Dummies	1970.II – 2006.IV with ’86 Dummies
Structures					
Total	0.199	0.852	0.507	0.853	0.591
Mining	0.039	0.898	0.113	0.963	0.944
Total Excluding Mining	0.480	0.877	0.839	0.806	0.625
Commercial and Healthcare	0.690	0.957	0.783	0.669	0.570
Manufacturing	0.895	0.957	0.969	0.859	0.873
Power and Communication	0.115	0.774	0.309	0.783	0.426
Other	0.428	0.361	0.713	0.855	0.620
Equipment					
Total	0.161	0.949	0.535	0.457	0.113
Mining and Oil Field	0.425	0.125	0.124	0.675	0.737
Total Excluding Mining and Oil Field	0.132	0.947	0.484	0.419	0.093
Information Processing	0.188	0.215	0.729	0.662	0.137
Industrial	0.116	0.158	0.172	0.338	0.090
Transportation	0.139	0.781	0.566	0.613	0.164
Other Excluding Mining and Oil Field	0.480	0.708	0.645	0.607	0.431

C: Percent Changes in Real Energy Prices.

Table A.2: Symmetry Tests
***LC* Specification**

	1970.II – 2006.IV	1988.I – 2006.IV	1970.II – 1987.IV	1970.II – 1987.IV with '86 Dummies	1970.II – 2006.IV with '86 Dummies
Structures					
Total	0.341	0.900	0.441	0.958	0.786
Mining	0.060	0.954	0.132	0.949	0.817
Total Excluding Mining	0.666	0.906	0.933	0.985	0.824
Commercial and Healthcare	0.817	0.956	0.838	0.861	0.789
Manufacturing	0.961	1.000	0.966	0.954	0.935
Power and Communication	0.098	0.523	0.910	0.980	0.473
Other	0.493	0.912	0.848	0.992	0.771
Equipment					
Total	0.100	0.908	0.760	0.694	0.057
Mining and Oilfield	0.689	0.316	0.038	0.769	0.863
Total Excluding Mining and Oil Field	0.087	0.904	0.706	0.652	0.050
Information Processing	0.114	0.274	0.783	0.697	0.067
Industrial	0.159	0.201	0.443	0.694	0.142
Transportation	0.123	0.800	0.885	0.933	0.131
Other Excluding Mining and Oil Field	0.510	0.812	0.923	0.935	0.435

LC: Large Percent Changes in Real Energy Prices.

Table A.3: Symmetry Tests
***NC* Specification**

	1970.II – 2006.IV	1988.I – 2006.IV	1970.II – 1987.IV	1970.II – 1987.IV with ’86 Dummies	1970.II – 2006.IV with ’86 Dummies
Structures					
Total	0.154	0.738	0.530	0.963	0.838
Mining	0.002	0.516	0.184	0.979	0.929
Total Excluding Mining	0.379	0.739	0.902	0.936	0.724
Commercial and Healthcare	0.719	0.871	0.856	0.744	0.729
Manufacturing	0.845	0.880	0.998	0.893	0.944
Power and Communication	0.051	0.118	0.504	0.912	0.720
Other	0.510	0.574	0.825	0.913	0.849
Equipment					
Total	0.476	0.831	0.767	0.607	0.375
Mining and Oilfield	0.218	0.869	0.038	0.581	0.782
Total Excluding Mining and Oil Field	0.458	0.815	0.761	0.602	0.349
Information Processing	0.379	0.761	0.647	0.650	0.483
Industrial	0.281	0.561	0.252	0.455	0.280
Transportation	0.415	0.950	0.763	0.702	0.374
Other Excluding Mining and Oil Field	0.764	0.989	0.768	0.772	0.842

NC: 1-Year Net Percent Changes in Real Energy Prices.

Figure A.1a: Response of Real Nonresidential Fixed Investment in Structures 1970.II-2006.IV

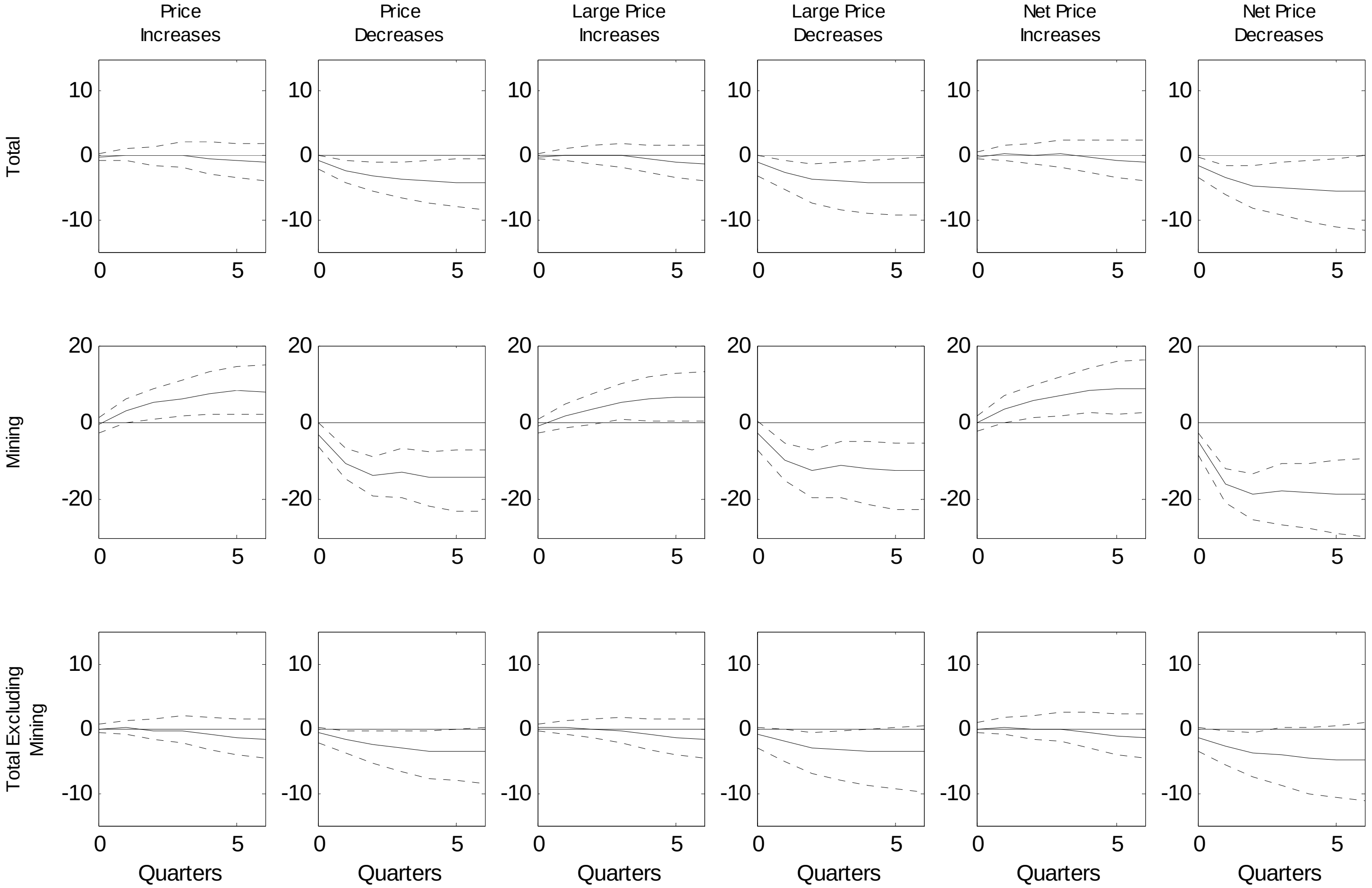


Figure A.1a (continued)

