PASS-THROUGH OF OIL PRICES TO JAPANESE DOMESTIC PRICES

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ABSTRACT

In this paper, we investigate changes in the impacts of world crude oil prices on domestic prices in Japan. First, we employ a time-varying parameter VAR (TVP-VAR) approach to confirm that the rate of pass-through of oil prices declined, both at the aggregate and sectoral levels, for the period 1980-2000. Second, by utilizing Input-Output Tables, we find that changing cost structure of Japanese firms goes a long way toward explaining this decline. That is, by the year 2000, oil had become a much smaller component of the Japanese production cost structure. We further find that much of this is attributable to changes in relative prices: as oil became cheaper, it became less important in the overall cost structure, and thus pricing behaviors of firms became less responsive to its prices. Substitution effects, namely firms' shifts toward less oil intensive production, on the other hand, appear to be less important. We also study the period 2000-2007. We find that, although pass-through rates of oil prices increase in many instances, those increases are small in comparison to the drastic resurgence of oil in the cost structure of firms. We present some possible explanations for this finding.

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1 Introduction

This paper studies the effects of oil prices on domestic prices using the Japanese data. Recent dramatic surge and fall of crude oil prices have renewed interest in their effects on domestic economies. In the literature, many authors have documented (in many cases using the US data) weakening impacts of oil prices on the domestic economy. For example, Hooker (1996) finds that impacts of oil prices on US GDP and US unemployment have diminished since the mid 1970s. Hooker (2002), which is more relevant for the current analysis, finds that the impact of oil prices on US domestic inflation has been weakened significantly since around 1980. De Gregorio, Landerretche, and Neilson (2007) apply a Hooker-type approach to a number of industrialized as well as developing countries and confirm his findings. They also estimate rolling VARs for those countries and again confirm declines in oil price pass-through. Blanchard and Gali (2007) also estimate rolling VARs for the US. They also estimate regular VARs for the US and other industrialized countries, splitting the sample at 1984. They arrive at similar conclusions as the previous authors[2]. Causes behind these changes have also attracted attention of macroeconomists. As Blinder and Rudd (2009) summarize succinctly, three possible candidates have been widely considered. First is increased credibility of monetary policy. Second is greater wage flexibility. Third is changing industrial structure after the two oil crises, i.e., the substitution effects: firms have shifted away from energy using technology to energy saving technology[3,4].

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[2] However, they find inexplicable impulse response results for Japan.

[3] Blanchard and Gali (2007) construct a New Keynesian DSGE model that incorporates all three elements. Their simulations show that all three have contributed to declining pass-through of oil prices. Kilian (2008) mentions two other candidates: one is a US specific reason (structure of the automobile industry) which is less relevant here. The other is a difference in the fundamental causes behind different episodes of oil price surges: it is hypothesized that the oil price increase in the 2000s was a consequence of a world wide demand increase rather than a supply shock. For inflation, however, it is not clear if demand-driven oil price increase should have either stronger or weaker effects on domestic prices. De Gregorio et. al. (2007) argue that a positive demand shock would tend to appreciate currencies of commodity importing countries, thus mitigating the effects of higher oil prices. De Gregorio et. al. (2007) also offer an additional candidate for the cause of the pass-through decline: under a low inflation environment, firms change prices less frequently, and, as a consequence, oil price increases are not easily passed through to domestic prices.

[4] Another important hypothesis is that oil prices were not so influential to begin with: it was another shock that occurred around the same time period that had much impact on the economy (the most notable candidate is an excessively tight monetary policy). Refer to, for example, Bernanke, Gertler and Watson (1997). Blinder and Rudd (2008), on the other hand, support the supply-shock view of the "Great Inflation" of the 1970s and the 1980s.

In this paper, we study the Japanese data using time series analysis technique and confirm the tendency of declining pass-through of oil prices to domestic prices, for the period 1980-2000. We find that the main driving force behind this was different from any of the above three. Investigation of the Japanese Input-Output tables reveals that changes in the cost structure alone go a long way toward explaining the declining pass-through. In that sense, at a first glance, our results might seem consistent with the third hypothesis mentioned above. But a further analysis indicates that the main reason behind the changing cost structure was not the substitution effects or changes in relative *quantities*: it was rather changes in the relative *prices* that played a more important role. Put simply, as oil became cheaper, it became less and less important in the overall cost structure (due partially to a relatively low degree of substitution between oil and non-oil inputs), and thus the pricing behaviors of the firms became less responsive to its prices. The real factor or the substitution effect did play some role, mainly in the short run, but its role in the long term decline in the pass-through rate was relatively minor (with some exceptions, such as the electricity sector)[5]. We also document the importance of taking into account features of the Japanese oil-related taxation system.

This paper is a sequel to Shioji and Uchino (2009). In that paper, we estimate a series of VARs with oil prices, the exchange rate, and various indicators of domestic prices, splitting the entire sample period into two sub-periods: the first is the period February 1976 to December 1989, and the second is from January 1990 to January 2009. It is reported that, as a general tendency, pass-through of both oil prices and the exchange rate tend to decline between the two periods. Then, those results are compared to the results of our study on the Japanese input-output table, though we use only information from the I-O Tables only for the years 1980, 1985, 1990, 1995 and 2000 in that paper.

This paper extends the above analysis in three important respects. First, the VAR analysis in the previous paper does not reveal how the pass-through rate evolved over time. Note that, if changes in the cost structure were the main reason behind its decline, we might expect it to happen gradually over time, rather than experiencing a one-time structural break. To pursue this issue further, in this paper, we estimate time-varying parameter (or TVP-) VARs (refer to, for example, Kim and Nelson (1999)). It is expected that this approach will help detect timing of structural changes, and thus give us more hint on the causes behind the decline in the pass-through rate. Like in Shioji and Uchino (2009), we compare the time series estimation

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[5] Among previous studies, Blanchard and Gali (2007) estimate oil shares in both consumption and production, based on the shares of oil and related products in overall *nominal* value added of the US economy. They compute these shares separately for 1973 and 1997, and use them for their simulations. In that sense, they do not distinguish between relative quantities changes and relative price changes.

results with predictions from the input output table analysis, to see how much of the observed changes in the pass-through rate can be explained by cost structure related reasons. The second feature of this paper is that we conduct a detailed analysis of the Japanese input output table for the 2000s. Especially, we pay a close attention to the mid to late 2000s, i.e., the period of a dramatic rise and a fall of oil prices.

The rest of the paper is organized as follows. In section 2, we revisit evidence from the simple VARs with split samples, for the sake of comparison with our TVP-VAR results. Section 3 presents the results based on the TVP-VARs, and, in section 4, we compare them with the results of the input-output table results for the period 1980-2000. In section 5, we turn our attention to the recent periods of volatile oil price movements. Section 6 concludes.

2 Evidence from regular VARs

Japan imports over 99% of crude oil it uses from abroad, and is thus considered to be vulnerable to its price changes. Figure 1 plots three variables. First is the World Crude Oil Price Index ("OIL" for short). This variable is defined in US dollars. We use IFS's "World Petroleum: Average Crude Price", monthly averages, all the way up to October 2008. As we could not obtain this data for the period November 2008 through May 2009, we supplement this with the data on North Sea Brent Spot, also monthly averages. Second is the Import Price Index for Crude Oil ("IPI" for short). This variable is denominated in the Japanese yen. It is taken from the Bank of Japan (BOJ)'s *Price Indexes Quarterly*. Third is Japan's Corporate Goods Price Index (overall average, "CGPI" for short), which corresponds to the wholesale price index in many other countries. The data source is the same as IPI. The figure spans the entire sample period of our analysis, namely from January 1975 to May 2009. The variables are normalized so that their values in January 1990 are all equal to 100. In Figure 1, note that, despite the surge in the US dollar price of crude oil (namely OIL) in the second half of the 2000s, its *yen* price (namely IPI) does not surpass its peak in the 1980s until late 2007. This is because the dollar-yen exchange rate changed in favor of the yen between those two periods.

Figure 1 Evolution of OIL, IPI and CGPI, January 1990 = 100

Source: Bank of Japan and International Financial Statistics (IFS).
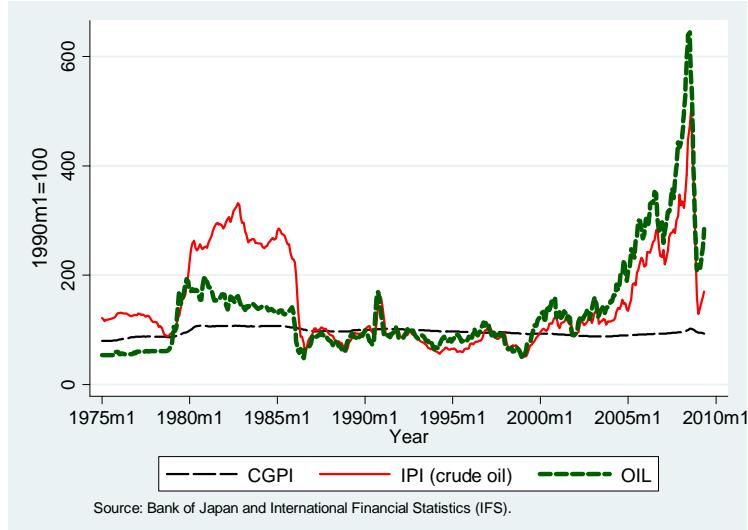
It is often stated that the pass-through rate of oil prices to the domestic prices in Japan has declined in recent years. To see if this claim is verified, we estimate VARs with OIL, IPI and Japanese domestic prices. In Shioji and Uchino (2009), we estimate VARs with multiple indices of domestic prices: some prices that represent the "upstream" of the production process, such as CGPI, as well as "downstream" prices such as CPI. This approach is in line with Ito and Sato (2008) who study exchange rate pass-through in Asian economies using VARs with multi stage domestic prices. Here, instead, we estimate a series of three variables VARs which includes just one index of domestic prices at a time. The reason is that, when estimating time varying parameter VARs which will be introduced later, we found that we quickly run out of computer memory if we include four variables or more, with 12 lags. This choice also precludes inclusion of other potential determinants of domestic prices but, as we show in an appendix that is available upon request, our VAR results are robust to inclusion of one more variable, such as industrial production, the exchange rate, and the interest rate.

All the data is monthly. The first sample period is from February 1976 to December 1989 (often referred to as the "first half") and the second sample period is from January 1990 to May 2009 (often referred to as the "second half")[6]. Throughout this paper (including the TVP-VAR part),

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[6] Our choices regarding the beginning of the first half and the last month of the second half are dictated by the data availability (at the time we started this research). The choice of where to break the sample is somewhat arbitrary, except that it roughly corresponds to the beginning of Japan's so-called "lost decade".

the lag length is set to equal 12. We take natural logarithms of all the variables and take their first differences. Reported impulse responses are all cumulative responses (that is, they are the responses of the log level of each variable) to one standard deviation shocks. The impulse response calculations are based on Cholesky decomposition, with OIL treated as the "most" predetermined, and IPI as the second. Although the exchange rate does not appear explicitly (unlike in Shioji and Uchino (2009)), it is implicitly included in our estimation. Note that OIL is in US dollars while IPI is in the Japanese yen. Hence, the difference between the two reflects the dollar-yen exchange rate fluctuations, among other things. An advantage of this approach is that it allows us to control for other factors that influence the difference between OIL and IPI, such as changes in transportation costs and margins charged by shipping firms. To save space, we report only cases that correspond to an OIL shock, and show its own responses (i.e., responses of OIL to OIL) and responses of IPI and domestic price indices. Figure 2 reports the case in which the domestic price index is CGPI total. In all the panels reported in this section, the left hand side figure is for the first half, and the right hand side is the second half. Also, the shaded areas are the 95 percentile bands. Panel (A) corresponds to the response of OIL to an OIL shock. Panel (B) is the response of IPI to OIL, and (C) is the response of CGPI to OIL. Note that the scales in Panels (B) and (C) are set in the same way as in (A) for the sake of comparison. But this makes the graphs in (C) too small. For that reason, in Panel (D), we present the same graph as in (C) but with a different scale. Note, first, that the sizes of the responses of OIL to an "own shock" are not that different between the first half and the second half (Panel (A)). This means that we can study changes in the magnitudes of pass-through primarily by looking at the responses of domestic prices[7]. Panel (B) shows that, within six months to one year, changes in the world wide oil prices are passed onto import prices to Japan, almost fully. Panel (C) shows that the response of CGPI to OIL was small compared with the own response, even during the first half and that it declined further in the second half (which is more evident in the magnified graphs in (D)).

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[7] To illustrate this point, consider the following counterfactual example: suppose that the responses of CGPI to OIL are of about the same size between the two periods, but the response of OIL to itself in the second half is twice as large as that in the first half. In such a case, it is reasonable to conclude that the pass-through rate of OIL to CGPI was halved in the second half. This example suggests importance of looking at the sizes of "own responses" in drawing economic conclusions.

