*MONETARY AND ECONOMIC STUDIES/JANUARY 2002*

# Identifying Aggregate Demand and Aggregate Supply Components of Inflation Rate: A Structural Vector Autoregression Analysis for Japan

**Hitoshi Mio**

*I estimate a bivariate output-price structural vector autoregression (VAR) model for Japan to decompose inflation rate time-series into two components explained by aggregate demand (AD) and aggregate supply (AS) shocks. For the model's identifying restriction, I assume that the long-run elasticity of output with respect to permanent changes in price due to AD shocks is zero; i.e., an AD shock has no long-run impact on the level of output. Dynamic properties of the estimated model are shown to be generally consistent with the predictions of the conventional AS-AD framework. The main features of the historical decomposition are the following: (1) the inflation rate explained by the AD shock shows a procyclical swing since 1970; (2) the inflation rate explained by the AS shock temporarily spikes during the two oil crises and experiences a large countercyclical swing in the 1990s; and (3) the coincidence of large and negative AS and AD shocks explains the combination of price stability and output stagnation during two recessions in the 1990s. These results are qualitatively robust to the sectoral shocks, alternative choices for the price variable, and assumptions for the lag length of VAR and the long-run elasticity of output with respect to permanent changes in price due to AD shocks. However, the bivariate approach does not allow the identification of more than three types of shocks with different dynamic effects on output and price. It might be necessary to expand the model to deal with this limitation.*

Key words: Aggregate demand and aggregate supply shocks; Decomposition of inflation rate; Identification of structural VAR

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I would like to thank Kousuke Aoki, Rishi Goyal, Yukinobu Kitamura, Ryuzo Miyao, and Kotaro Tsuru for their valuable comments and suggestions. Opinions expressed herein are my own and do not necessarily reflect those of the Bank of Japan.

# I. Introduction

In the conventional aggregate supply-aggregate demand (AS-AD) framework, the monetary policy response to price fluctuations has different consequences for output depending on the sources of the price fluctuation. For example, a monetary contraction contributes to stabilizing output when a positive AD shock raises the inflation rate, while it amplifies the decline in output when a negative AS shock raises the inflation rate. Hence, identifying the sources of price fluctuation is important for effective monetary policy.[1]

In this framework, output *increases* when the price level rises due to a positive AD shock, while it *decreases* when the price level rises due to a negative AS shock. This suggests that output fluctuations contain information for identifying the sources of price fluctuations. Focusing on this point, I estimate a bivariate output-price structural vector autoregression (VAR) for Japan to decompose the inflation rate time-series into two components explained by aggregate demand (AD) and aggregate supply (AS) shocks. For the model's identifying restriction, I assume that the long-run elasticity of output with respect to permanent changes in price due to AD shocks is zero; i.e., an AD shock has no long-run impact on the level of output.

The existing literature on the empirical application of structural VARs has mainly focused on output fluctuations and examined the relative importance of different types of shocks, especially of monetary policy shocks, at the business cycle frequency and long-run neutrality of monetary shocks.[2] Recently, Quah and Vahey (1995) proposed applying this method to the decomposition of the inflation time-series. Assuming that one of two types of shocks has no long-run impact on the level of output, they estimated a bivariate output-price model to identify "core inflation," which is explained by the shocks that have no long-run impact on the level of output.[3]

Their approach has stimulated research, including this paper, on the decomposition of inflation time-series.[4] However, two aspects of the historical decomposition have not been investigated so far: (1) compatibility with major historical episodes such as business cycles or oil crises; and (2) robustness to the sectoral shocks, alternative choices for the price variable, and assumptions for the lag length of VAR and the long-run elasticity of output with respect to permanent changes in price due to AD shocks. Since these are important for the evaluation of the empirical validity of the historical decomposition, I investigate these aspects carefully.

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[1] See Okina (1997) for a survey that discusses monetary policy responses to aggregate supply shocks in the context of policy rules and inflation targeting. This paper does not address the issue of desirable policy responses to the shocks.

[2] See, for example, Hutchison (1994), Iwabuchi (1990), Kama (1990), Kitasaka (1993), Miyao (2000), Nishimura and Teruyama (1990) and West (1993) for studies focusing on Japan; see Bergman (1996), Bernanke, Gertler, and Watson (1997), Bernanke and Mihov (1998), Blanchard and Quah (1989), Blanchard and Watson (1986), Bullard and Keating (1995), Christiano, Eichenbaum, and Evans (1999), Galí (1992), King and Watson (1997), Leeper, Sims, and Zha (1996), Shapiro and Watson (1988), and Weber (1994) for studies focusing on other countries including the United States and G-7 countries.