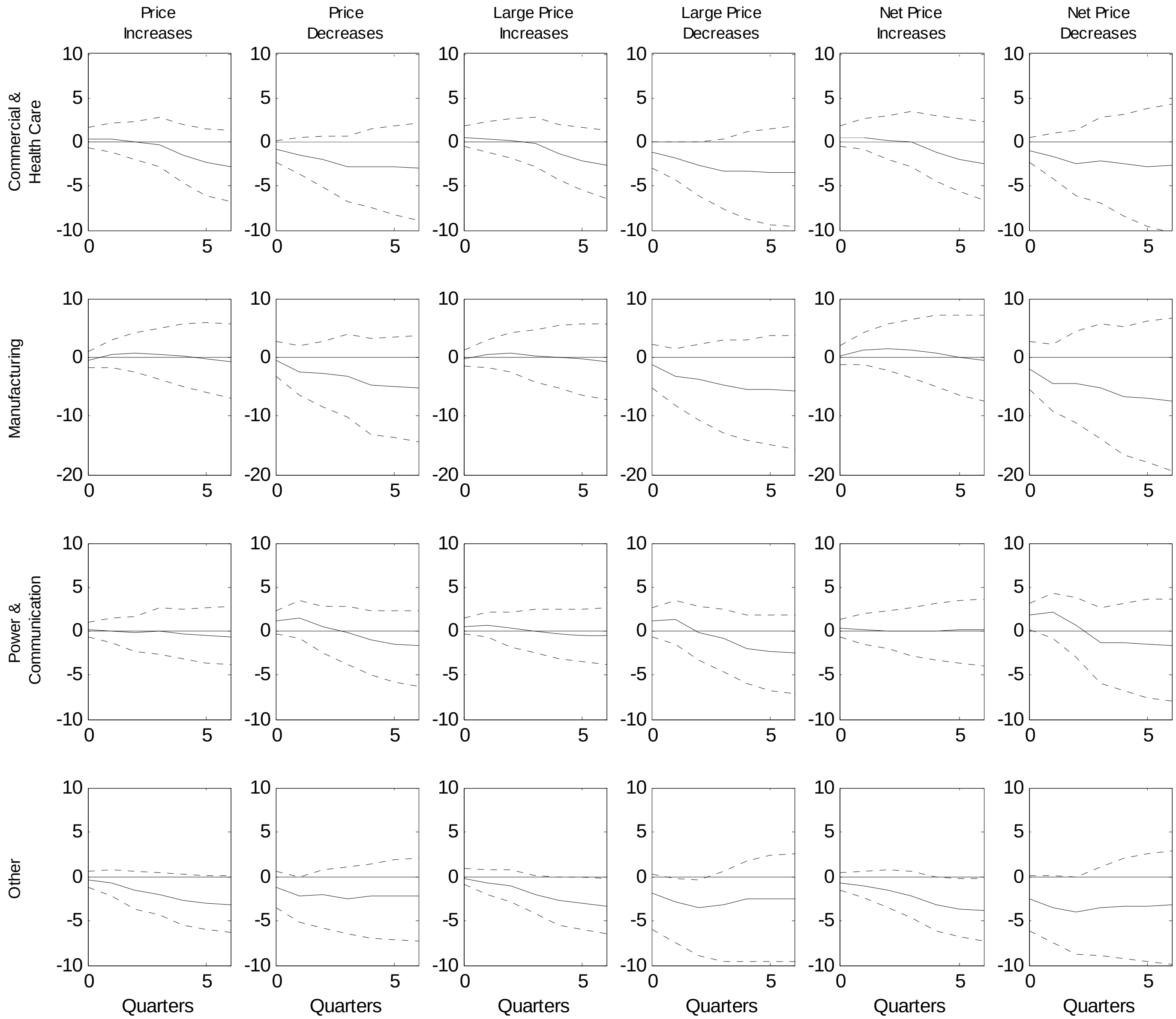


**Figure A.1b: Response of Real Nonresidential Fixed Investment in Structures
1988.I-2006.IV**

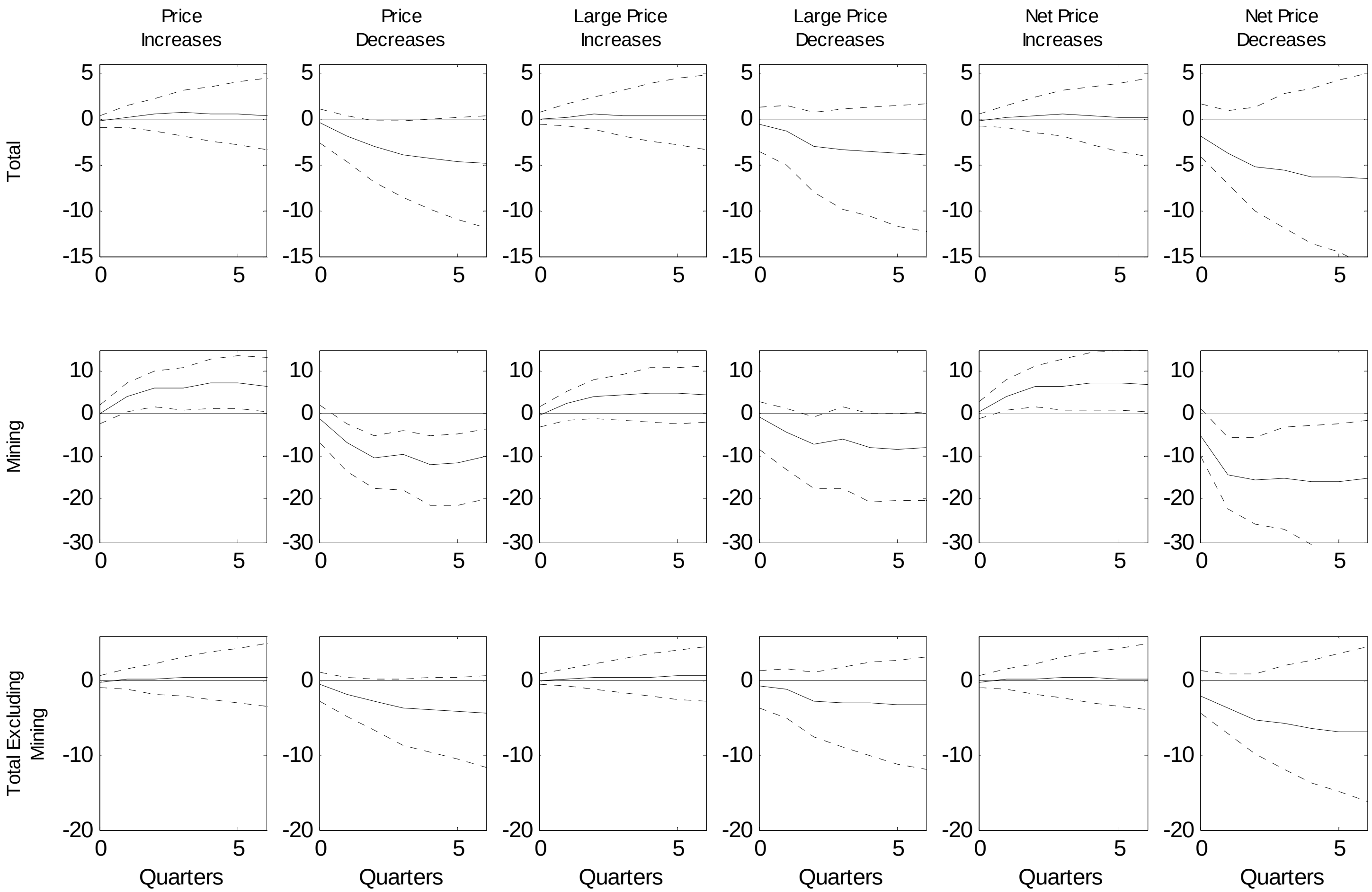


Figure A.1b (continued)

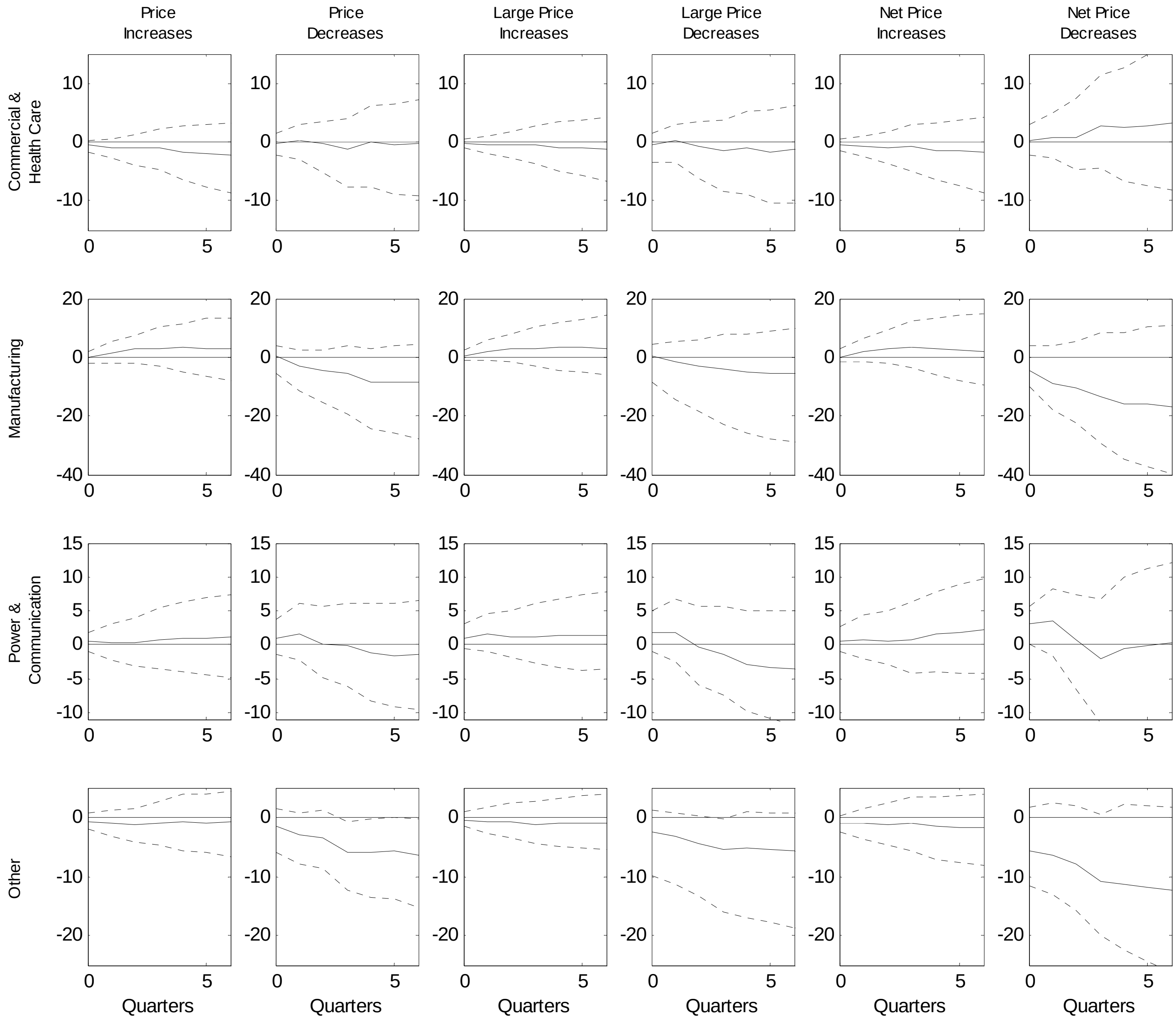


Figure A.1c: Response of Real Nonresidential Fixed Investment in Structures 1970.II-1987.IV