Figure 2: Regular VAR with CGPI, first half (February 1976 – December 1989, left) and second half (January 1990-May 2009, right)

(A) Response of OIL to OIL
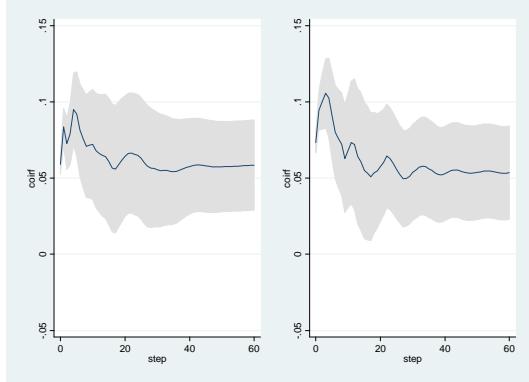
(B) Response of IPI to OIL
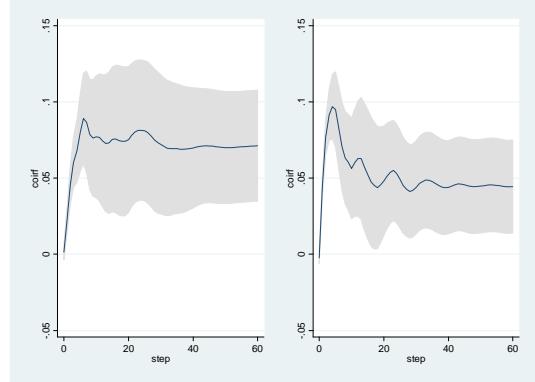
(C) Response of CGPI to OIL
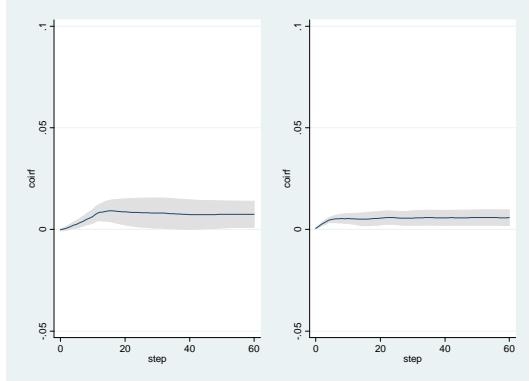

(D) Same as (C), magnified
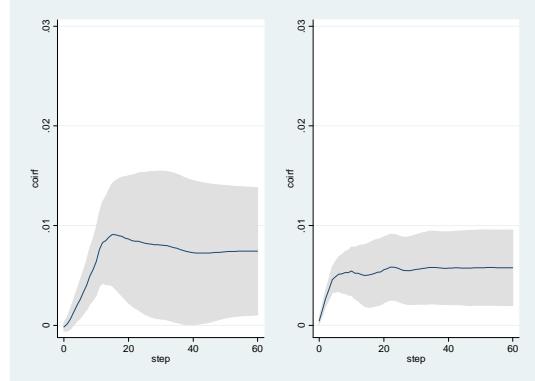
One of the possible shortcomings of using the overall CGPI is that it is constructed as the weighted average of prices of goods sold at various stages of production. This means that the same oil can be counted many times: as a raw material, as a part of an intermediate input (such as naphtha, ethylene, and polyethylene), and as a part of a final product (such as plastic hoses). To minimize this problem, we redo the analysis utilizing the information on CGPI "by stage of demand and use" published by the Bank of Japan. That is, overall CGPI is decomposed into the intermediate goods part and the final goods part. In panel (A) of Figure 3, we use the average CGPI for intermediate products (domestically produced) only, which is denoted as "CGPI-M"., and report its responses to OIL for the first half as well as the second half. Next, in panels (B) and (C) of the same figure, we further decompose CGPI for final goods between consumer goods and capital goods, as their responses are quite different. In panel (B), we use CGPI for consumer goods, restricted to manufacturing products. This means excluding agricultural and mining products, though their shares in consumer goods are quite limited (electricity, gas and water are excluded from the beginning). We do this for the sake of comparison with CPI which will appear below. This series is called "CGPI-C(M)" ("M" for manufacturing)[8]. In panel (C), we use CGPI for capital goods, denoted as "CGPI-K". It is also interesting to compare the results for CGPI with those for CPI, to see how price changes at wholesale levels are reflected in those at retail levels. A direct comparison is difficult, though, as the two cover very different ranges of products. Most notably, CPI includes not only goods but also services. To make the comparison as meaningful as possible, in panel (D), we report results for CPI for manufactured goods, denoted as "CPI-G(M)", and compare the results with those for CGPI-C(M), in panel (B). For CGPI-C(M), CGPI-K and CPI-G(M), we detected seasonality and influences of consumption tax rate changes. For those variables, we deseasonalize them by the Census X-11 method prior to the estimation, and also include two dummy variables, corresponding to the introduction of the consumption tax rate in April 1989 and the tax rate change in April 1997, in our estimation.

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[8] The 1975 base index for CGPI-C(M) is not available, although the CGPI of overall consumption goods (hereafter CGPI-C) is available. The difference is that CGPI-C includes agricultural goods: we do have information on CGPI of those goods, but their weight in CGPI-C is not reported. In order to deal with this problem, we eliminate the effect of agricultural goods prices from CGPI-C, assuming that their weight for the 1975 base index is the same as that in the 1980 base index.

<u>Figure 3</u>: Regular VAR with alternative prices, first half (February 1976 – December 1989, left) and second half (January 1990-May 2009, right)

(A) Response of CGPI-M to OIL
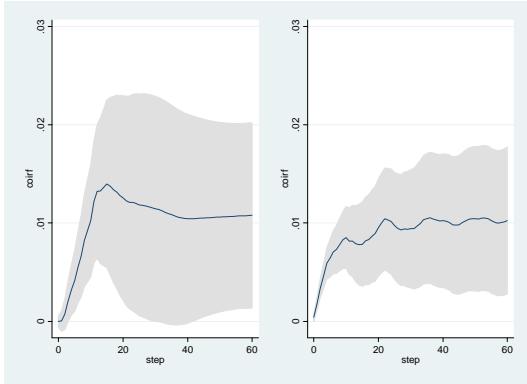
(B) Response of CGPI-C(M) to OIL
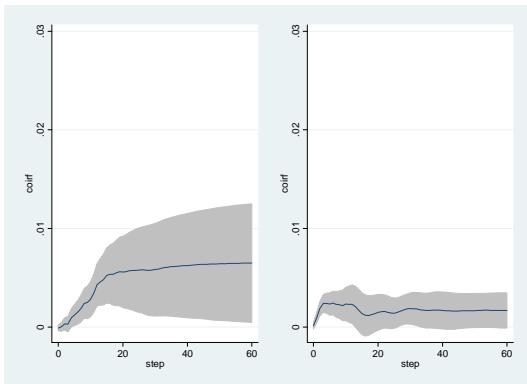
(C) Response of CGPI-K to OIL
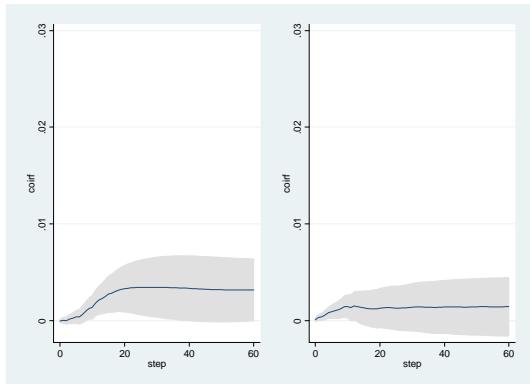
(D) Response of CPI-G(M) to OIL
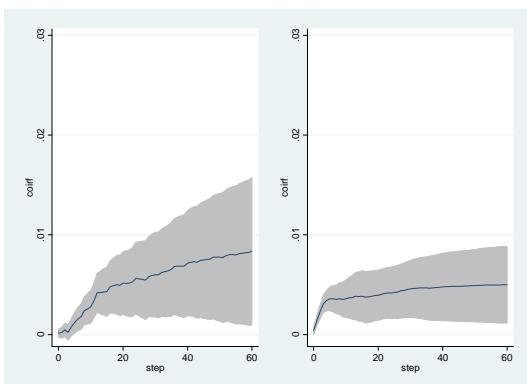
Going through different panels of Figure 3, we see that the general tendency for declining pass-through applies to those alternative measures of domestic prices as well. We can also see that the pass-through rate tends to decline as we move downstream from CGPI-M to CGPI-C(M) and CGPI-K, with the former being more sensitive to oil price changes than the latter. Comparing panels (B) and (D), we can see that the responses of CGPI-C(M) are smaller than those for CPI-G(M). The result seems quite puzzling, because wholesale prices, which are more "upstream", are expected to be more sensitive to oil price changes than retail prices, which are more "downstream". We shall come back to this issue in the next section.

3 Evidence from TVP-VARs

3-1 Evidence for aggregate prices

As we have already argued, regular VARs with sub-samples are not necessarily helpful in detecting timing and speed of structural changes. In this section, we employ a time varying parameter VARs (TVP-VARs) to overcome these shortcomings. Refer to Appendix at the end of the paper for the details of the empirical method employed here. Very briefly, our method is an application of the Kalman Fliter, and only the reduced form VAR coefficients are allowed to change over time.

In this section, we continue with our study on aggregate domestic prices. As in the previous section, we estimate a series of TVP-VARs with three variables, namely OIL, IIP, and a measure of domestic prices[9]. In Figure 4, we show an example in which we use CGPI as the domestic price index. These are impulse responses, evaluated at January of years 1980, 1985, 1990, 1995, 2000, 2005, and 2009, of each variable to an OIL shock. We can observe that the responses of CGPI shifted upward during the 1980s, moved down sharply at the beginning of the 1990s, and then continued to decline gradually until the mid-2000s. There is a slight shift upward in 2009.

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[9] Both the VAR and the TVP-VAR approaches treat OIL as an endogenous variable. It might be more appropriate to model it as exogenous to the Japanese economy. We tried estimating a TVP-VARX model with OIL, IPI and CGPI (total), in which OIL is regarded as an exogenous variable. The estimated pass-through rates were virtually the same as the ones reported below. For this reason, in the paper, we report results from standard TVP-VARs.

Figure 4: TVP-VAR results for CGPI total: Impulse responses to OIL
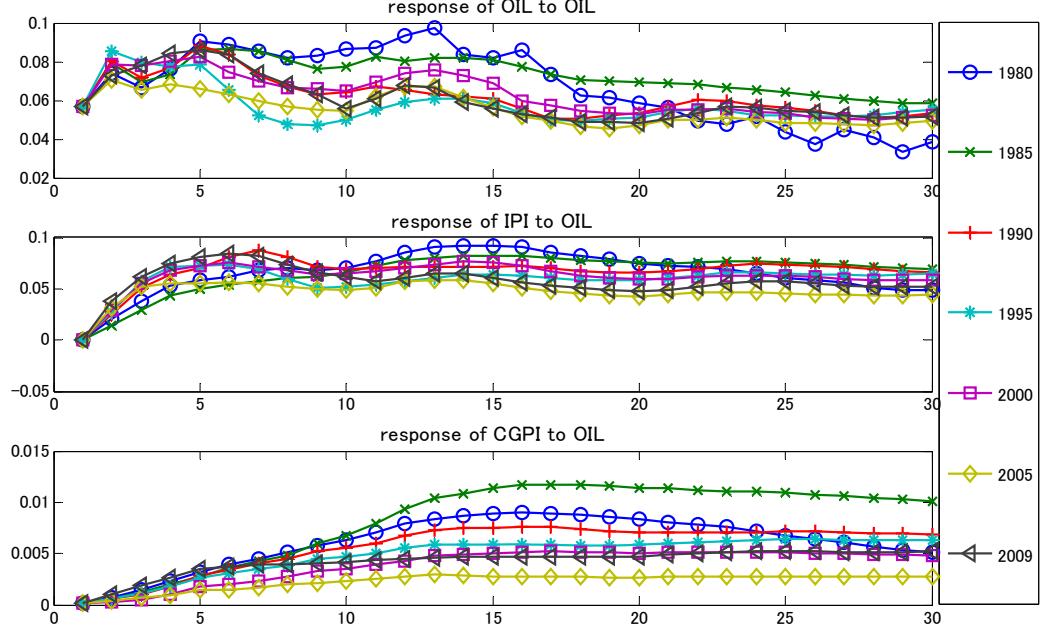
While the regular impulse responses in Figure 4 are undoubtedly informative, it is difficult to grasp the big picture from here. This is especially so because we wish to compare the responses of the domestic price index (CGPI here) with the "own responses" at each point in time. Next, we try to summarize the vast information provided by the estimation in a little more succinct way. In Figure 5, we report time series evolution of the estimated "pass-through rates". With respect to an OIL shock, it is defined in the following way:

(Pass-through rate of OIL at time horizon *s* in period *t*)

= (impulse response of domestic price to an OIL shock at horizon *s* in period *t*)

/ (impulse response of OIL to an OIL shock at horizon *s* in period *t*).

We present the results in three dimensional graphs. On the vertical axis, we put the estimated pass-through rate as defined above. On the axis titled "year", we put time period (we show results for January of each year). On the axis labeled "horizon", we put the time horizon, i.e., the number of months after the shock hits. Along the time period dimension, we start all the figures from 1979. This is because, in the TVP-VARs, the

first few years of estimation results tend to be influenced by initial values set by the researcher.