[3] They focused on the United Kingdom and used the monthly industrial output for the output variable and the monthly retail price index (RPI) for the price variable. Their estimation period is from 1969/III to 1994/III. While I call the long-run output-neutral shock an "AD shock," they call it a "core disturbance."

[4] See Álvarez and Matea (1999) for the case of Spain, Gartner and Wehinger (1998) for the cases of Euroland economies, Monetary Authority of Singapore (1998) for the case of Singapore, and Oh (2000) for the case of South Korea.

The remainder of this paper is organized as follows. Section II discusses the econometric issues. Section III carries out unit root and cointegration tests, investigates the dynamic properties of the models, and chooses the benchmark model to investigate the historical decomposition. Section IV examines the compatibility of the historical decomposition with some major historical episodes such as business cycles or oil crises. Section V investigates the robustness of the historical decomposition to the sectoral shocks, alternative choices for the price variable, and assumptions for the lag length of VAR, and the long-run elasticity of output with respect to permanent changes in price due to AD shock. Section VI concludes.

## II. Econometric Issues

In this section, I first present the model for decomposing the inflation time-series into AS and AD components and discuss two sets of assumptions. The first set is required to transform the structural vector moving average (VMA) into a structural VAR. The second set is required to econometrically identify parameters of the structural VAR. Then, I briefly contrast two estimation methods that are used in the literature.

### A. Decomposition and Invertibility

Consider a bivariate output-price structural VMA:

$$\Delta y_t = \sum_{i=0}^{\infty} \theta_{i,11} \varepsilon^S_{t-i} + \sum_{i=0}^{\infty} \theta_{i,12} \varepsilon^D_{t-i}, \tag{1}$$

$$\Delta p_t = \sum_{i=0}^{\infty} \theta_{i,21} \varepsilon^S_{t-i} + \sum_{i=0}^{\infty} \theta_{i,22} \varepsilon^D_{t-i}, \tag{2}$$

where $y_t$ and $p_t$ denote log of output and price, $\Delta y_t$ and $\Delta p_t$ denote their first-difference from the previous period,[5] and $\varepsilon^S_t$ and $\varepsilon^D_t$ denote AS shock and AD shock at time $t$, respectively. Both shocks are assumed to be mean-zero serially uncorrelated and uncorrelated with each other; i.e., the covariance matrix of these two shocks $E(\varepsilon_t \varepsilon_t') = \Omega$ is a $2 \times 2$ diagonal matrix where $\varepsilon_t = (\varepsilon^S_t, \varepsilon^D_t)'$. In this model, output and price fluctuation at time $t$ is assumed to be solely explained by the cumulative impact of AS and AD shocks from the infinite past up to time $t$. The first term on the right-hand side of equation (2) represents the inflation rate explained by AS shocks, and the second term of equation (2) represents the inflation rate explained by AD shocks. Each of $\theta_{i,jk}$ (for $j$, $k = 1, 2$) represents the dynamic response, i.e., the impulse response, of the $j$-th element of $X = (\Delta y, \Delta p)'$ to the $k$-th shock of $\varepsilon$ at time $t + i$. Rewriting equations (1) and (2) in matrix form yields equation (3):

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[5] As $y_t$ and $p_t$ are defined in log, their differences, $\Delta y_t$ and $\Delta p_t$, are approximately equal to the rate of change from the previous period.

$$X_t = \Theta(L)\varepsilon_t, \qquad (3)$$

where $L$ is the lag operator and $\Theta(L)$ is the matrix of lag polynomials; i.e., $\Theta(L) = \sum_{i=0}^{\infty}\Theta_i L^i$ with $\Theta_i = 2 \times 2$ matrix. Assuming that $\Theta(L)$ is invertible,[6] equation (3) can be inverted to yield the structural VAR equation (4):[7]

$$\alpha(L)X_t = \varepsilon_t, \qquad (4)$$

where $\alpha(L) = \sum_{i=0}^{p}\alpha_i L^i = \Theta(L)^{-1}$. Thus, under the assumptions stated above, one can decompose the observed inflation rate into its AS and AD components when the parameters in the structural VAR are identified.