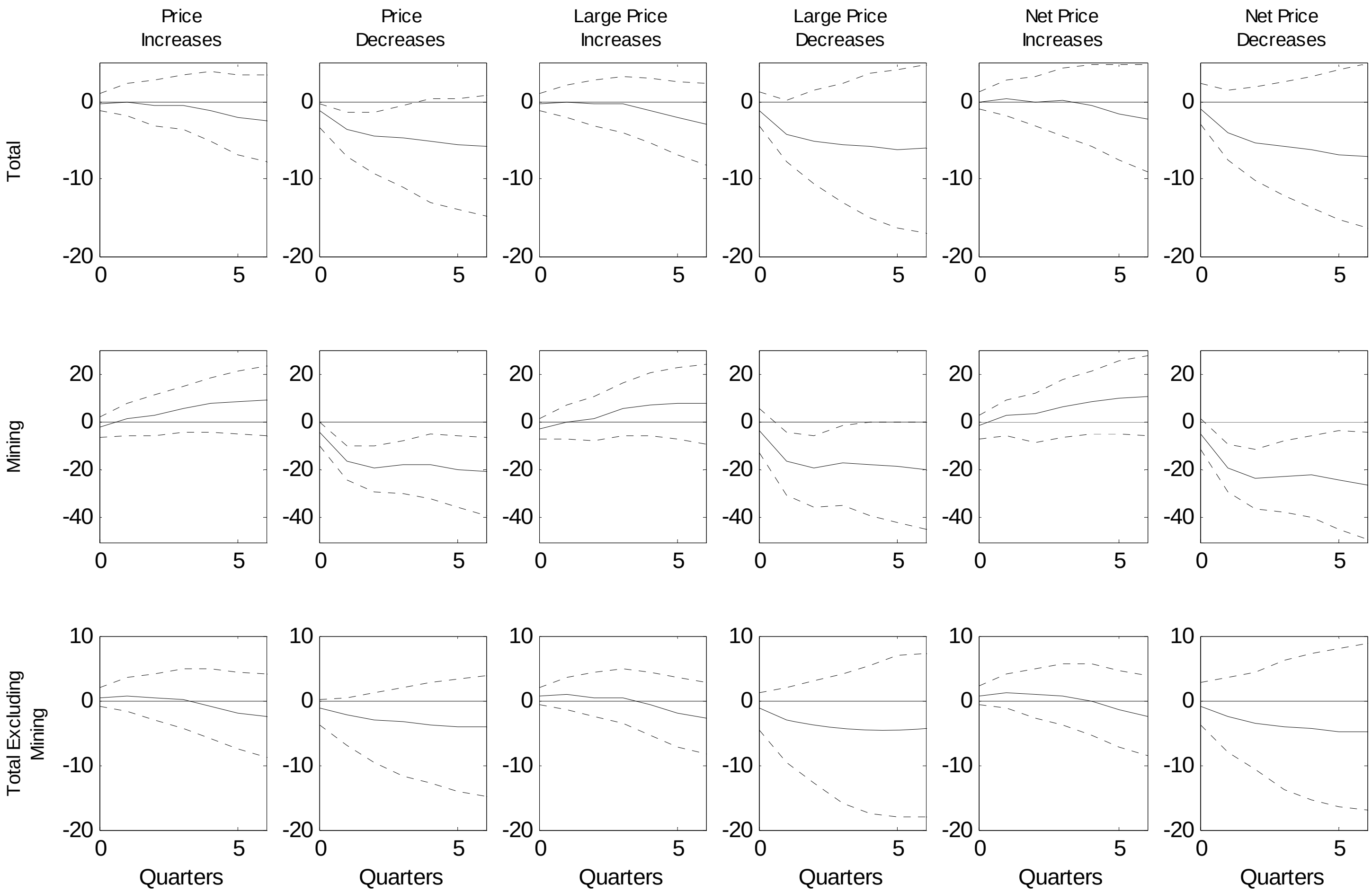


Figure A.1c (continued)

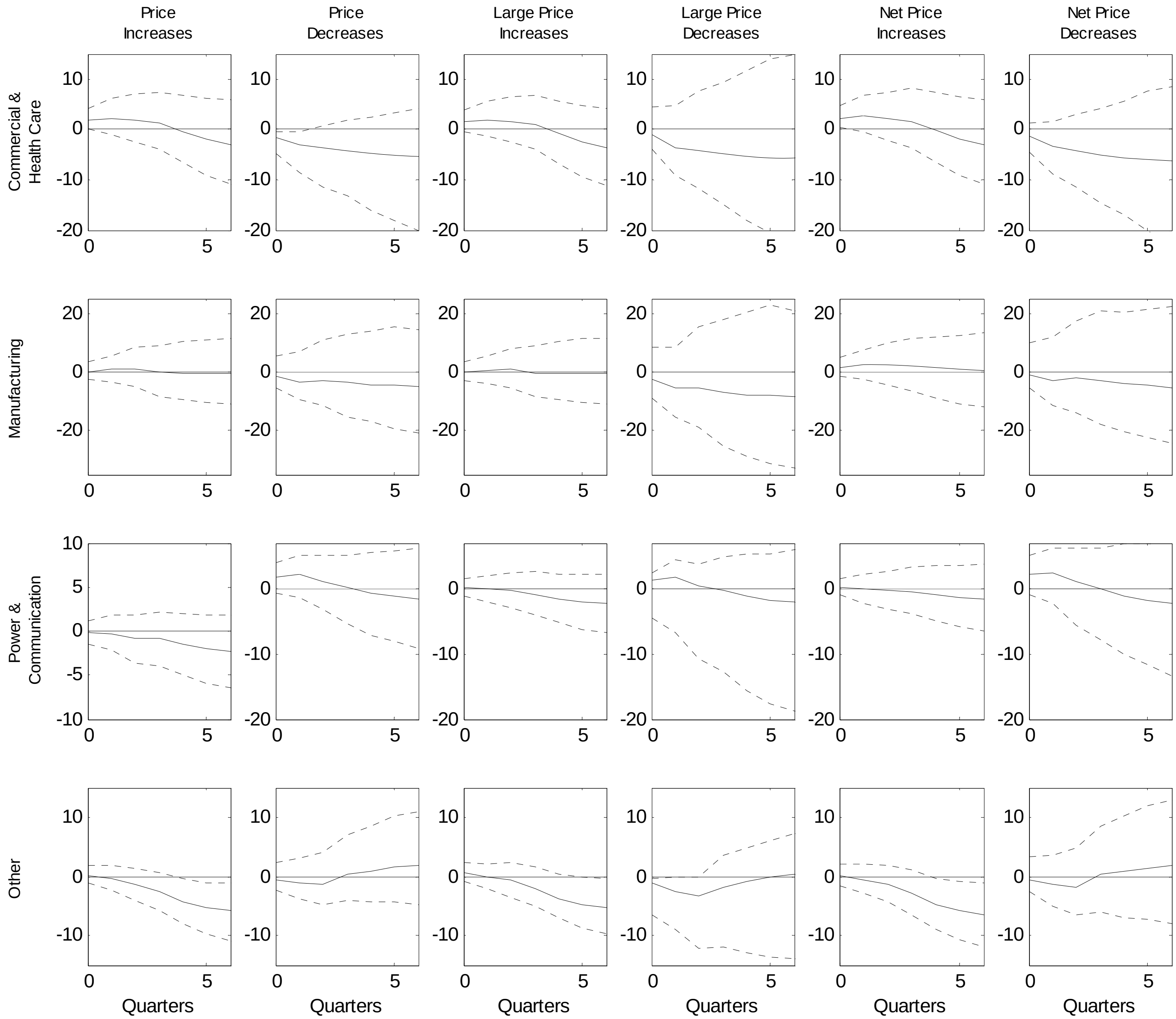


Figure A.1d: Response of Real Nonresidential Fixed Investment in Structures 1970.II-1987.IV with 1986 Dummies