Figure 5 Estimated Pass-through rates for aggregate price indices
(A) CGPI total

(B) CGPI-M


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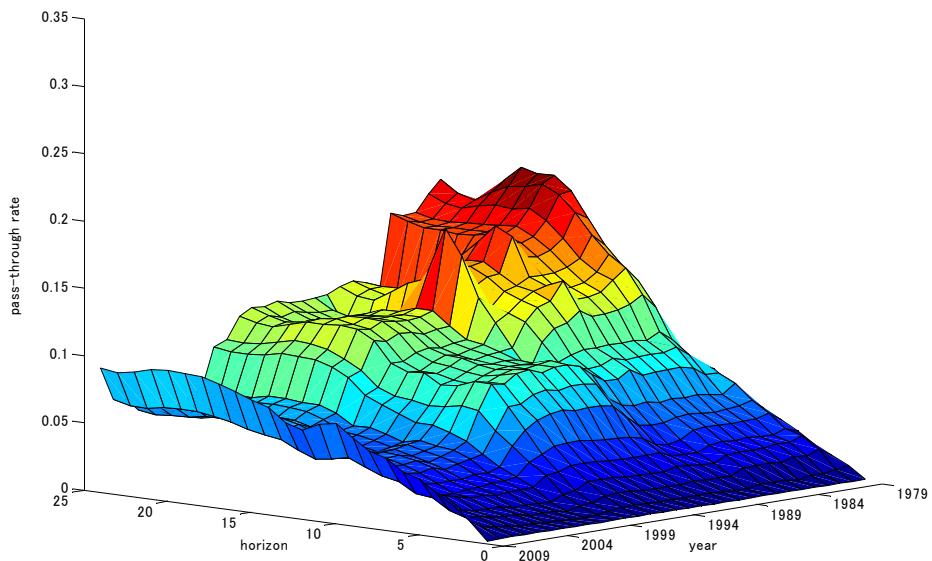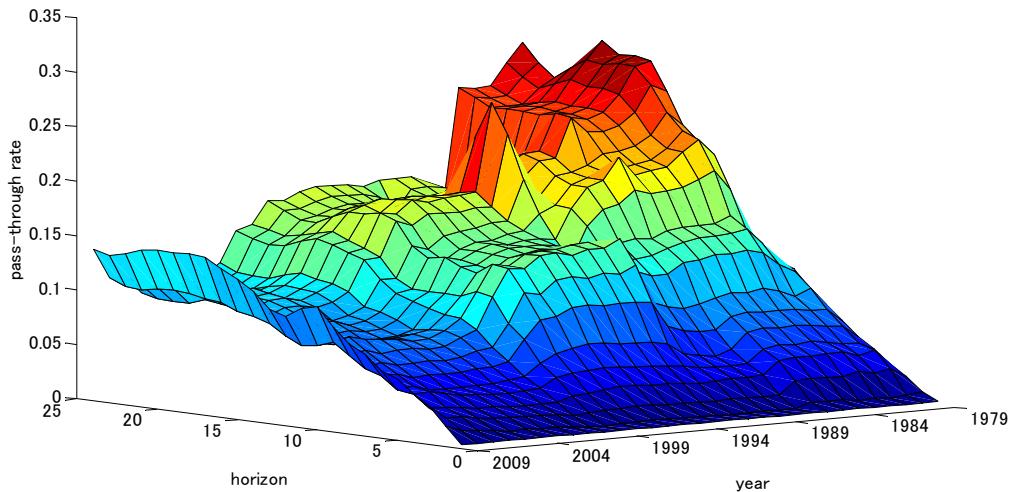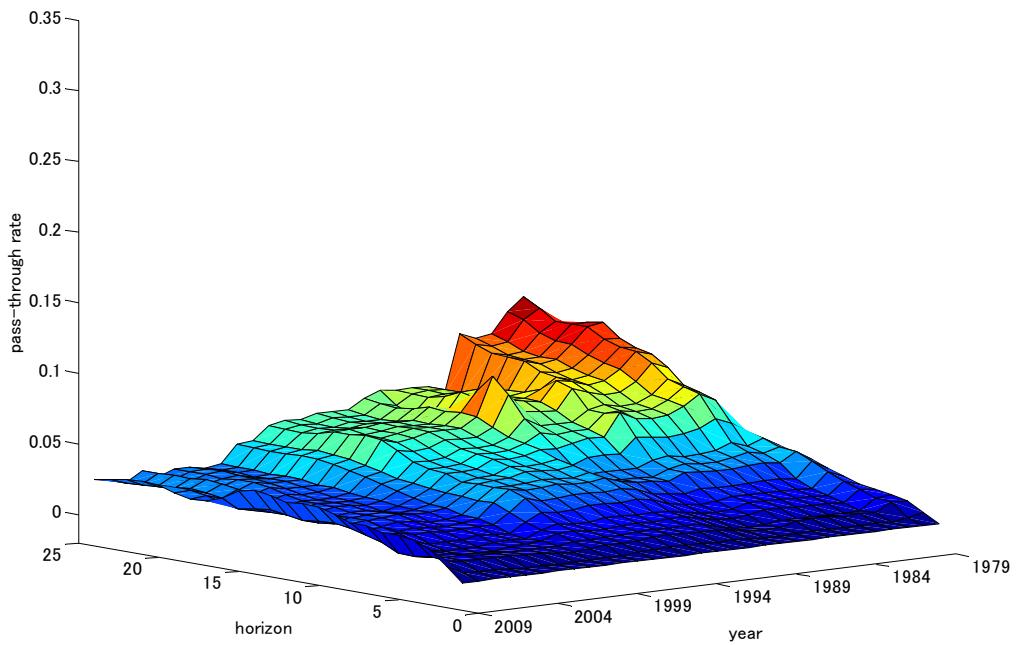
(C) CGPI-C(M)

(D) CGPI-K
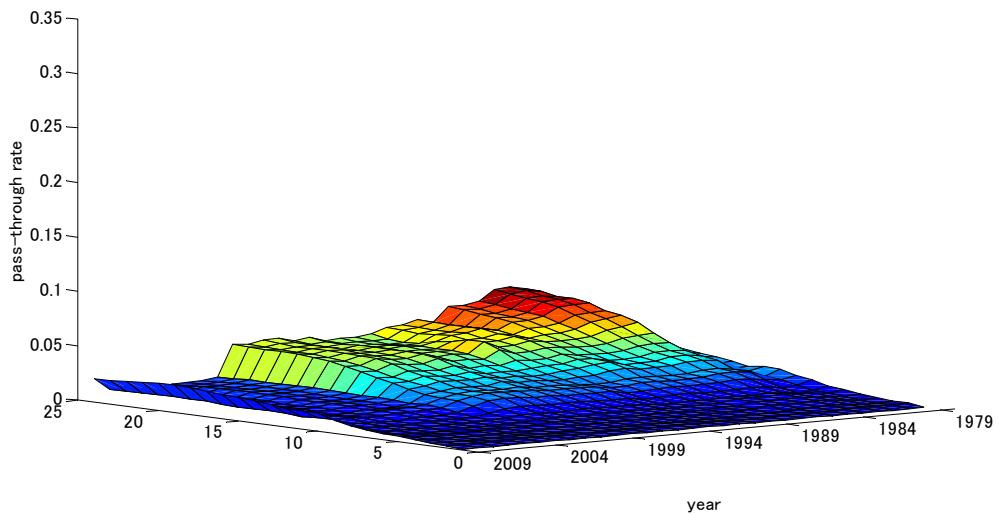
(E) CPI-G(M)
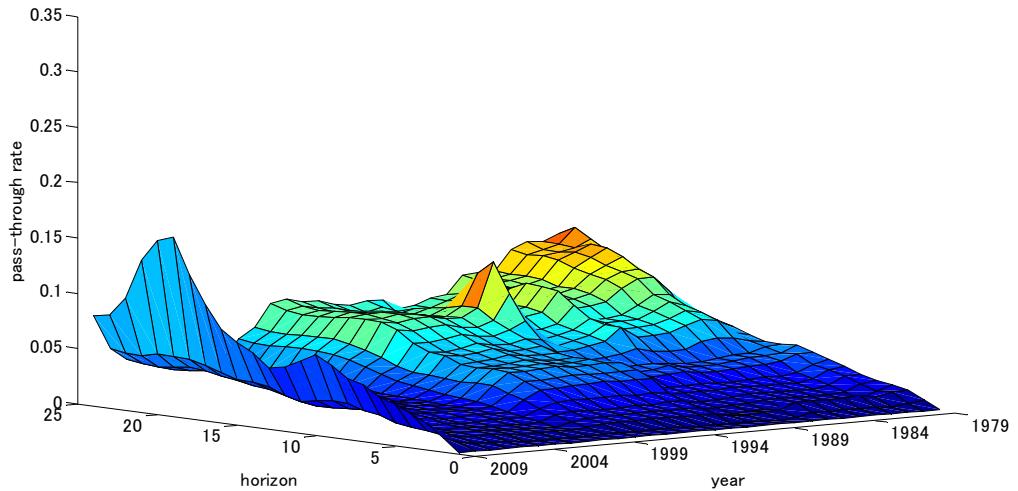
(F) Comparison of CGPI-C(M) and CPI-G(M)
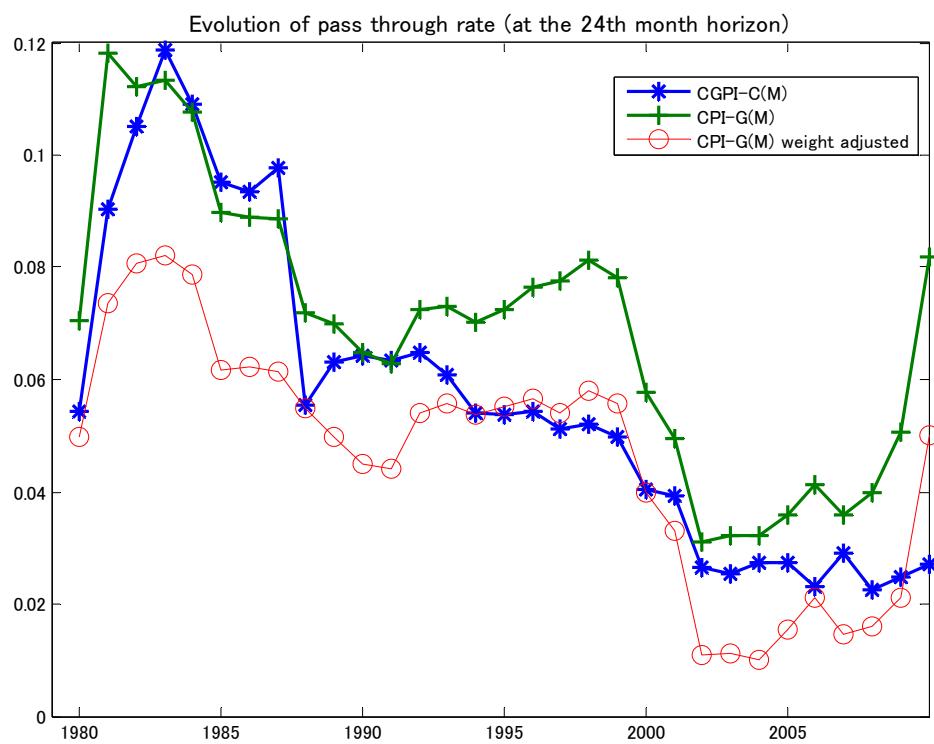
In Figure 5(A), we calculate the estimated pass-through rate of OIL to CGPI total. We observe that the pass-through rate goes up at the beginning of the 1980s and comes down gradually but fast in the latter half of the 1980s. It declines further at the end of the 1990s and there is a small increase toward the end of our sample period.

In Figure 5(B), (C), (D) and (E), we report the pass-through rates for CGPI-M, CGPI-C(M), CGPI-K, and CPI-G(M), from three variable TVP-VARs that incorporate each of those variables in place of CGPI. For the latter three, we deseasonalize them prior to the estimation and regress each of them on the two consumption tax dummies mentioned above, and use the residual in the TVP-VAR. In each of the panels, we find that the basic patterns of the pass-through rate changes over time are similar to those in panel (A). The magnitudes of the pass-through rates among the different CGPI variables are in the order of CGPI-M > CGPI > CGPI-C(M) > CGPI-K.

However, we observe again that the pass-through rate for CPI-G(M) is larger than that of CGPI-C(M) for much of the sample, contrary to our prior expectation. This could be due to different weights attached to durable goods between the two indices: the weight is about 10% for CPI-G(M) while it is about 30% for CGPI-C(M). As we report in an appendix that is available upon request, when we decompose consumer goods into non-durables and durables, we find that the former is more sensitive to oil prices than the latter. Therefore, the above puzzling result could be due to the difference in the composition of the two indices[10].

In order to examine this hypothesis, we construct a counterfactual series of CPI-G(M) by adjusting the weight for durable goods to be equal to that of CGPI-C(M), and re-estimate the three variable TVP-VARs. In Figure 5(F), we report the evolution of the estimated pass-through rate at the 24th month horizon derived from this hypothetical price index in the line with circles. We find that, for the most part of the sample, this

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[10] Some argue that these differences are related to a statistical problem that might exist in the Japanese household survey on which the calculation of the CPI's weights is based (Shiratsuka (2005)). It is widely recognized, not only in Japan, that the weight of household durables consumption are possibly underreported in household surveys (see ILO (2004), chapter 4).

pass-through rate is lower than that for CGPI-C(M). This result is consistent with our hypothesis[11].

Although our primary interest in this paper is in variations of the pass-through rates over time, it is also of interest to see how the levels of the pass-through rates in Japan compare with those of other countries, especially in Asia. Jongwanich and Park (2008) conduct VAR analyses of oil price pass-through for various countries in Asia, for the late 1990s and the 2000s, and report their estimated pass-through rates, defined in the same way as in our study. Their estimated rate for PPI is high for Indonesia (around 0.22), Malaysia (0.16), Singapore (0.16), and, to some extent, PRC (0.14). Korea, Thailand, and the Philippines are intermediate cases with about 0.07. The rate is much lower for India and Vietnam. In Figure 5(A), the pass-through rate for CGPI for the same period varies between 0.06 and 0.12 at the 24th month horizon, which places Japan below Indonesia, PRC, etc., and closer to Korea and Thailand. This may not be so surprising: Japan, for an industrialized country, has had a high share of manufacturing, especially heavy manufacturing such as automobiles. Even if each plant is energy efficient, it is still possible that the country as a whole is rather energy intensive. Before jumping up to a conclusion, however, we would have to further investigate comparability of the data between Japan and those countries.