### B. Identification and Restriction

Next, I discuss identification. Since equation (4) is a set of dynamic simultaneous equations, standard simultaneous methods can be used to estimate parameters if the model is identified. Rewriting equation (4) in reduced form yields equation (5):

$$\beta(L)X_t = e_t, \qquad (5)$$

where $\beta(L) = \sum_{i=0}^{p}\beta_i L^i$ and

$$\beta_i = \begin{cases} I & \text{for } i = 0 \\ \alpha_0^{-1}\alpha_i & \text{for } i > 1 \end{cases}, \qquad (6)$$

$$e_t = \alpha_0^{-1}\varepsilon_t, \qquad (7)$$

$$\alpha_0^{-1}\Omega(\alpha_0^{-1})' = \sum\nolimits_e = E(e_t e_t'). \qquad (8)$$

Each of $\beta_i$ $(i = 1, \ldots, p)$ in equation (5) has four independent elements, and the covariance matrix $\sum_e$ has three independent elements. Since AS and AD shocks are assumed to be mean-zero serially uncorrelated and uncorrelated with each other, these $4p + 3$ parameters completely characterize the probability distribution of the data. On the other hand, $\alpha_i$ $(i = 0, \ldots, p)$ in equation (4) has a total of $4p + 4$ independent elements and $\Omega$ has two independent elements, since $\Omega$ is assumed to be diagonal. Thus, three restrictions are required for identification of equation (4). Assuming that $\alpha_0$ has ones on the diagonal elements gives another two restrictions,[8] leaving only one additional necessary restriction.

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[6] This requires $|\Theta(z)|$ has all of its roots outside the unit circle. This implies that $y_t$ and $p_t$ have a unit root but do not cointegrate with each other (since $\Theta(1)$ has full rank). In Section III, I test this assumption and the assumption that AS and AD shocks are serially uncorrelated.

[7] Here, I also assume that the lag length of VAR is $p$.

[8] Blanchard and Quah (1989) and Leeper, Sims, and Zha (1996), for example, assumed that $\Omega$ has ones on the diagonal elements ($\Omega = I$). However, their assumption and the assumption used in this paper yield the same historical decomposition, since estimated coefficients offset these differences.

One of two types of linear restrictions on the coefficients of equation (4) can accommodate the final *a priori* restriction. The first type is a "short-run restriction." This specifies a contemporaneous relationship between endogenous variables and shocks. For example, letting $\alpha_{0,jk}$ be the $j$, $k$-th element of $\alpha_0$ and assuming $\alpha_{0,12} = 0$ implies that AD shocks have no impact on output within the period. The second type is a "long-run restriction." This specifies a long-run relationship between endogenous variables and shocks. For example, letting $\alpha_{jk}(L)$ be the $j$, $k$-th element of $\alpha(L)$ and assuming $\gamma_{yD} = -\alpha_{12}(1)/\alpha_{11}(1) = 0$ implies that the long-run elasticity of output with respect to permanent changes in price due to AD shocks is zero.[9] In other words, this implies that AD shocks have no long-run impact on output.[10]

By using one of these *a priori* linear restrictions, parameters in equation (4) can be identified. Since the choice of the identifying restriction can have a major impact on the estimation result, it is now widely recognized that the rationale of the restrictions should be derived from economic theory. Given that most macroeconomists accept the idea that AD shocks have no long-run impact on the level of output, the zero-restriction on $\gamma_{yD}$ is widely adopted. In this paper, I also use the zero-restriction on $\gamma_{yD}$ for the identification of the model.

### C. Estimation Method

Various simultaneous methods are available for the consistent estimation of the structural VAR parameters.[11] Blanchard and Quah (1989), whose seminal paper applied long-run restriction for the identification of the structural VAR, used indirect least squares (ILS).[12] Their method was to estimate equation (5) through equation-by-equation ordinary least squares (OLS) and solve equation (8) for each element in $\alpha_0$ using estimated $\sum_e$ and identifying restrictions. Then they identified equation (4) using $\alpha_0$, equations (6) and (7). While estimating equation (5) is easy, solving equation (8) is somewhat complex: since the latter is a set of quadratic equations, the sign for each element in $\alpha_0$ cannot be determined uniquely. This forces one to choose one set of $\alpha_0$ (and impulse responses) among alternative $\alpha_0$'s (and impulse responses) on a discretionary basis.[13]

On the contrary, Shapiro and Watson (1988) and King and Watson (1997) proposed the use of instrumental variables (IV). While the IV method requires some messy re-parameterization prior to estimation, it has the advantage of being able to uniquely identify the structural VAR. Thus, I choose the IV method for the estimation of the model.[14]

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[9] In the structural VMA, $\gamma_{yD}$ is defined as $\Theta_{12}(1)/\Theta_{22}(1)$, where $\Theta_{jk}(L)$ is the $j$, $k$-th element of $\Theta(L)$. Given $\alpha(L) = \Theta(L)^{-1}$, $-\alpha_{12}(1)/\alpha_{11}(1)$ is equal to $\Theta_{12}(1)/\Theta_{22}(1)$.