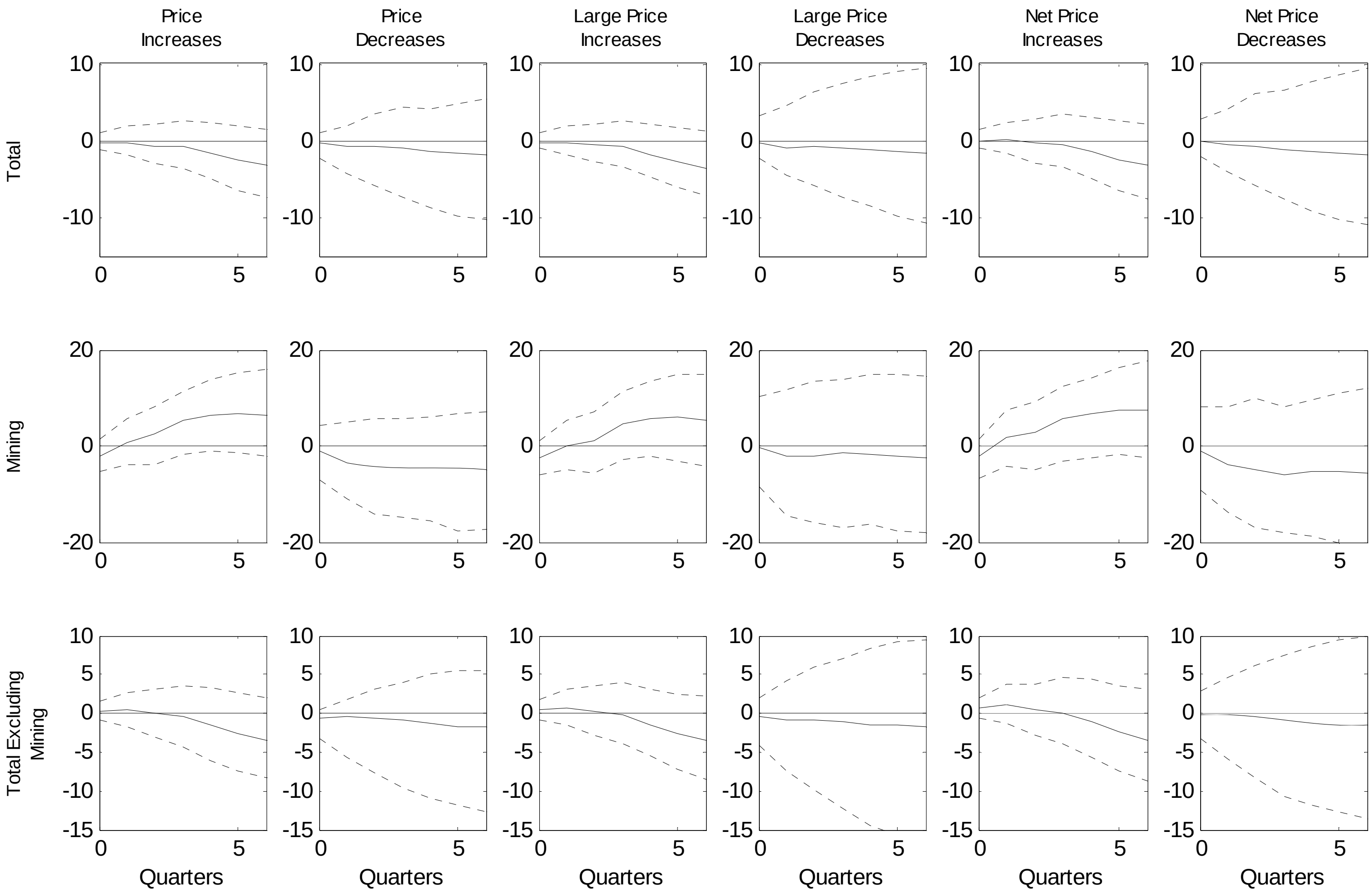


Figure A.1d (continued)

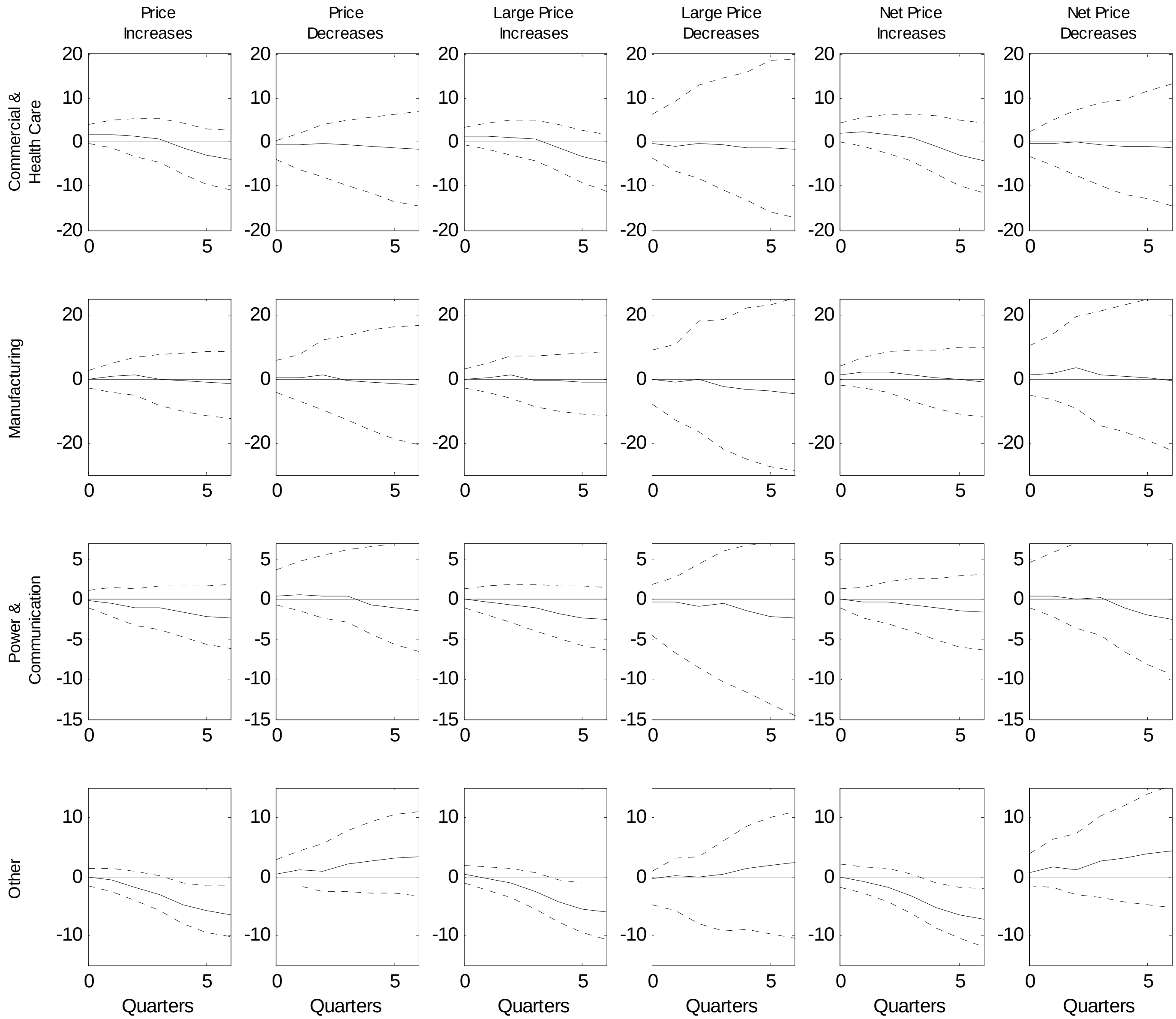


Figure A.1e: Response of Real Nonresidential Fixed Investment in Structures 1970.II-2006.IV with 1986 Dummies

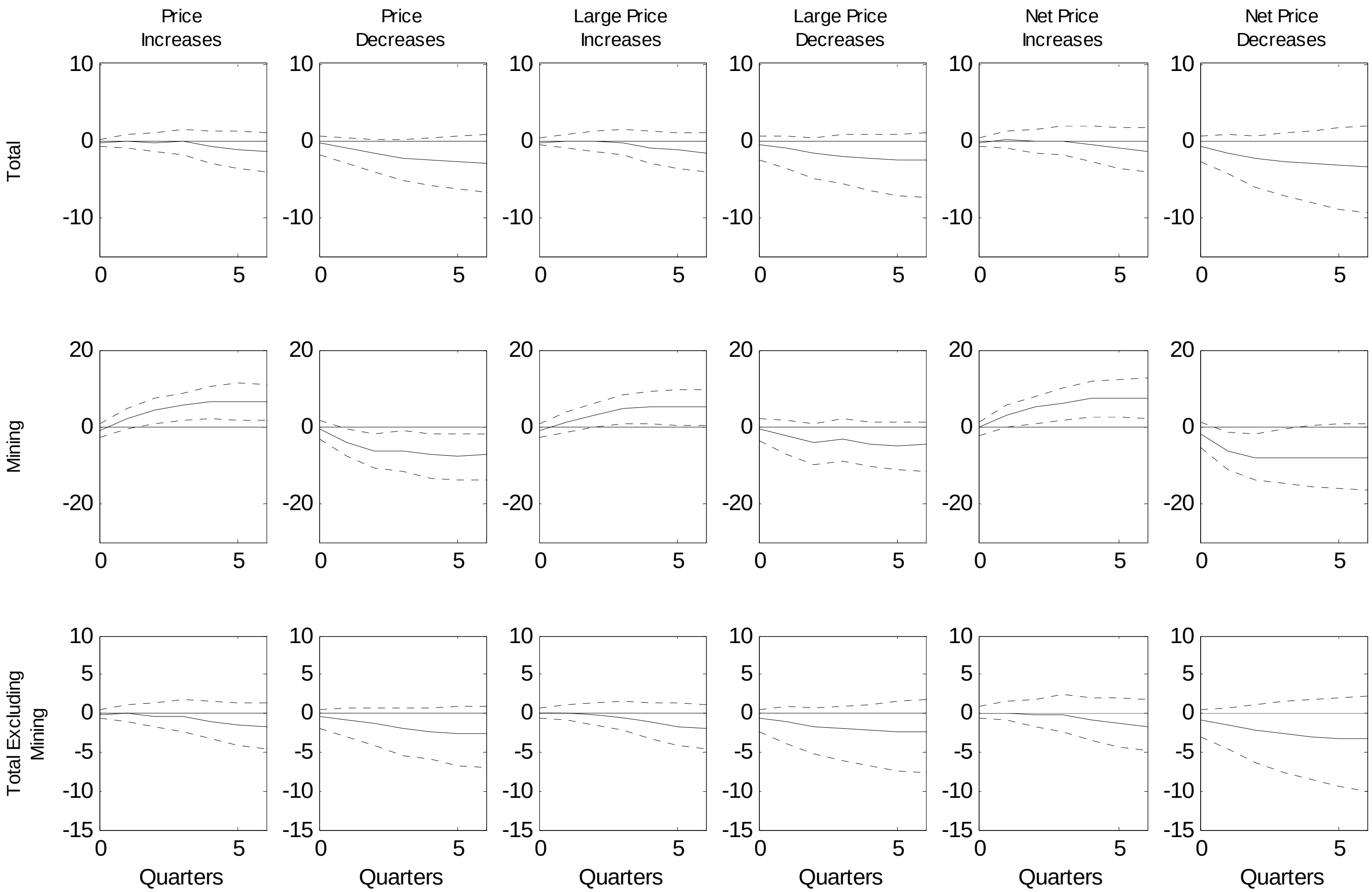


Figure A.1e (continued)