3-2 Evidence from Plastic

The previous sub-section revealed declining tendencies of pass-through of oil prices to Japanese aggregate prices. This, however, could be due to a mixture of two causes: declines in responsiveness of prices of oil-related products to oil prices, and increases in the shares of non-oil-related products (and also services, in the case of CPI). To extract the former effects from the data, we now turn our attention to industry level price data and focus on products that are very oil intensive. In this sub-section, we take up plastic

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[11] Exceptions are in the latter half of the 1990s and around the year 2009. The difference in the estimated pass-through rates between the two is relatively small for the former period. The difference is larger for the last part of our sample: a possible cause is a deregulation of the retail market for gasoline: refer to the discussion in section 3-3.

and related products. Distilling crude oil at oil refineries produces "naphtha", among other things, and cracking naphtha in petrochemical steam crackers yields so-called "basic petrochemical products" (ethylene, propylene, benzene, etc.), and they are used to produce various types of "plastic" (polyethylene, polypropylene, etc.). Then plastic is supplied for various purposes, including production of so-called "plastic products" (such as plastic hoses). Here, we study how the pass-through rates of crude oil prices to those products at each of these stages evolved over time.

Figure 6: Estimated pass-through rates for plastic and related products
(A) Naphtha (CGPI)
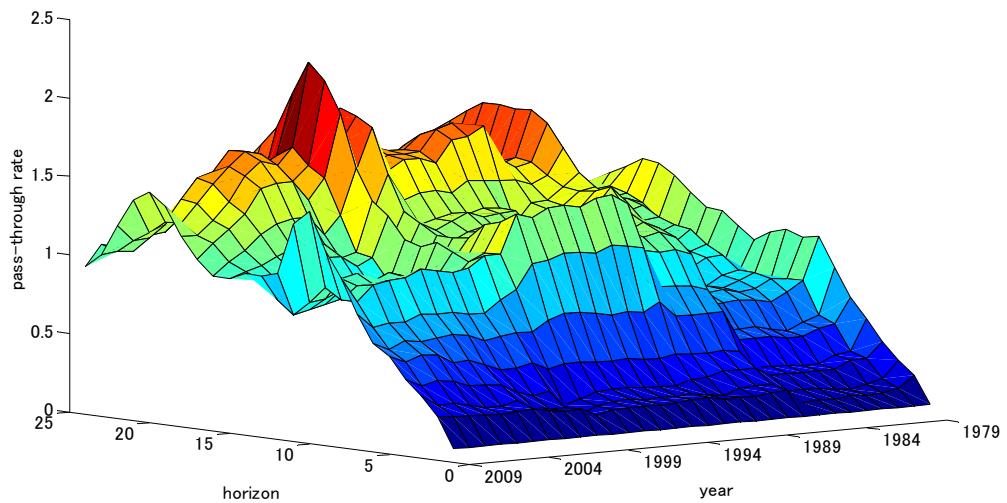
(B) Petrochemical (CGPI)
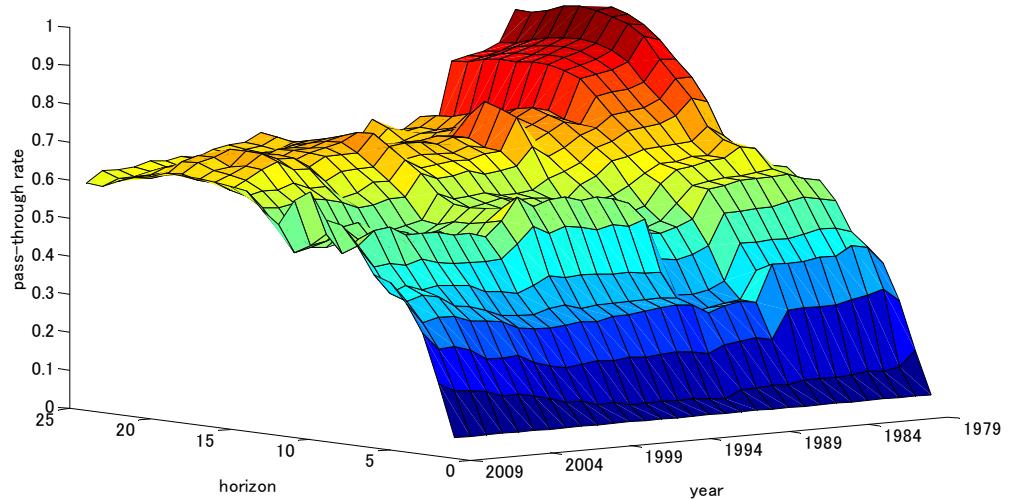
(C) Plastic (CGPI)
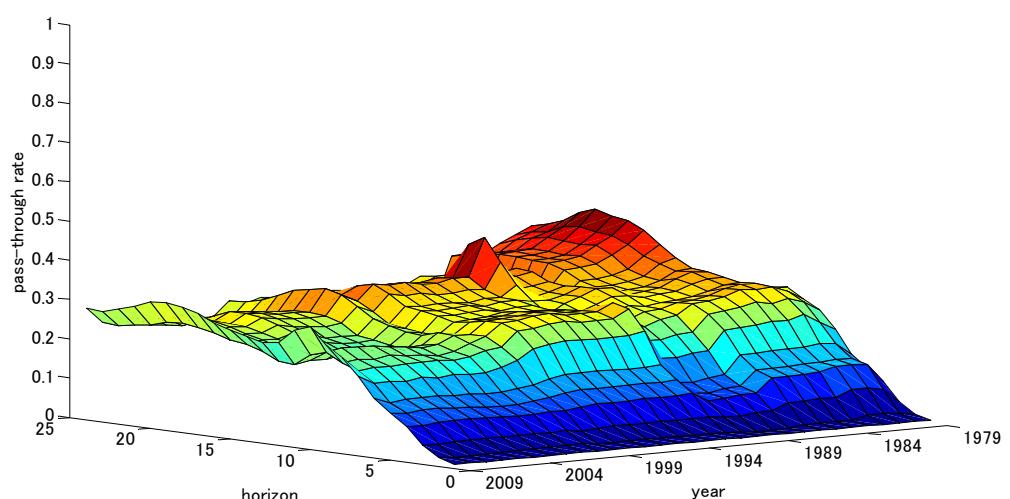
(D) Plastic Hose (CGPI)
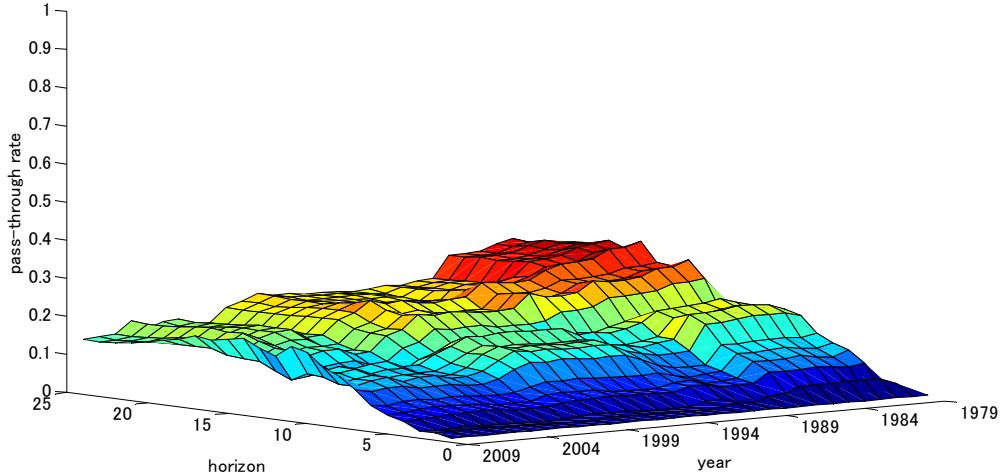
In Figure 6, we report results from a series of three variable TVP-VARs, with crude oil (OIL), IPI of Naphtha, and one of the product-level domestic price indices: that is, CGPI of Naphtha, CGPI of Basic Petrochemical Products, CGPI of Plastic, or CGPI of Plastic Hose. The last one is used as a representative of Plastic Products[12]. In this sub-section, we use IPI of Naphtha in place of that of crude oil: this is because domestic prices of naphtha are determined in reference to prices of imported naphtha[13]. First, note that, as we move down the panels, that is, as we move toward downstream of production stages, the estimated pass-through rate tends to decline, as one would expect. Next, we see the same general pattern that we saw in the aggregate prices: the pass-through rate increases sharply at the beginning of the 1980s, declines in the latter half of the 1980s, again toward the end of the 1990s, and we see slight increases in some cases toward the end of the sample period. The only exception to this general tendency is naphtha. The estimated pass-through rate seems too high, often exceeding 1 (note that the scale of the vertical axis is different for panel (A) only), and the pattern of

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[12] It was difficult to find many CGPI series for plastic products that go back all the way to the year 1975: we could identify only four. We use Plastic Hose as a representative example.

[13] To be more precise, this custom started formally in 1982, when the Ministry of International Trade and Industry decided that domestic prices of naphtha should be determined by adding certain margin to prices of imported naphtha, and that the price should be revised every quarter (rather than monthly).

the time variation is unclear. This could be because, as mentioned above, prices of domestically produced naphtha are determined by some non-market rule.

3-3 Evidence from Gasoline

Next, we turn to the case of gasoline. Again, we estimate a three variables TVP-VAR, with OIL, IPI of crude oil, and CPI of gasoline. To control for disruptive effects of a temporary reduction and a subsequent increase in the gasoline tax rate in 2008, we first regress log differences of gasoline prices on the March 2008 dummy and the April 2008 dummy. Then the residuals are included in out TVP-VAR estimation. We report the estimated pass-through rates in Figure 7(A). We observe that the level of the pass-through rate is lower compared with, for example, naphtha. Its tendency to decline over time, before starting to increase again in the late 2000s, is similar to the previous results.

Figure 7: (A) Estimated pass-through rate for Gasoline (CPI)
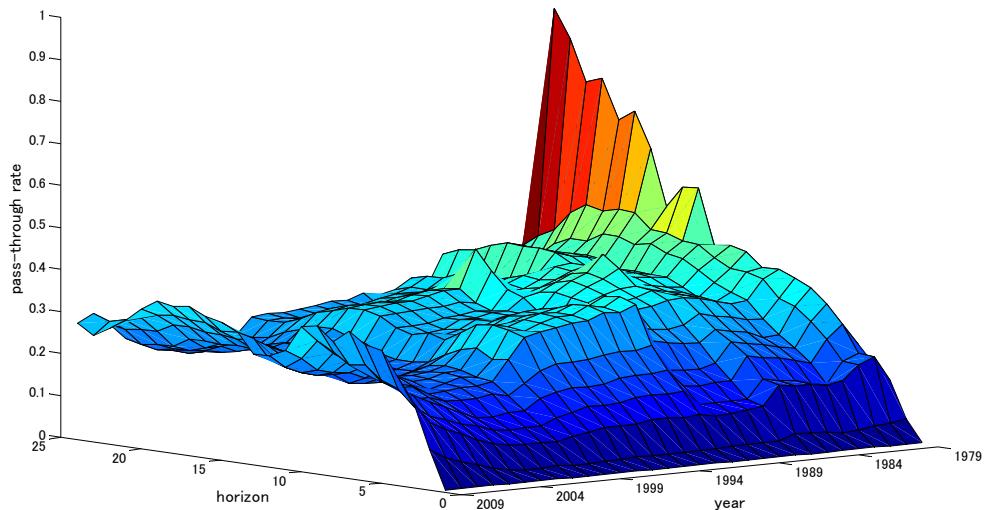
As gasoline is one of few oil-intensive items that appear in both CGPI and CPI, it is of interest to study how the results differ between the two. In Figure 7(B), we compare the evolution of their estimated pass-through rates at the 24th month horizon. As expected, the pass-through rate is higher for CGPI of gasoline than its CPI counterpart for much of the sample. However, somewhat surprisingly, toward the end of the sample, the order is reversed. One possible cause of this is the deregulation of the retail market for gasoline. According to Japan Fair Trade Commission (2004), a series of deregulation put gasoline stations under strong competitive pressures. This might have made retail gasoline prices sensitive to various factors affecting oil prices. On the other hand, the supplier side of gasoline to those stations remains oligopolistic[14].