[10] This restriction can also be interpreted as a time series equivalent to a vertical AS curve. In this paper, I sometimes simply call this assumption the "long-run neutrality of AD shocks."

[11] See Watson (1994) for a survey.

[12] Their model is a bivariate output-unemployment structural VAR.

[13] In addition, for an $n$-variable model, equation (8) is an $n^2$ dimensional quadratic equation system. This implies that when the system is larger, solving equation (8) becomes more difficult. See Enders (1995) for a step-by-step explanation of Blanchard and Quah's identification scheme.

[14] See the appendix for re-parameterization.

## III. Estimation Results

In this section, I first test the unit root for each output and price variable and cointegration for 15 output-price combinations. Then, I estimate bivariate output-price structural VARs using 15 output-price combinations and compare the dynamic properties with the predictions of the AS-AD framework. Finally, the dynamic properties of the selected benchmark model are investigated in detail.

### A. Unit Root and Cointegration Tests

Identification of the model shown in the previous section assumes that output and price have unit roots, i.e., they are first-difference stationary, and do not cointegrate with each other. I check these assumptions using the augmented Dickey-Fuller (ADF) test, the Phillips-Perron (P-P) test, and the Engle-Granger residual-based test.

Three output and five price variables are used for the test. The three output variable are gross domestic product (GDP), domestic demand (DD), and private demand (PD). The five price variables are GDP deflator (PGDP), domestic demand deflator (PDD), private demand deflator (PPD), consumer price index (CPI), and domestic wholesale price index (DWPI).[15]

ADF and P-P test statistics are summarized in Table 1. For most of the cases, the null hypothesis of the unit root in the first difference of the variable is rejected at the 5 percent level. This implies the assumption that each variable has a unit root is plausible.[16]

**Table 1 Unit Root Tests**

| | No constant | | With constant | | Sample period |
|---|---|---|---|---|---|
| | ADF | P-P | ADF | P-P | |
| ΔGDP | –2.996*** | –6.320*** | –9.166*** | –10.927*** | 1970/I–1999/I (117) |
| ΔDD | –3.408*** | –6.447*** | –4.521*** | –8.558*** | |
| ΔPD | –3.470*** | –6.218*** | –4.931*** | –7.935*** | |
| ΔPGDP | –1.962** | –2.433** | –2.441 | –3.110** | |
| ΔPDD | –2.096** | –2.437** | –2.556 | –3.003** | |
| ΔPPD | –2.138** | –2.521** | –2.675* | –3.214** | |
| ΔCPI | –2.081** | –2.740*** | –2.614* | –3.808*** | 1971/IV–1999/IV (111) |
| ΔDWPI | –3.535*** | –4.041*** | –3.755*** | –4.815*** | |

Note: Lag length for ADF test is set at four. Truncation lag length for the P-P test is also set at four. Rejection of the null hypothesis of a unit root in the first-difference of each variable at the 1 percent, 5 percent, and 10 percent level is indicated by ***, **, and *, respectively.

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[15] All variables are in log transformed and are seasonally adjusted except for DWPI (since no seasonality is observed for DWPI). Quarterly DWPI and CPI are the simple three-month averages of monthly indices. Data sources are as follows:
GDP, DD, PD, PGDP, PDD and PPD: Annual Report on National Accounts (Cabinet Office, 68SNA, 1990 CY basis);
DWPI: Price Indexes Monthly (Bank of Japan, 1995 CY basis);
CPI: Consumer Price Index Monthly (Ministry of Public Management, Home Affairs, Posts and Telecommunications, 1995 CY basis).