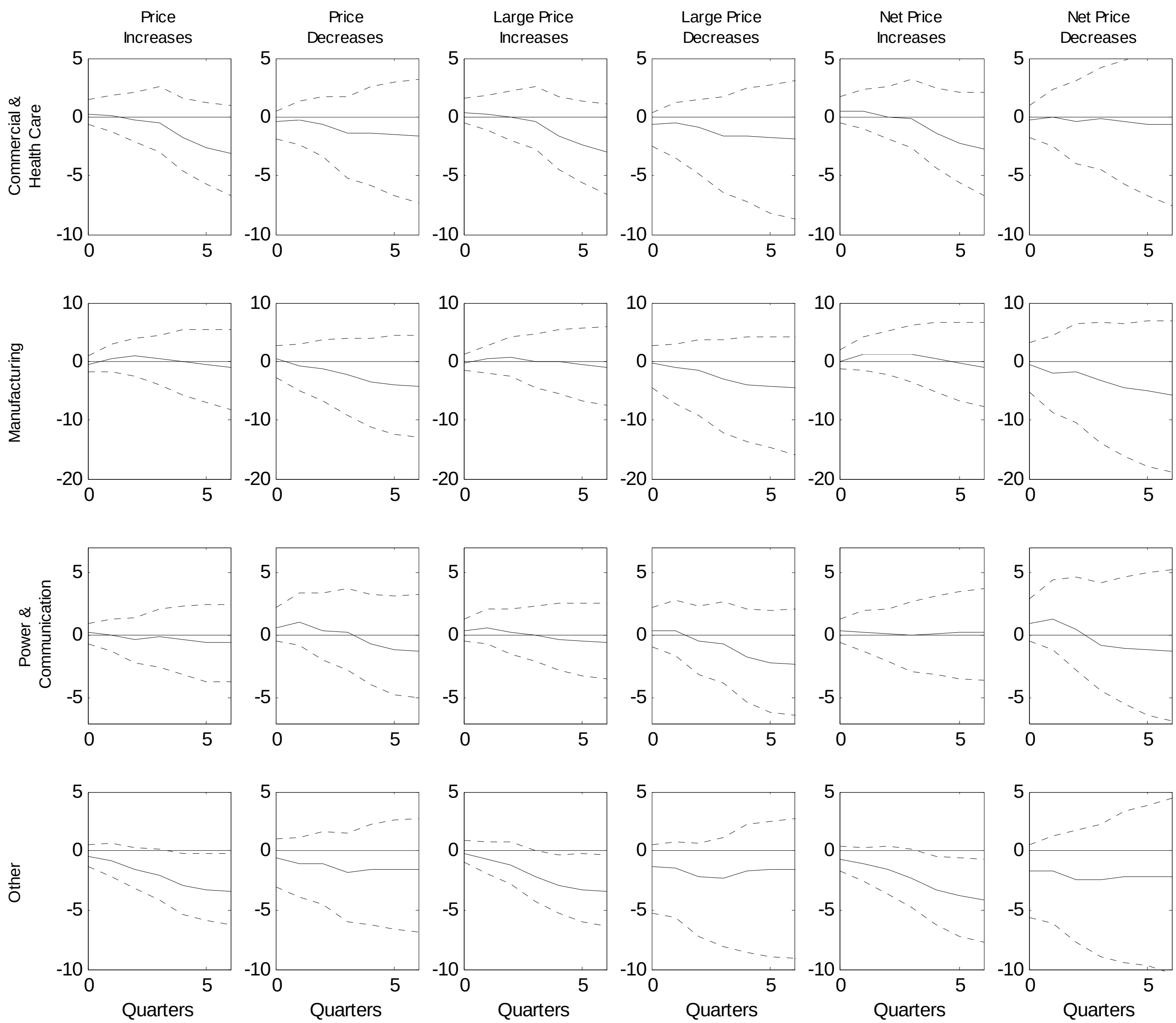


Figure A.2a: Response of Real Nonresidential Fixed Investment in Equipment
1970.II-2006.IV

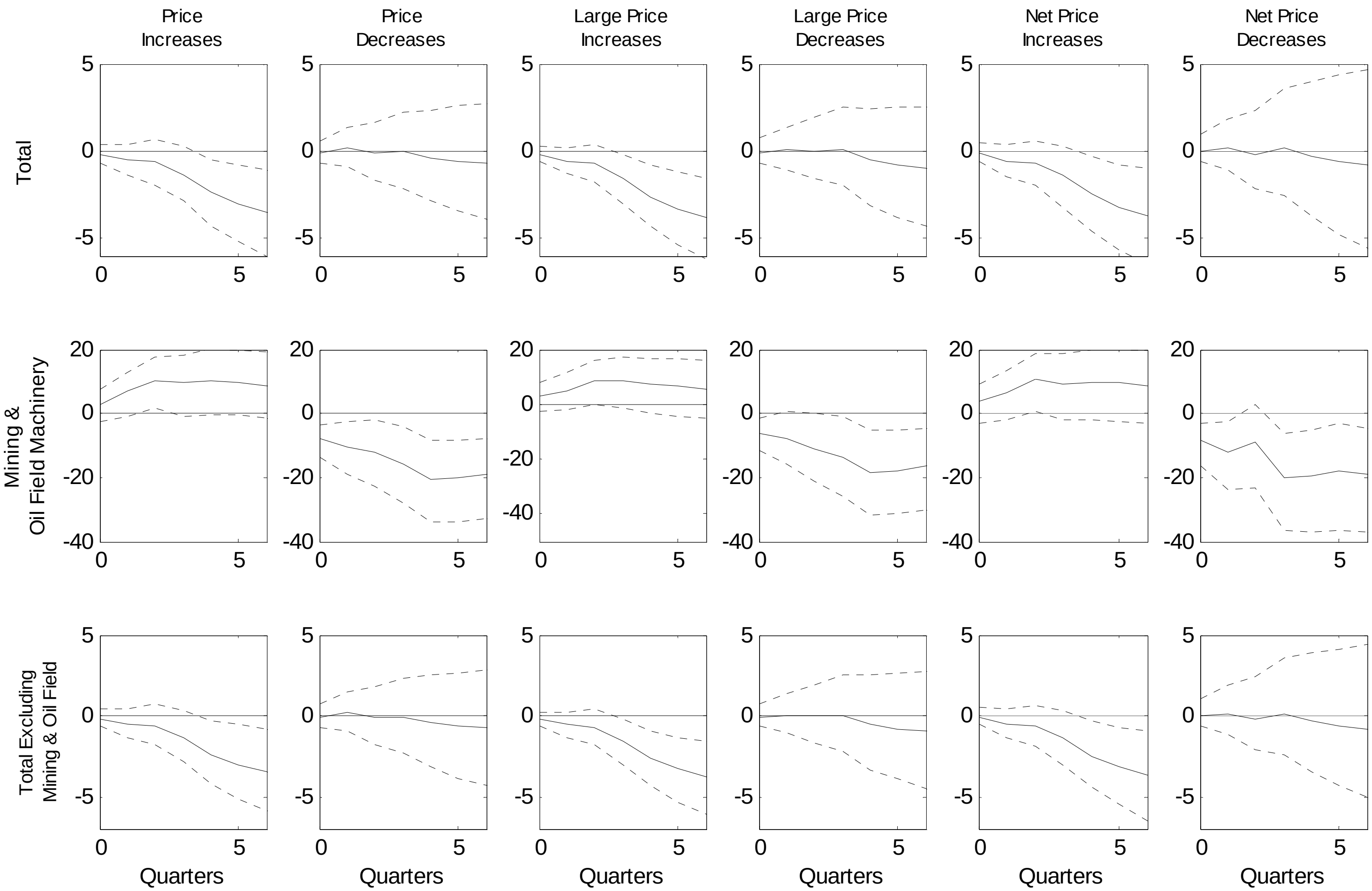


Figure A.2a (continued)