Figure 7(B) Estimated pass-through rates, Gasoline (CGPI) and Gasoline (CPI)

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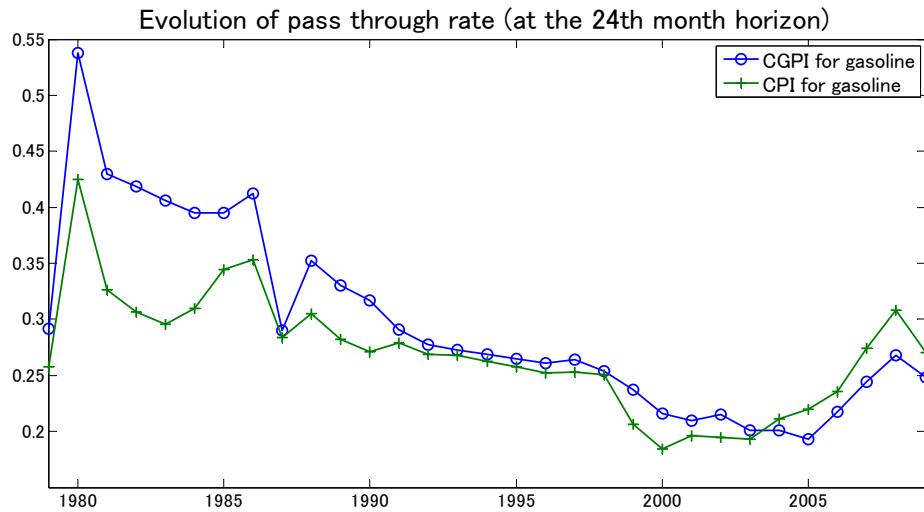
[14] Some participants at the 20th East Asian Seminar on Economics suggested using the gasoline tax reduction in March 2008 (and the subsequent tax hike in the following month) as a natural experiment to study how cost changes are transmitted to wholesale and retail prices. We think this incident was quite different in its nature from most of oil price increases in history in one important aspect: the tax reduction was fully expected to be very temporary from the beginning. As a consequence, this policy induced tremendous intertemporal substitution of gasoline usage, both before and after the tax rate changes. We think it is difficult to make inference about the effects of oil price changes, which are typically more persistent, by studying this event.

3-4 Evidence from Electricity

Finally, we turn to the case of electricity. In this case, we estimate a three variable TVP-VAR, with OIL, IPI of "crude oil, coal and natural gas", and CGPI of electric power. We include natural gas etc. in our definition of IPI here, because even thermal power plants use not only oil but also coal and natural gas[15]. CGPI of electric power is deseasonalized by the Census X-11 Method. We report the estimated pass-through rates in Figure 8. We can observe continuous declines in the pass-through rate, starting in the early 1980s and lasting throughout much of the sample period, until it starts to increase again toward the end of the sample.

Figure 8: Estimated pass-through rate for Electricity
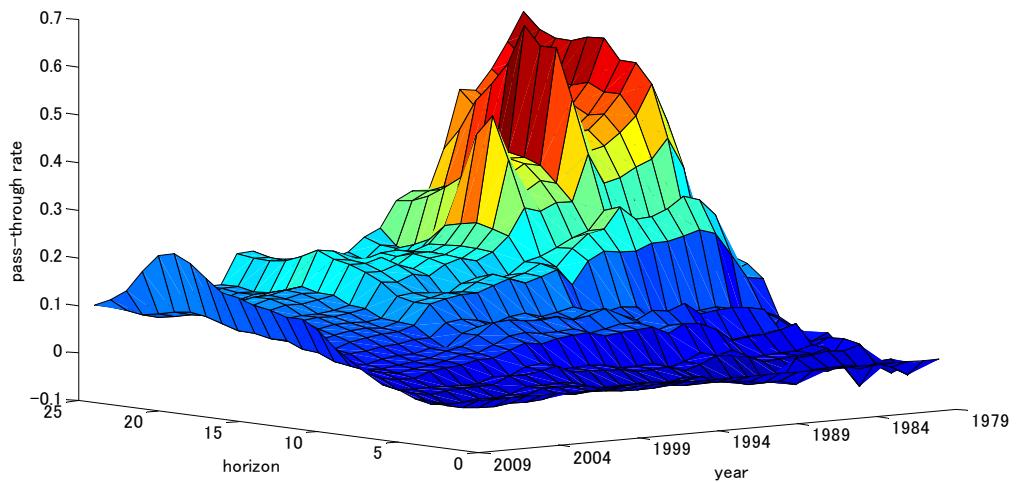
To summarize this section, we have seen that the declines in the pass-through rates at the aggregate level are not simply a result of shrinking shares of oil-related products. Even at the level of those products, we can find declines in the pass-through rates. In the next section, we study implications from the Input-Output Tables to see if this can be explained from changes in the cost structure of oil-related production.

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[15] In fact, oil has come to play a relatively minor role. We shall discuss this matter further in the next section.

4 Cost structure and pass-through rates: what do the Input-Output Tables predict? The 1980-2000 period.

4-1 Data and Methodology

In Japan, frequent changes in rules and methodology (such as classification of goods and services) make a long run comparison of input-output structure difficult. Fortunately, the Research Institute for Economy, Trade and Industry (RIETI) provide detailed Input-Output Tables for years 1980, 1985, 1990, 1995 and 2000 that are directly comparable between each other. They provide tables in both nominal units and real (constant 1995 price) units. Each of the tables contains 511 rows (industries that provide inputs) and 398 columns (industries that use those inputs). Most notably, "crude oil" appears as a single row item (though, on the column side, it is combined with natural gas). Also, different types of Petroleum Products, such as "gasoline", "naphtha", "fuel oil A" and "fuel oil B&C", all appear as separate items on the row side (though they are all combined into one on the column side). This is important, as different types of Petroleum Products receive very different tax treatments. We make suitable assumptions to expand the tables into matrices of dimensions 511 times 511[16].

Naturally, we are also interested in the period after 2000. The next section employs more recent I-O tables, which are much smaller than the ones explained above (due to limited data availability), to study the 2000s.

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[16] The numbers of columns and rows do not coincide basically because certain row industries are combined into single column industries. In such cases, in principle, we assume that each row industry that belongs to the same column industry group has the same input structure. There are only very minor exceptions in which the correspondence between the row industries and the column industries is not perfect. For Petroleum Products, it is important to consider the fact that different types of products are subject to very different tax schemes. For this reason, we take the following approach. From the input-output table for each year, we obtain the total amount of indirect taxes paid by the whole Petroleum Products sector. From tax revenue statistics of the Ministry of Finance, we obtain the shares of taxes imposed on each type of Petroleum Products. We allocate indirect taxes to each of the sub-sectors according to those shares. The rest of the cost structure is assumed to be the same across those sub-sectors. We consider this to be a reasonable assumption, as all of those products are by-products of a single distillation process.

The I-O Tables can be used to derive predictions on a percentage response of the average price of products of a certain sector when the price of imported goods (say) of another sector increases by 1%. The Input-Output analysis with N sectors (with trade) has the following basic structure:

$$x = Ax + d + e - M(Ax + d)$$

where x is the vector of output ($N \times 1$), A is the input coefficient matrix, d is the vector of domestic final demand ($N \times 1$), e is the vector of exports ($N \times 1$), and M is the matrix of import coefficients. The matrix M is a diagonal matrix whose ith diagonal element is the ratio of the imports of the ith sector to the sum of intermediate inputs from the ith sector to all the sectors plus the domestic final demand to this sector's output. From here, it is possible to derive the following pricing equation:

$$\Delta p = \left[\left(I - (I - M)A \right)^{-1} \right] \cdot A'M' \cdot \Delta p^m ,$$

where Δp is the vector of the rate of domestic price change in each sector and Δp^m is the vector of the rate of price change of imported goods in each sector. For example, suppose that the crude oil sector is the Jth sector and that we wish to study the impact of one percentage increase in imported crude oil price. Then we set the Jth element of the vector Δp^m to be 1 and all the other elements to be 0. Then each element of Δp would indicate the predicted percentage increase in the domestic prices of goods in each sector, under the assumption of flexible prices (complete pass-through at each production stage) and zero substitution. In essence, the above equation provides a way to compute "oil contents" of the cost of production for each sector, which takes into account the complex input output structure of the economy.

In this paper, we utilize both nominal and real I-O tables to derive those predictions. The current prices table will predict the impact of an increase in oil prices given the current cost structure of each industry. The constant price table, on the other hand, will give a hypothetical prediction on what would happen if only the real cost structure changed between the current year and the bench-mark year (due to, for example, substitution between oil and other types of materials) while maintaining the same

relative price structure. It turns out that differences in predictions from those two types of tables are quite informative.

4-2 Plastic, 1980-2000

We start with product level analysis here. Figure 9(A) uses the *nominal* I-O Tables to derive the predicted responses of Naphtha, Basic Petrochemical Products (ethylene, propylene, benzene, etc.), Thermoplastic Resin (a type of plastic: polyethylene, polypropylene, etc.), and Plastic Products. Solid lines with cubes show the predicted percentage responses of those prices when the price of imported crude oil increases by one percent. Dashed lines with triangles show the predicted responses when imported prices of both crude oil and petroleum products increase by one percent, simultaneously. This calculation is necessary because currently Japan imports much of naphtha it needs from abroad (which was not the case in 1980). Solid lines with circles show what happens when prices of all the imported goods increase simultaneously by one percent. Figure 9(B) performs an analogous study using the *real* I-O Tables (1995 constant prices).

The contrast between Figure 9(A) and 9(B) is striking. While the nominal I-O Table predicts sharp declines in the price responsiveness over time, the real I-O Table does not predict any systematic tendency. The fact that the real I-O table does not predict much decline suggests that there was not much of a real substitution away from the use of oil during this period. We had expected a decline in the importance of oil, at the very least in the comparative sense, as we had originally thought the importance of services such as distribution and finance would have increased over time: apparently, that did not happen. Yet the nominal I-O table tells a very different story. The difference comes from the fact that, during this period, there were substantial declines in prices of imported oil, naphtha, and other imports. To summarize, although there were very little substitution between quantities of different types of input, the relative importance of oil still declined substantially basically because it became cheaper. As the lower price of oil reduced its share in overall nominal production costs, prices of those products became much less responsive to fluctuations in oil prices.

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Figure 9: Predicted responses of Plastic and related products to OIL etc.

(A) Predictions from *NOMINAL* I-O Tables
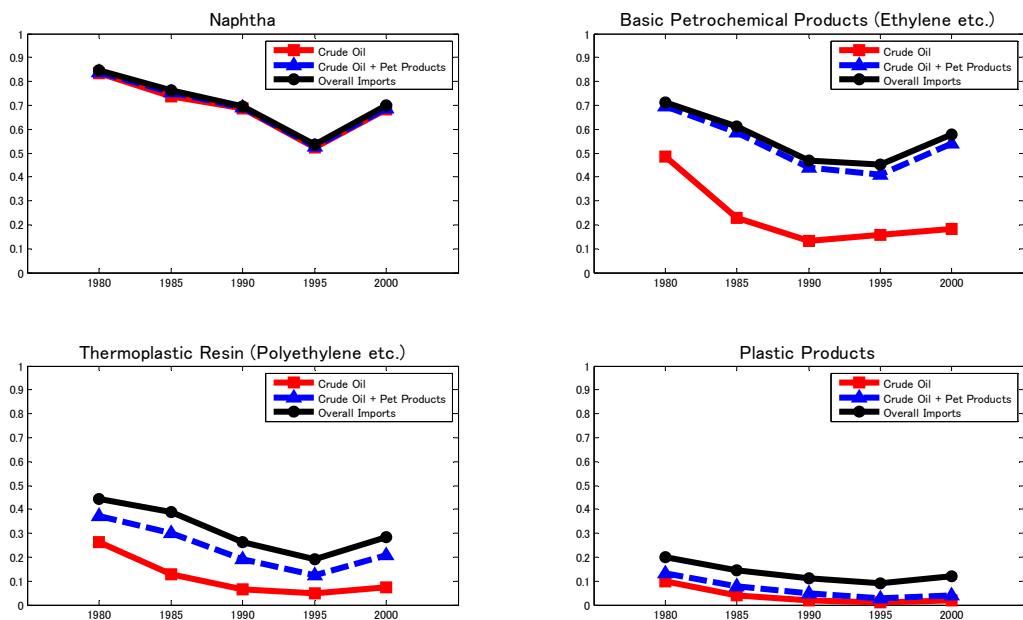
(B) Predictions from *REAL* I-O Tables (1995 constant prices)
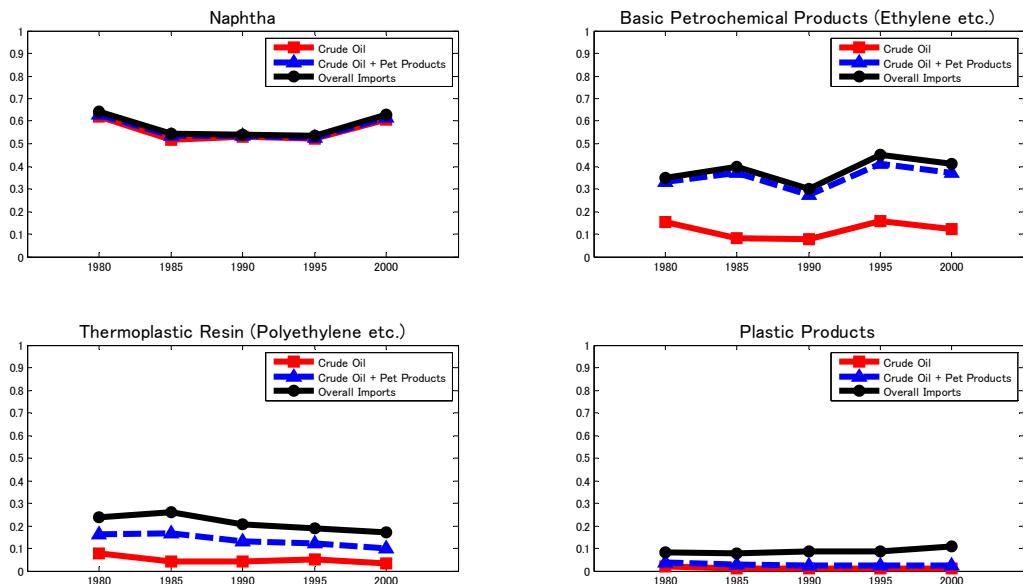
How do these predictions in Figure 9(A) compare with the actual estimation results in Figure 6? Comparing the two panel by panel (looking at the long run estimated pass-through rates at the 24 months horizon in each panel of Figure 6), we learn that the cost-related factors that appear in Figure 9(A) are enough (in some cases, more than enough) to explain the declines in the estimated pass-through rates. Our conclusion for these sectors is that the pass-through rates of oil declined because oil became cheaper and thus became less important in overall costs for those sectors.