[16] Kitasaka (1993), Nishimura and Teruyama (1990), and West (1993) also reported that the level of output and price have a unit root. On the other hand, Quah and Vahey (1995), Shapiro and Watson (1988), Galí (1992) and Bullard and Keating (1995) reported that the inflation rate has a unit root. To avoid misspecification in time-series analysis, it is important to know the true order of integration for the variables used. However, depending on differences in sample size, countries studied, and methods, test results might derive different implications.

Next, Table 2 summarizes the results of cointegration tests for 15 output-price combinations. The null hypothesis for no cointegration cannot be rejected for any of the 15 combinations.

Results for the two tests are consistent with the assumptions for transforming the structural VAR into a structural VMA for these output-price combinations.

**Table 2 Cointegration Tests**

| | | Output | | | 1/5 percent critical value | Sample period |
|---|---|---|---|---|---|---|
| | | GDP | DD | PD | | |
| Price | PGDP | –0.994 | –0.930 | –1.150 | –3.992/–3.389 | 1970/I–1999/I (117) |
| | PDD | –1.084 | –0.986 | –1.198 | | |
| | PPD | –1.183 | –1.077 | –1.271 | | |
| | CPI | –1.448 | –1.307 | –1.464 | –3.997/–3.392 | 1971/II–1999/I (112) |
| | DWPI | –0.479 | –0.391 | –0.537 | | |

Note: Output is regressed to the constant and price, and its residual is subjected to the Engle-Granger residual-based test.

### B. Selection of the Benchmark Model

Table 3 indicates predicted short-run and long-run dynamic responses of output and price due to AS and AD shocks based on the AS-AD framework. I next examine the compatibility of the identified dynamic responses of output and price with the prediction shown in Table 3 to choose a benchmark combination.[17]

**Table 3 Predicted Dynamic Responses from the AS-AD Framework**

| | | Short-run | Long-run |
|---|---|---|---|
| Output response to positive | AS shock | Positive | Positive |
| | AD shock | Positive | Neutral |
| Price response to positive | AS shock | Negative | Negative |
| | AD shock | Positive | Positive |

The left-hand side of Table 4 shows that every combination of identified dynamic responses is compatible with a set of short-run predictions up to four quarters. However, none of them satisfies the prediction after 12 quarters. Every identified long-run dynamic response of price due to the AS shock for 15 combinations becomes positive, although it is predicted to be negative. This leads the long-run elasticity of price with respect to permanent changes in output due to the AS shock $\gamma_{pS}$, shown on the right-hand side of Table 4, to be positive for all combinations.[18]

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[17] The estimation period is from 1970/I to 1999/I. Due to the limitation in the data availability, estimation period for models containing CPI and DWPI is from 1971/II. The lag length of VAR is set at four. Robustness of the results against the alternative choices for the lag length is examined in Section V. Constants are added to the estimation of equation (4). Also, two dummy series which have one at 1989/II and 1997/II, respectively, and zeros for the all other points in time are added to the estimation of the upper block of equation (4). When the model is estimated without these dummy series, major negative AS shocks are identified for 1989/II and 1997/II. However, this must simply reflect the price hike due to the introduction of consumption tax (1989/II) and revision in the consumption tax rate (1997/II). Hence, there is a need to control these impacts through some means, such as the inclusion of dummy variables.

[18] Analogous to the case for $\gamma_{yD}$, $\gamma_{pS}$ is defined as $-\alpha_{21}(1)/\alpha_{22}(1)$.

**Table 4 Identified Dynamic Responses and the Predictions**

| | Identified dynamic responses and the predictions | | | Parameter estimates for $\gamma_{pS}$ | | |
|---|---|---|---|---|---|---|
| | GDP | DD | PD | GDP | DD | PD |
| PGDP | *-- | *-- | *-- | 1.424 | 1.045 | 0.655 |
| PDD | *-- | *-- | *-- | 1.266 | 0.970 | 0.493 |
| PPD | *-- | *-- | **- | 1.046 | 0.700 | 0.290 |
| CPI | *-- | *-- | **- | 1.918 | 1.319 | 0.855 |
| DWPI | *-- | *-- | *-- | 1.358 | 1.021 | 0.441 |

Notes: *-- indicates that all of the four identified dynamic responses are compatible with the predictions in Table 3 after four quarters, but at least one response is not after eight quarters.
**- indicates that all of the four identified dynamic responses are compatible with the predictions in Table 3 after eight quarters, but at least one response is not after 12 quarters.