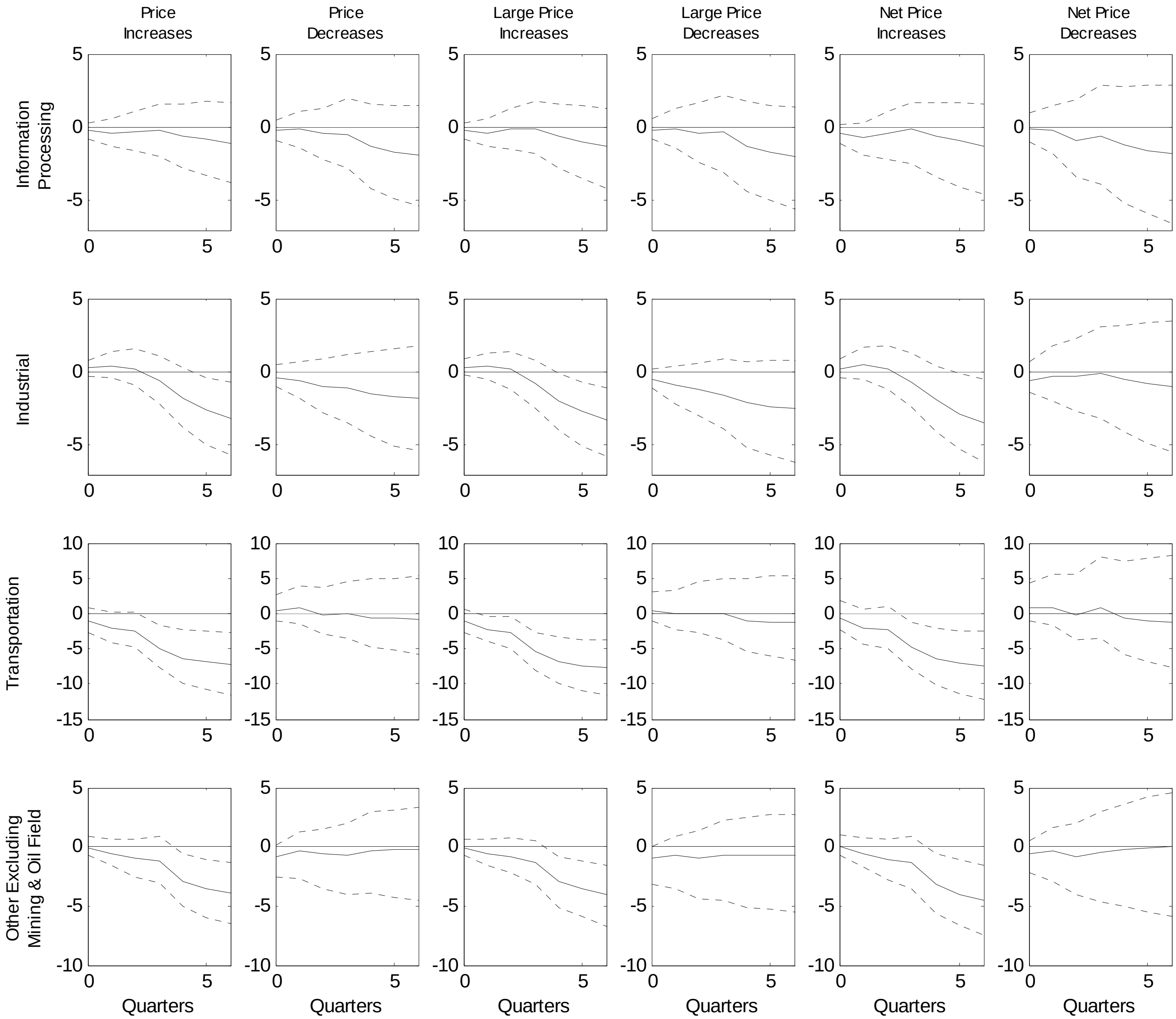


Figure A.2b: Response of Real Nonresidential Fixed Investment in Equipment 1988.I-2006.IV

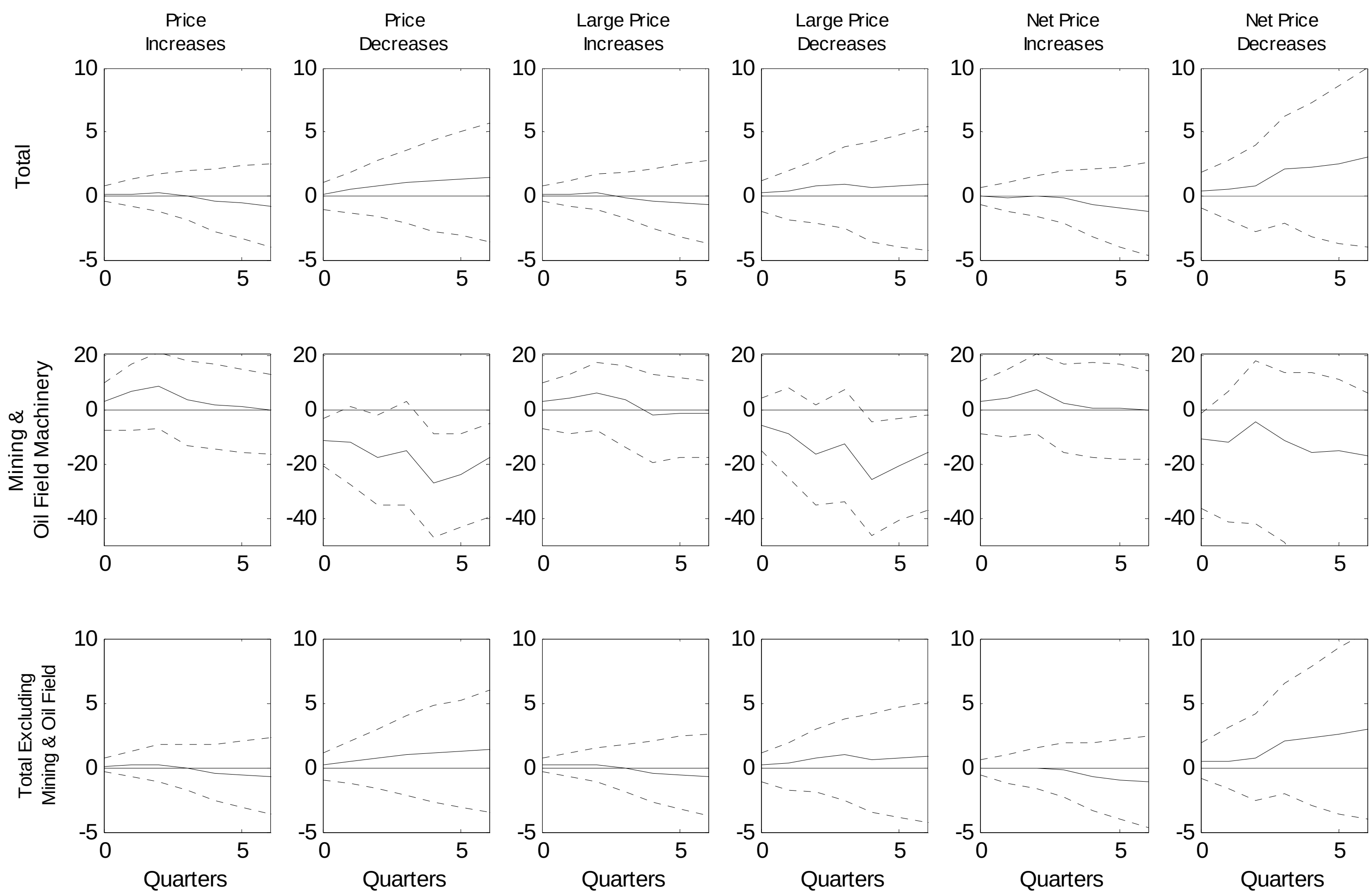


Figure A.2b (continued)

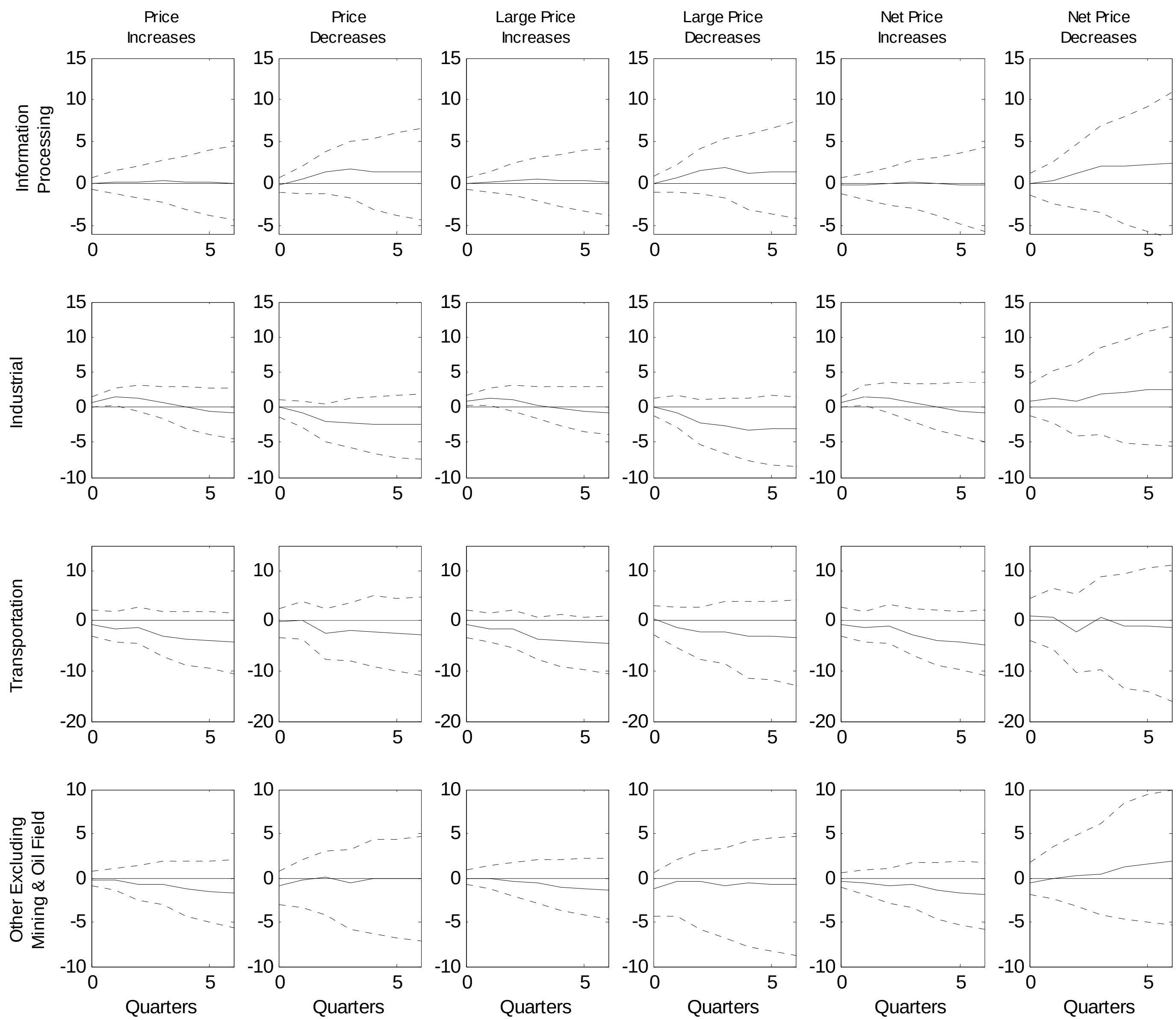


Figure A.2c: Response of Real Nonresidential Fixed Investment in Equipment 1970.II-1987.IV