4-3 Gasoline, 1980-2000

Studying the case of gasoline in Japan requires a caution, as it is subject to heavy taxation[17]. What is important is that those taxes are *per-unit* taxes (or specific duties) as opposed to ad valorem taxes. Taxes therefore do not go up when oil prices increase. In the period of high oil prices, the share of those taxes in overall gasoline prices is thus relatively low. Gasoline prices will move nearly one-for-one with oil prices. When oil prices are lower, the share of taxes, the portion that does not respond to oil price fluctuations, in overall gasoline prices is higher. Gasoline prices are thus expected to be less responsive to oil price changes. Pass-through rates of oil prices are thus expected to change endogenously with the level of oil prices. This could at least partially explain the declining pass-through rate we saw in Figure 7.

In fact, we estimate that, as of 1980, indirect taxes were equal to about 29.6% of total output value of gasoline. In 2000, this ratio was up to as high as 53.8%.

To study the magnitude of this effect, in Figure 10(A), we first compute predicted response of gasoline prices to oil prices from the nominal I-O tables, under the actual cost structure (solid line with cubes). Note that those predictions are fairly close to the actual estimated pass-through rates, that are reported in Figure 7, for the medium and long runs. Next, we redo the calculation under the counterfactual assumption that the indirect taxes did not exist (or the taxes move proportionately with prices), and the results appear in dashed line with triangles. Lastly, we redo the analysis by assuming

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[17] Also, diesel and jet fuel are heavily taxed in Japan. On the other hand, naphtha and heavy fuel oil are, relatively speaking, lightly taxed. This necessitates careful treatment of indirect taxes that we explained in the previous section.

that not only domestic taxes but also tariffs did not exist (or they also move proportionately with prices), and the results appear in solid lines with circles.

Figure 10: Predicted responses of Gasoline to OIL

(A) Predictions from *NOMINAL* I-O Tables
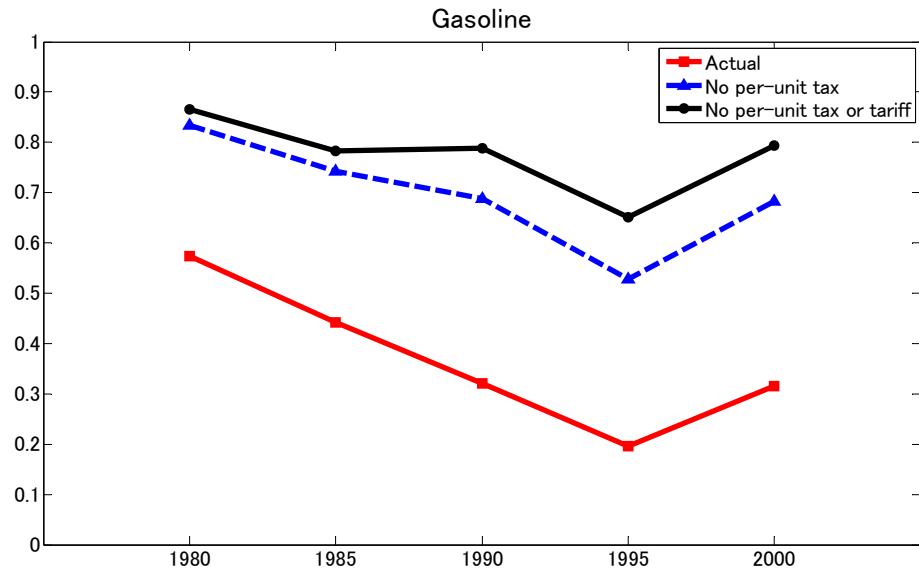
(B) Predictions from *REAL* I-O Tables (1995 constant prices)
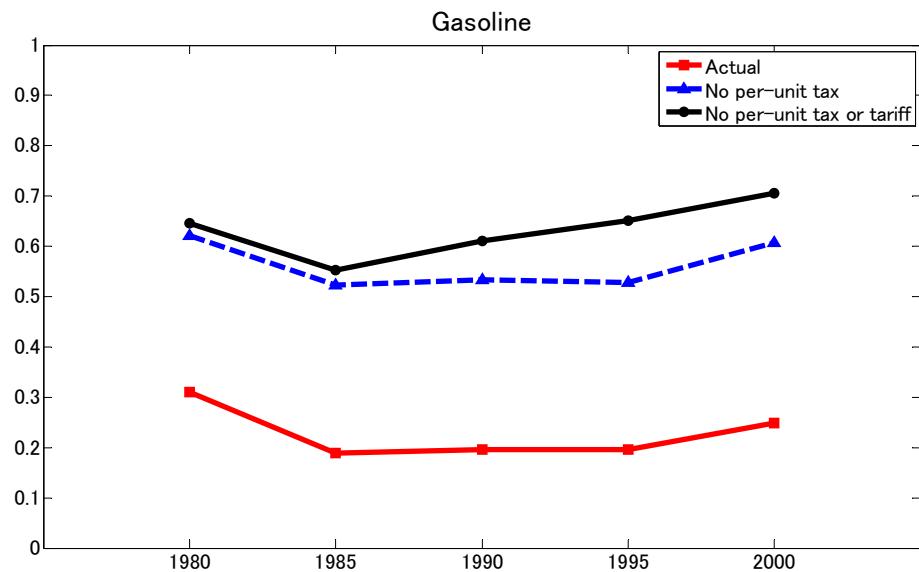
Comparing those lines reveals that the presence of those taxes is greatly mitigating the responsiveness of gasoline prices to oil prices. More importantly, the presence of those

taxes made the responsiveness to decline substantially between 1980 and 2000. Without those taxes and tariffs, the responsiveness would have decreased by relatively small percentages. Figure 10(B) does analogous calculation based on the real I-O table. We see that, without the effects of nominal price levels and taxes and tariffs, the responsiveness would have remained nearly constant, and high. We conclude that the declining pass-through rates in Figure 7 could possibly be explained entirely by those two effects.

4-4 More on the importance of taxes: Diesel and "Type A fuel", 1980-2000

To further investigate the importance of the presence of taxes in pass-through of oil prices, we next consider two types of petroleum products, diesel and so-called "type A fuel". Those two are almost identical in their physical nature. The difference is that diesel is heavily taxed. From the I-O tables, we estimate that the ratio of indirect taxes to diesel production was 20.0% for 1980 and 40.6% in 2000. On the other hand, type A fuel is very lightly taxed. As a consequence, usage of this type of fuel is restricted mainly to agriculture and fishery. According to our argument in the previous sub-section, we should observe higher pass-through rates for type A fuel.

In Figure 11(A), we show the difference between prices of those two types of products (in logarithms), along with crude oil prices. It is evident that the two are highly correlated. This is an indication that type A fuel responds more strongly to fluctuations in oil prices, that is, their pass-through rates are higher.

Next, we estimate regular three variable VARs with OIL, IPI (of crude oil) , and either type A fuel or diesel. Figure 11(B) shows impulse responses of type A fuel (solid line) and diesel (dashed line) to OIL for the first half of the sample (left panels) and the second half (right panels). We confirm our hypothesis that, as type A fuel is lightly taxed, it tends to be more responsive to oil price changes.

Figure 11(A) Evolution of price differentials between type A fuel and diesel (solid line) and oil prices (dashed line), all the prices are in logs
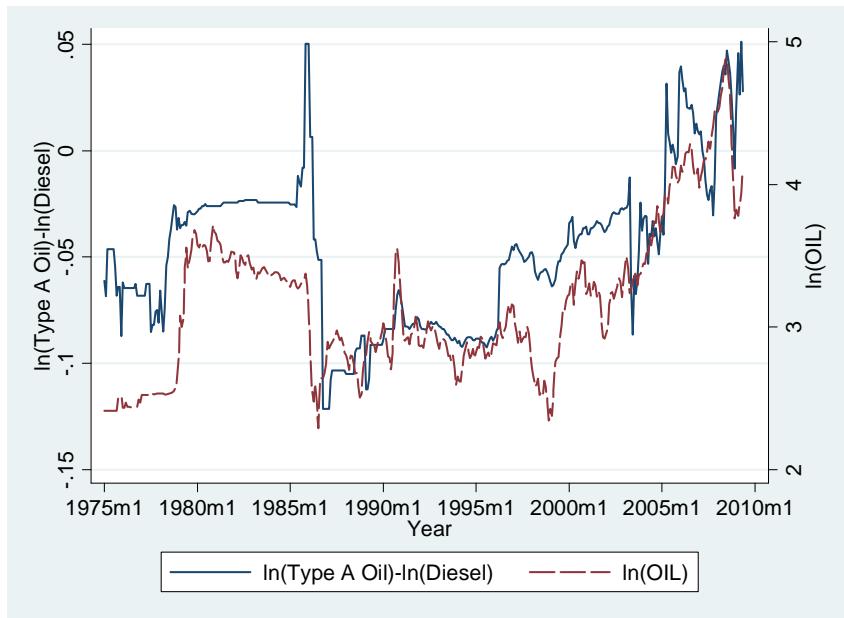
Figure 11(B) Impulse responses to OIL of type A fuel (solid lines) and diesel (dashed lines), first half (left) and second half (right)
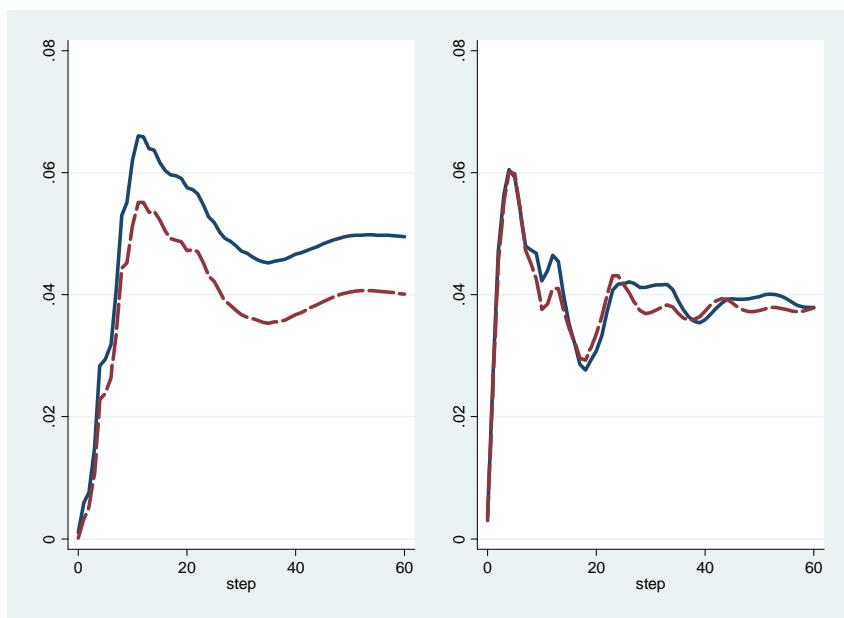
4-5 Electricity, 1980-2000

We next turn to the case of electricity. There are two electricity-related entries in the I-O table, namely electricity for business uses and self uses. We derive the predicted responses for both of them, and the results are shown in Figure 12(A) for the nominal table and Figure 12(B) for the real table. We study the case in which only crude oil prices increase (solid lines with cubes), the case in which oil and natural gas prices increase simultaneously by one percent (dashed lines with triangles) and the case in which prices of all the imported goods increase at the same time (solid lines with circles). The nominal tables predict substantial declines in pass-through rates of oil. The estimated pass-through rates in Figure 8 are close to predictions that appear in the solid line with circles in the electricity for self use case. What is noteworthy about this sector is that, even in the predictions from the real tables, we observe some declines in the predicted responsiveness, though the declines are much smaller compared with the predictions from the nominal tables. The decline is most evident for "crude oil" in the "electricity for self use" case. It is also likely that increasing use of imported coal and construction of nuclear power plants have contributed to the general tendency. Evidently, some part of this decline, since 1990, is the emergence of natural gas as an alternative to using oil. Hence, we conclude that, for this sector, real substitution played a minor but non-negligible role.

Another feature of the electricity industry is that prices were under strict regulations previously, but a series of deregulation took place during our sample period. This would have contributed to increase the pass-through rate. But such an increase does not seem to show up in a noticeable manner either in Figure 8 or in 12

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Figure 12: Predicted responses of Electricity to OIL etc.