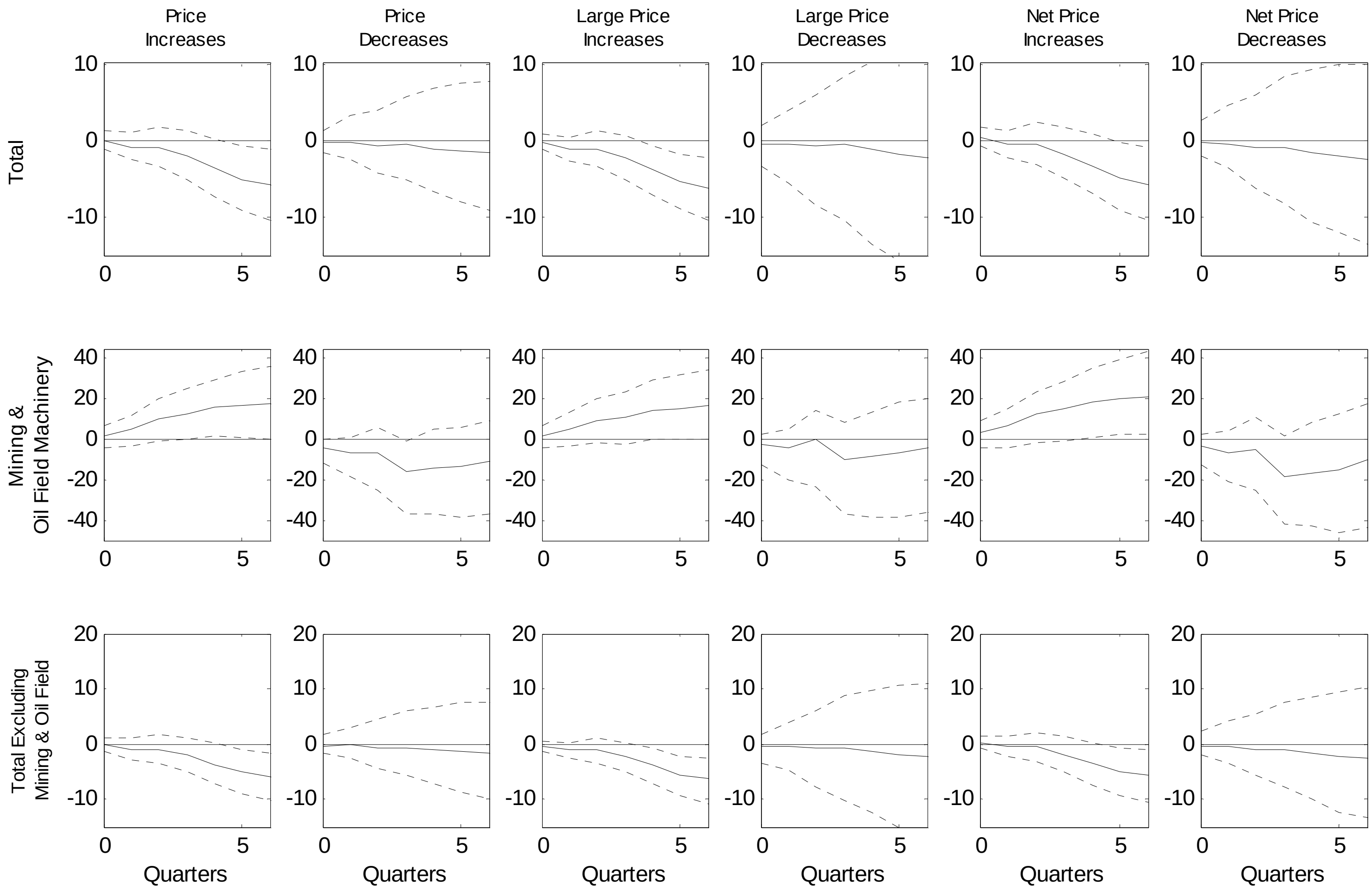


Figure A.2c (continued)

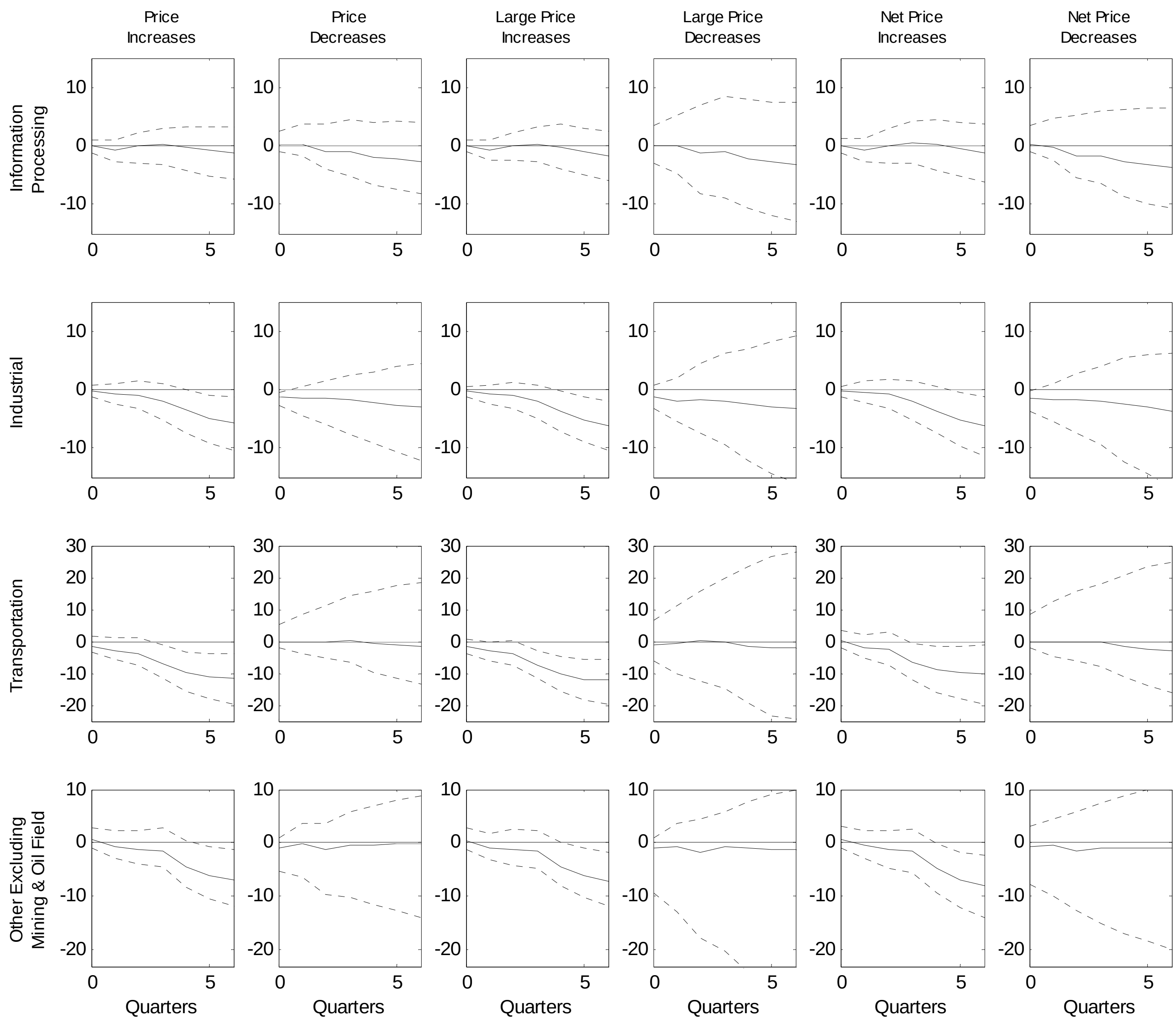


Figure A.2d: Response of Real Nonresidential Fixed Investment in Equipment 1970.II-1987.IV with 1986 Dummies

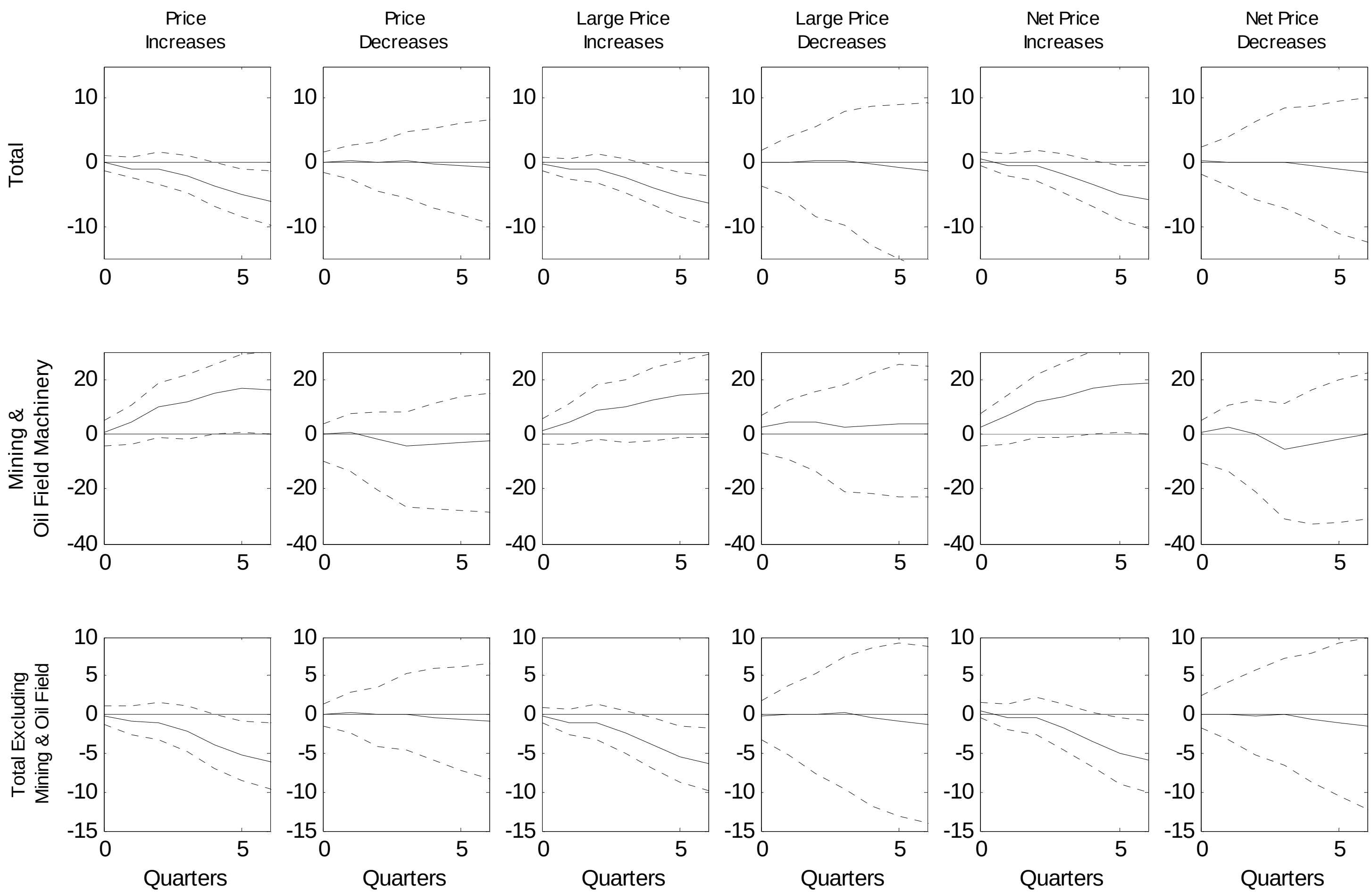


Figure A.2d (continued)

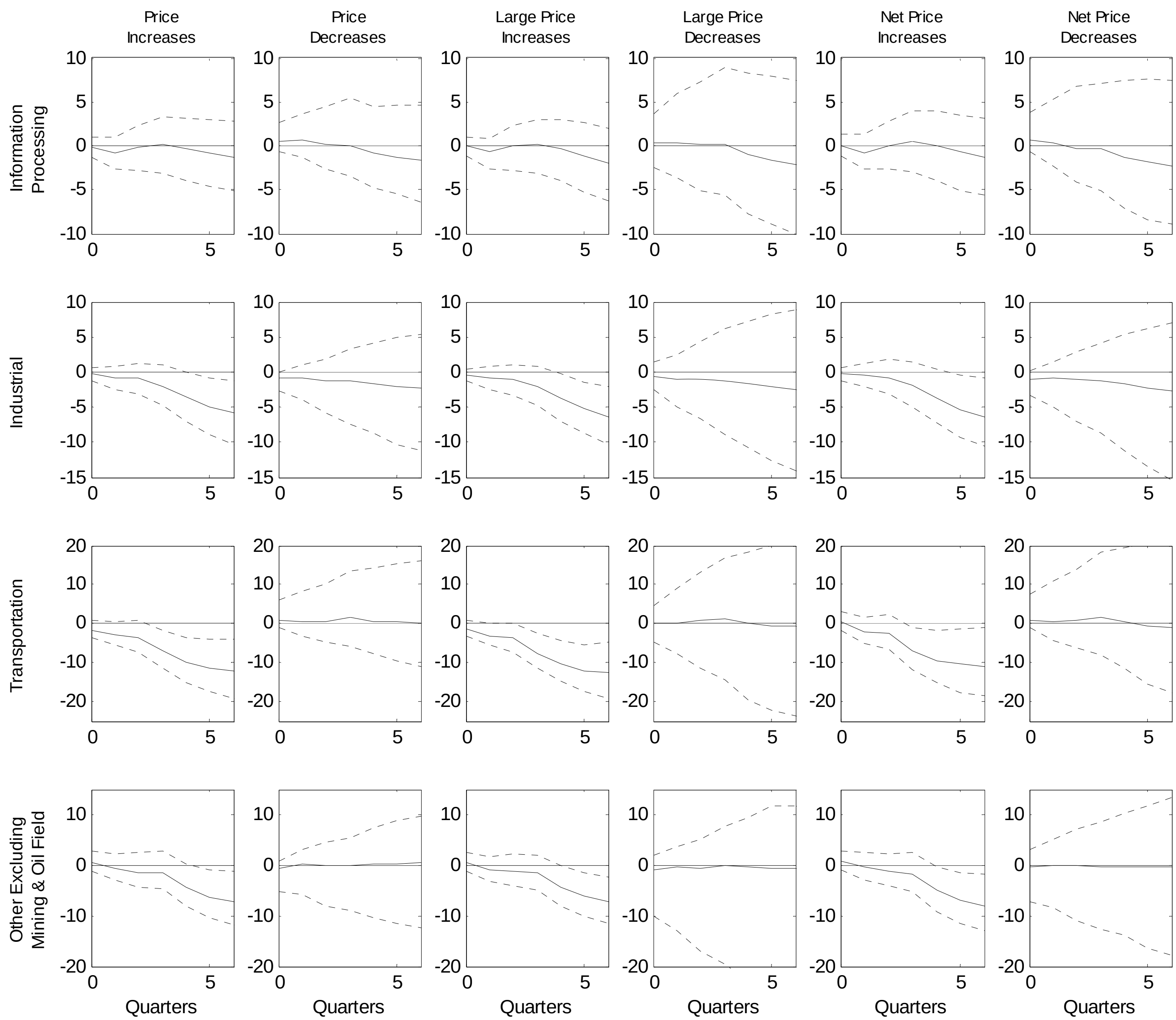


Figure A.2e: Response of Real Nonresidential Fixed Investment in Equipment 1970.II-2006.IV with 1986 Dummies

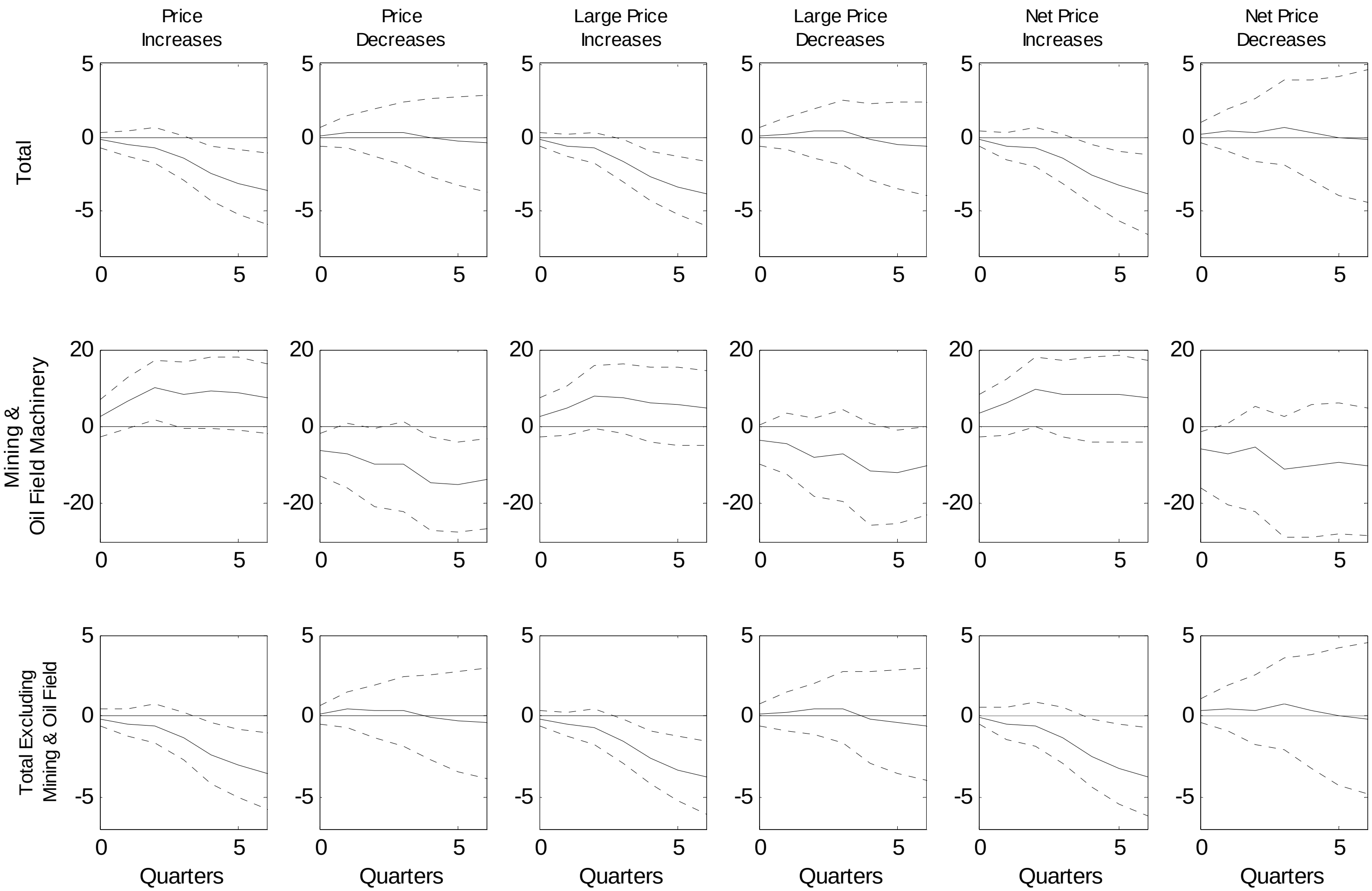


Figure A.2e (continued)