(A) Predictions from *NOMINAL* I-O Tables
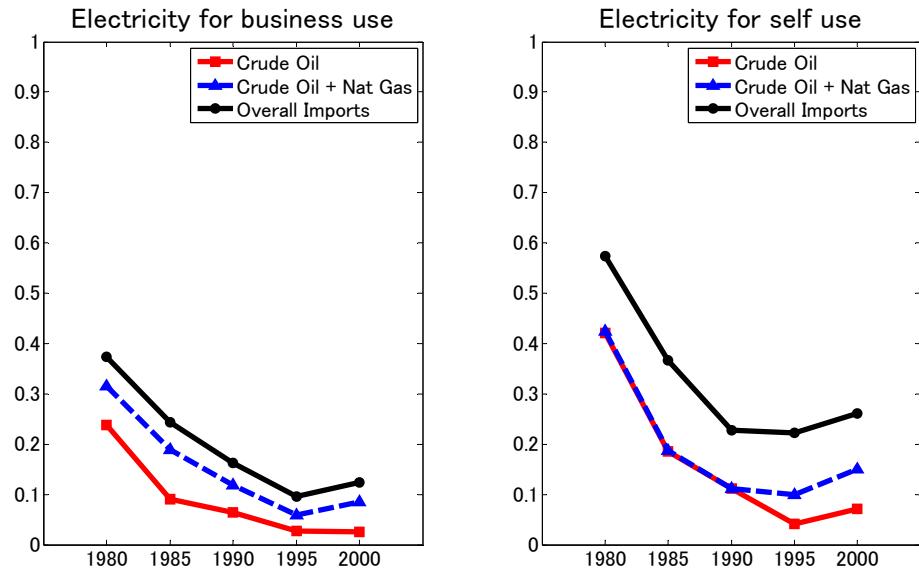
(B) Predictions from *REAL* I-O Tables (1995 constant prices)
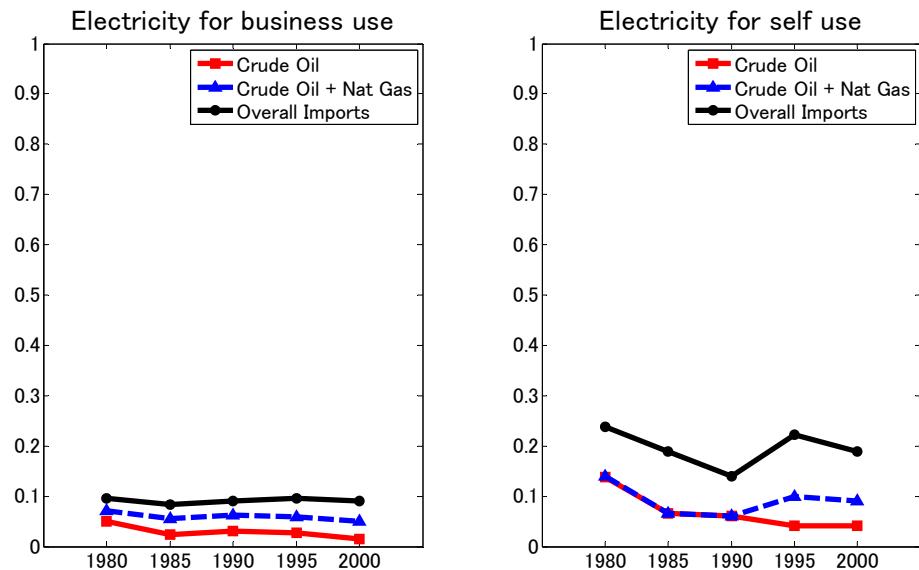
4-5 Overall consumer goods prices, 1980-2000

Through the I-O analysis in this section, we have found some important elements that could explain declining pass-through of oil prices. The most notable factor has been the relative price factor, or the relative price of oil itself. Input substitution showed up as a minor (but non-negligible) factor for electricity. Also, the analysis for gasoline has pointed out importance of the tax structure. Are they important in accounting for declines in pass-through rates in overall prices as well? To answer this question, we apply the same procedure we have employed so far to all the sectors in manufacturing simultaneously. Then we take weighted averages of their predicted responses, where the weights are based on the amount consumed by households. This is an effort to derive predictions about how manufactured consumer goods prices, or CGPI-C(M), would respond to oil prices. The results are in Figure 13. Panel (A) uses the nominal tables. Panel (B) uses the real tables. Panel (C) uses the nominal tables, under the hypothetical assumption that there are no per-unit taxes or tariffs on Petroleum Products (such as gasoline, diesel, and jet fuel).

Predictions from Panel (A) fit very well with the evolution of the estimated pass-through rates for CGPI-C(M), that appears in Figure 5(A). This leads us to suspect that changing cost structure could go a long way toward explaining observed declines in pass-through between 1980 and 2000. Comparison between Panels (A) and (B), on the other hand, seems to indicate that the real side story plays only a minor role in the structural change that lowered pass-through during this period: we observe only slight declines in the predicted responsiveness to imported oil, petroleum products (basically naphtha), and natural gas. This indicates that, once again, the main factor behind the change was the relative price factor: as oil became cheaper, it became less relevant in the cost structure.

Figure 13: Predicted responses of manufactured consumer goods prices to OIL etc.

(A) Predictions from *NOMINAL* I-O Tables

Consumer Goods (Manufacturing only)

(B) Predictions from *REAL* I-O Tables

Consumer Goods (Manufacturing only)
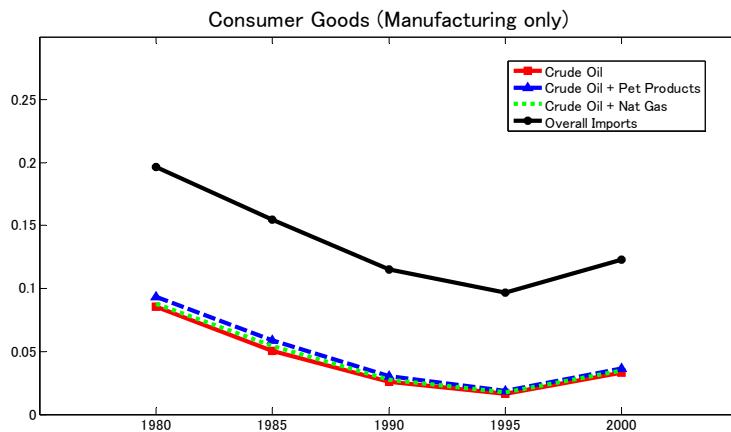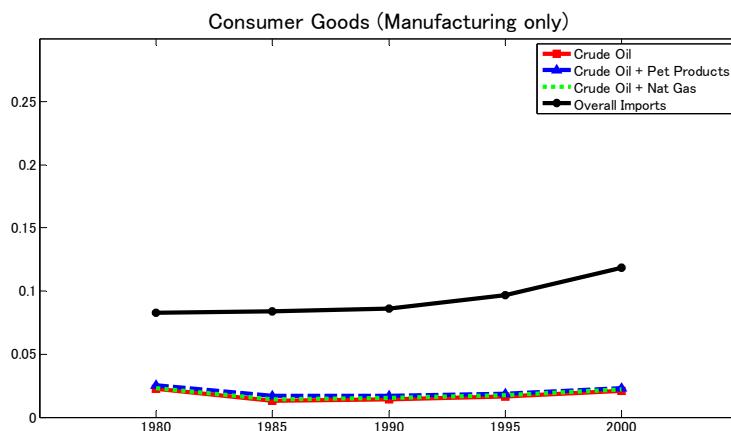
(C) Predictions from *NOMINAL* I-O Tables with no taxes or tariffs on petroleum products

Consumer Goods (Manufacturing only)
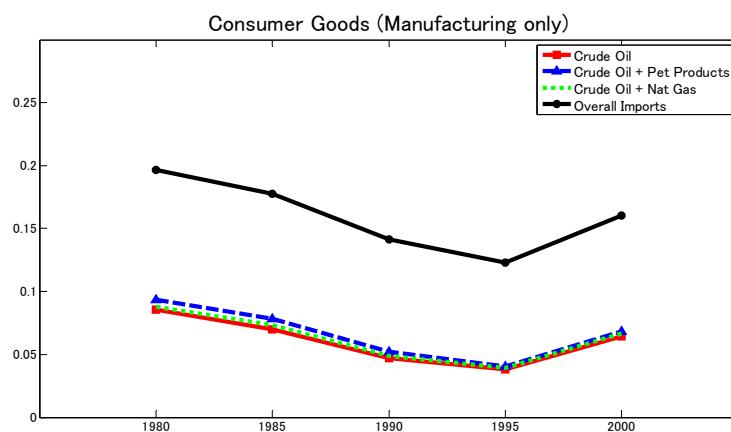
To give more formal and quantitative support to the above-mentioned impressions, in Table 1, we contrast our TVP-VAR estimates for the pass-through rates for CGPI-C(M), that appear in Figure 5(C), with predictions from both nominal and real I-O tables for manufactured consumer goods, that appear in Figure 13(A) and (B). All the numbers are percentage declines in pass-through rates, either estimated or predicted. The first column indicates that the estimated pass-through rate at the 12th month horizon declined, between January 1982 (its peak in Figure 5(C)) and 2002 (its bottom), by 69%. Likewise, the second column indicates that the estimates at the 24th month horizon declined by 78.6%. The third column indicates that the predicted pass-through rate from the nominal I-O table declined, between 1980 and 2000, by 61.3%. Hence, changes in cost structure, namely the relative price changes and relative quantity changes combined, can account for between 78% and 89% of the declines in the estimated pass-through rate, leaving only about 11% to 22% for the other factors to explain. The fourth column indicates that the predicted pass-through rate from the real I-O table declined by just 7.1%. Thus, the relative quantity factor played a minor role in this long term decline in the pass-through rate.

We should acknowledge that our results do not eliminate the possibility that there was some other important factor that contributed to the declining pass-through, whose effect was largely offset by yet another factor that happened to work in the opposite direction. But, to be able to support such a view, one would first have to specify what this force that was working in the other direction was, and this is, in our view, not an easy task.

It is also important to note that our results do not entirely deny the importance of the real factor or the relative quantity factor. We have already seen that it was quite important in the electricity sector. Figure 13(B) indicates that the relative quantity factor was also important in the period 1980-1985: during this short period, the predicted pass-through rate from the real I-O table declines by as much as 40.7%, and this accounts for all of decline in the prediction from the nominal I-O table. This suggests that, in reaction to the sudden increase in oil prices in the early 1980s, Japanese households and firms shifted away from oil-intensive products and inputs, temporarily. After oil prices declined in the late 1980s, however, there was some unwinding of this

effect. As a result, the relative quantity effect does not contribute much to the long run trend of declining pass-through.

Table 1: Comparisons between TVP-VAR estimates and predictions from I-O tables for consumer goods (manufacturing only): Percentage declines in estimated vs. predicted pass-through rates to oil prices

	TVP-VAR estimates, 12th month (1982-2002)	TVP-VAR estimates, 24th month (1982-2002)	Prediction from NOMINAL I-O tables (1980-2000)	Prediction from REAL I-O tables (1980-2000)
Percentage decline in pass-through rates	-69.0%	-78.6%	-61.3%	-7.1%

Finally, Panel (C) of Figure 13 is similar to Panel (A), but the decline in the predicted responsiveness to oil prices for the 1990s is milder. In fact, between 1980 and 2000, it declines by only 24.5%, compared to 61.3% in Table 1. This confirms the importance of the presence of taxes that are imposed per volume.

5 Predictions from the I-O Tables, 2000-2007

In this section, we shift our focus to the 2000s, especially toward the end of this period. At the time of this writing, detailed Input-Output Tables were available only up to the year 2006, which is not sufficient for our purpose. We have decided to employ basic Input-Output Tables provided on the Ministry of Economy, Trade, and Industry, with only 73 sectors, which were available for years 2000 and 2003-2007. In these tables, "crude oil" is no longer a separate sector but is combined with natural gas. Also, all the Petroleum Products sub-sectors are merged into one. We expand them by making suitable assumptions to decompose a single Petroleum Products sector into nine

sub-sectors[18]. As in the previous section, we compute predicted responsiveness of sectoral prices to prices of imported oil and natural gas.

Figure 14 presents the results. Panel (A) is for plastic and related products, (B) is for gasoline, (C) is for electricity and (D) is for the weighted average of manufactured consumer goods. All of those are based on the nominal I-O tables. Lastly, panel (E) is similar to panel (D) except that it is based on the real I-O table.

Note that, in all cases with the exception of gasoline[19], the nominal I-O tables predict increases in the responsiveness. This is natural, from what we have seen so far: as oil prices increase, the share of oil and related products in overall production cost returns to be large, and thus their prices are expected to become more sensitive to oil prices. We have seen that our TVP-VAR results indicate, in most cases, increases in the estimated pass-through rates of oil during this period: in that sense, they are consistent with the predictions from the I-O tables. However, the magnitudes are very different. Note that the nominal I-O tables predict swift and sharp increases in oil price sensitivities: for the average of manufactured consumer goods prices, predictions on oil price pass-through in Figure 14(D) increases by 58.1% between 2000 and 2007. On the other hand, according to numbers underlying Figure 5(C), the estimated pass-through rate at the 24th month horizon increased between 2002 (its bottom) and 2007 by only 15.7%, and, even for the period between 2002 and 2009, the rate of increase was 32.4%.

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[18] On the row side, for years 2004-2006, we have information from detailed I-O Tables with 511 row sectors, and we can directly utilize information provided by these tables to decompose a single row into nine separate ones. For year 2003, we assume that the shares of each sub-product of Petroleum Products used in different sectors, in *real* units, were the same as in year 2004. We then use deflators provided for 511 sectors in each year's I-O Table to convert them into nominal units. For year 2007 we utilize information from the 2006 detailed table to conduct a similar approximation. On the column side, we apply a procedure analogous to the one explained in the previous section.

[19] The predicted responsiveness of gasoline is large in 2000 because our estimated tax revenue from gasoline tax for this year was small. We suspect this is related to changes in tax treatment of diesel, which is a close substitute for gasoline, that happened around this time.

Figure 14: Predicted responses for the 2000s

(A) Plastic and related products, based on NOMINAL I-O Tables
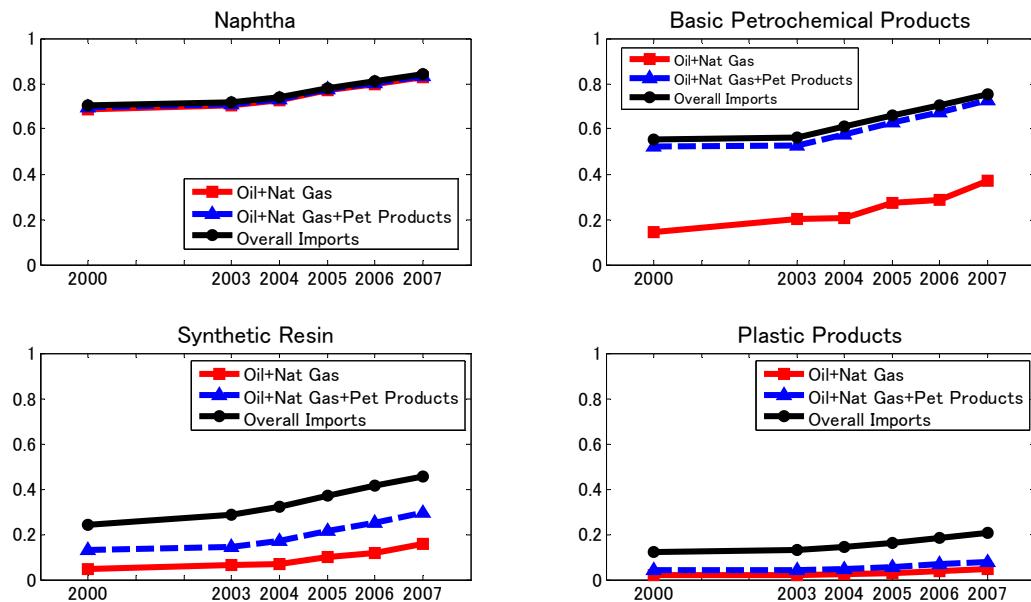
(B) Gasoline, under actual and hypothetical tax systems, based on NOMINAL I-O Tables
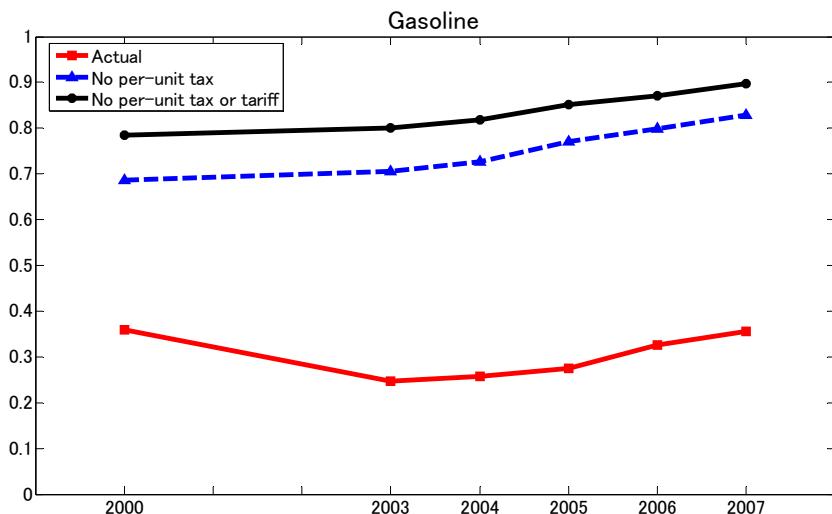
(C) Electricity, based on NOMINAL I-O Tables

Electricity
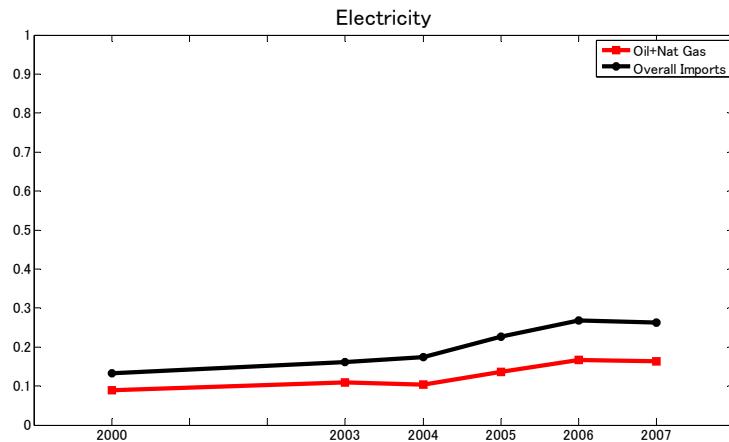
(D) Overall manufactured consumer goods prices, based on NOMINAL I-O Tables

Consumer goods, manufacturing only
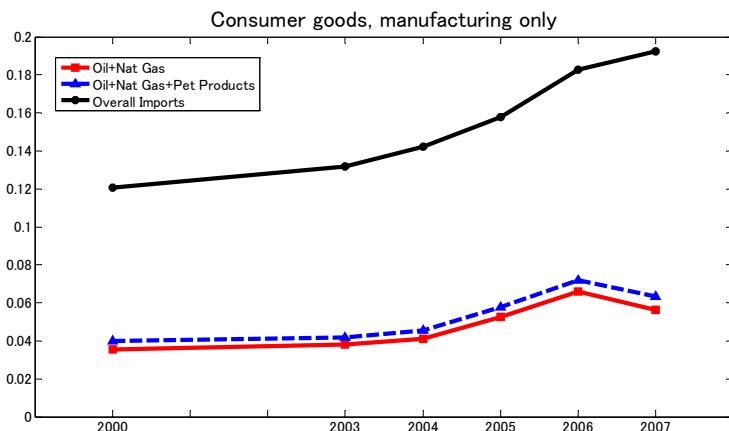
(E) Overall manufactured consumer goods prices, based on REAL I-O Tables

Consumer goods, manufacturing only
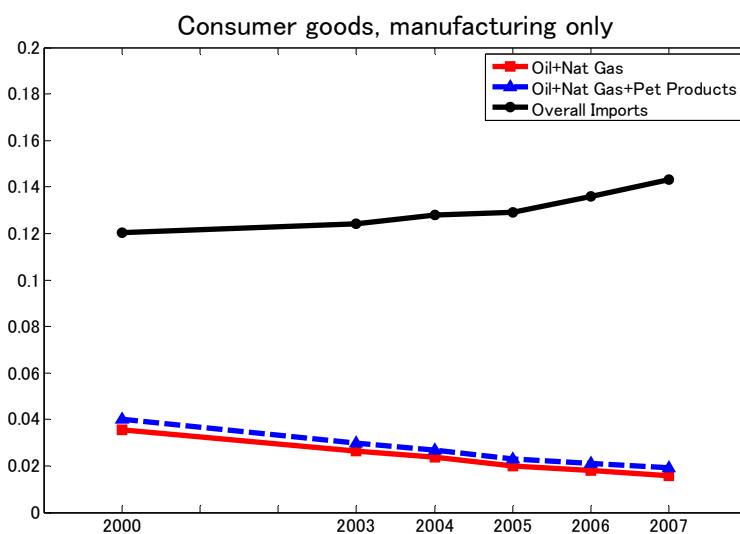
What accounts for the discrepancies between the TVP-VAR results and the predictions from the nominal I-O tables? We can think of several possible explanations. First, our TVP-VAR estimation uses the fixed weight Laspeyres price indices[20]: the data for the post 2005 period uses the year 2005 weights. Thus, the rapidly increasing nominal weights of oil-related products after 2005 are not reflected in those indices. Thus, our estimation could have underestimated the true extent of the increase in the pass-through rate which was caused by the oil price increase in this period. The second hypothesis is that, around 2000, there was a factor that pushed down the pass-through rate in Japan. One possible cause would be that the Bank of Japan's monetary policy stance suddenly gained enhanced credibility around this period. This is not totally impossible: amendment of the Bank of Japan Law in 1998 gave greater independence to Japan's central bank[21]. Another possible reason is that, due to deregulation, the labor market became more flexible[22]. The third hypothesis is that firms perceived the oil price increase during this period to be very temporary (which turned out to be the case, eventually), thus did not wish to respond to such a shock. Further analyses of this period would be needed to investigate plausibility of each of the hypotheses.

Finally, panel (E) indicates that the relative quantity factor contributed greatly to reduce predicted pass-through of oil prices. This is consistent with our previous finding that this factor was important for the short period of 1980-1985. In a short period of exceptionally high oil prices, households and firms adjust quite rapidly, to reduce dependence on oil-intensive products and inputs. This kind of flexibility has certainly helped alleviate the negative impact of rapidly rising oil prices of this period.

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[20] Chained price indices were not available for long enough time periods.

[21] It should also be remembered, though, that this period was a difficult time for the central bank policy. Due to the zero bound on the nominal interest rate, there was not much room to lower the interest rate. The still sluggish economy implied that rate hikes, even small ones, would have been vastly unpopular, politically.

[22] On the other hand, the rapid aging of the Japanese society increased the share of workers with high seniority at workplaces, which might have reduced flexibility of the labor market.

6 Conclusions

In this paper, we have investigated factors behind the declining pass-through rate of oil prices to Japanese domestic prices. We have found that, for the period 1980-2000, the main driving force behind the decline is the price level of oil itself. As oil became a less important cost item for firms, they naturally decided to respond less to its price changes. Consistently with this view, we find increasing pass-through rates in many of our TVP-VAR results for the 2000s, when oil prices were on the rise. However, at this point, those increases seem a little muted and delayed compared to the sharp increase in oil prices during this period. Investigating this matter further once more data becomes available for this period will be an important topic for future research.

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Appendix on TVP-VAR

In this Appendix, we explain our time varying parameter (TVP-) VAR methodology based on Kim and Nelson (1999). Consider the following VAR model with *K* variables and *L* lags, in which the coefficients are varying over time with a specific dynamic structure.

$$y_t = x_t \beta_t + e_t, \quad t = 1, 2, 3, ..., T, \tag{A1}$$

$$\beta_t = \beta_{t-1} + \upsilon_t, \tag{A2}$$

$$e_t \sim i.i.d. N(0, R), \tag{A3}$$

and $\quad \upsilon_t \sim i.i.d. N(0, Q), \tag{A4}$

where the vector x_t consists of lagged dependent variables. In this specification, we assume that the coefficient vector follows a random walk, but Kim and Nelson (1999) allow a more general VAR(1) specification. The dimensions of the vectors and matrices are as follows: $x_t : (K \times (K \times L + 1))$, $y_t : (K \times 1)$, $\beta_t : ((K \times L + 1) \times 1)$, $R : (K \times K)$, and $Q : ((K \times L + 1) \times (K \times L + 1))$.

We consider estimating this model by the Kalman Filter. Note that, in implementing this estimation, we need to specify the matrices Q and R, known as "hyper-parameters". We introduce the following notations.

$\beta_{t|s}$: expectation of β_t conditional on information available in period s,

$P_{t|s}$: variance-covariance matrix of β_t conditional on information available in s,

$y_{t|s} = E(y_t | \Psi_s) = x_t \beta_{t|s}$: forecast of y_t given information available in period s,

$\eta_{t|s} = y_t - y_{t|t-1}$: prediction error,

and $\quad f_{t|s} = E(\eta_{t|s}^2)$: conditional variance of the prediction error.

Given the information available up to period t-1, the prediction rules for period t are written as follows:

$$\beta_{t|t-1} = \beta_{t-1|t-1}, \quad P_{t|t-1} = P_{t-1|t-1} + Q, \text{ and } f_{t|t-1} = x_t P_{t|t-1} x_t' + R.$$

Define the prediction errors in period t as:

$$\eta_{t|t-1} = y_t - y_{t|t-1} = y_t - x_t \beta_{t|t-1}.$$

Then the updating rules are given by

$$\beta_{t|t} = \beta_{t|t-1} + K_t \eta_{t|t-1}, \tag{A5}$$

and $\quad P_{t|t} = P_{t|t-1} - K_t x_t P_{t|t-1} \tag{A6}$

where $\quad K_t = P_{t|t-1} x_t' f_{t|t-1}^{-1}$ (Kalman gain). $\tag{A7}$

In our estimation, the initial values $\beta_{0|0}$ and $P_{0|0}$, as well as the hyper-parameters Q and R are chosen in the following manner. We first estimate a reduced form VAR using the entire sample. The initial coefficient vector $\beta_{0|0}$ is set to be equal to the estimated coefficient vector from this estimation, and $P_{0|0}$ is set to be equal to h_0 times the estimated variance covariance matrix of the coefficients. Denote the variance covariance matrix of the estimated coefficients as $\hat{Q}$ and the residual variance covariance matrix as $\hat{R}$. Then we impose the following relationships:

$$Q = h_Q \cdot \hat{Q}, \tag{A8}$$

and $$R = h_R \cdot \hat{R}, \tag{A9}$$

where both h_Q and h_R are positive constants. This restriction greatly reduces the number of parameters to be chosen by the researcher.

We set $h_0 = 10$ in all the estimations reported in the text[23]. For h_Q and h_R, we try several different values and choose a combination that minimized the likelihood:

$$l(\theta) = -\tfrac{1}{2} \sum_{t=1}^{T} \ln((2\pi)^n \, | f_{t|t-1} |) - \tfrac{1}{2} \sum_{t=1}^{T} \eta'_{t|t-1} f_{t|t-1}^{-1} \eta_{t|t-1}. \tag{A10}$$

In practice, we tried four different values, 0.01, 0.025, 0.05, and 0.1, for h_Q, and three different values, 0.9, 1, and 1.1 for h_R (for the latter, the value of 1 was usually preferred by the likelihood criterion).

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[23] It is customary to choose a relatively large number for this parameter, so that the results are not very sensitive to the initial values. We avoid reporting results for the first five years of the sample, namely 1975-1979, in an effort to further minimize the effects of those initial values.