The right-hand side of Table 4 also shows that for all price variables, the smallest $\gamma_{pS}$ is obtained when private demand (PD) is used for the output variable. Similarly, for all output variables, the smallest $\gamma_{pS}$ is obtained when the private demand deflator (PPD) is used for the price variable. While none of the combinations satisfies the prediction in Table 3, the PD-PPD combination shows the most compatible dynamic responses with the prediction of the AS-AD framework among the 15 combinations, in terms of getting the smallest $\gamma_{pS}$.

This evidence suggests that identified shocks for other combinations are likely to commingle different types of shocks which have varying dynamic properties on output and price. In particular, this result implies that the government expenditure, net-export, and their deflators, which are excluded from PD and PPD, contain somewhat *noisy* information for the decomposition.

To sum up, the PD-PPD combination yields relatively the most compatible result with the prediction of the AS-AD framework among 15 output-price combinations. I consider this combination as a benchmark in the following analysis.

## C. Dynamic Properties of the Benchmark Model

Next, I examine identified dynamic properties and the serial correlation of shocks further for the benchmark model.

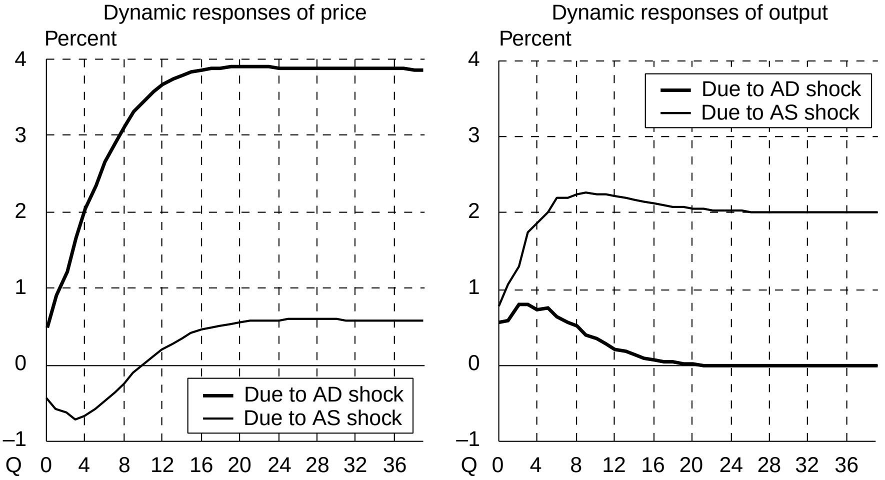
### 1. Dynamic responses

Figure 1 depicts identified dynamic responses of the price and output due to the AS and AD shocks. They are compatible with the prediction shown in Table 3, except for the dynamic response of price due to AS shocks. However, it turns from negative to positive after 10 quarters and remains slightly positive, while its long-run prediction is negative.

### 2. Variance decomposition

The results of the forecast error variance decomposition are summarized in Table 5. From the table, it can be inferred that AD shocks explain the dominant proportion of price fluctuations after 10 quarters, when the dynamic response of price due to the AS shock turns from negative to positive (for example, it is 97.1 percent after 12 quarters). This implies that even if the identified long-run dynamic response of price due to the AS shock and the prediction shown in the Table 3 are contradicted, it

**Figure 1 Identified Dynamic Responses**



Note: Each dynamic response indicates the cumulative percentage deviation of price and output in response to AS and AD shock normalized at one standard deviation.

**Table 5 Forecast Error Variance Decomposition**

| | Price | | Output | |
|---|---|---|---|---|
| | AD shock | AS shock | AD shock | AS shock |
| 0 quarter | 55.9 | 44.1 | 34.8 | 65.2 |
| 4 quarters | 83.6 | 16.4 | 19.9 | 80.1 |
| 8 quarters | 93.9 | 6.1 | 12.3 | 87.7 |
| 12 quarters | 97.1 | 2.9 | 8.3 | 91.7 |
| 36 quarters | 97.8 | 2.2 | 2.9 | 97.1 |

Note: Values in the table indicate the percentage contribution of each type of shock to the forecast error variance of the output and price fluctuation.

would not be a serious problem in interpreting the historical decomposition under the AS-AD framework.[19]

### 3. Serial correlation of the identified shocks

Finally, I test higher-order serial correlation of the identified AS and AD shocks by Ljung and Box's Q(12) statistics. The null hypotheses for no serial correlation in two shocks cannot be rejected at the 5 percent level. This implies that the assumption for no serial correlation in the identified shocks is plausible.

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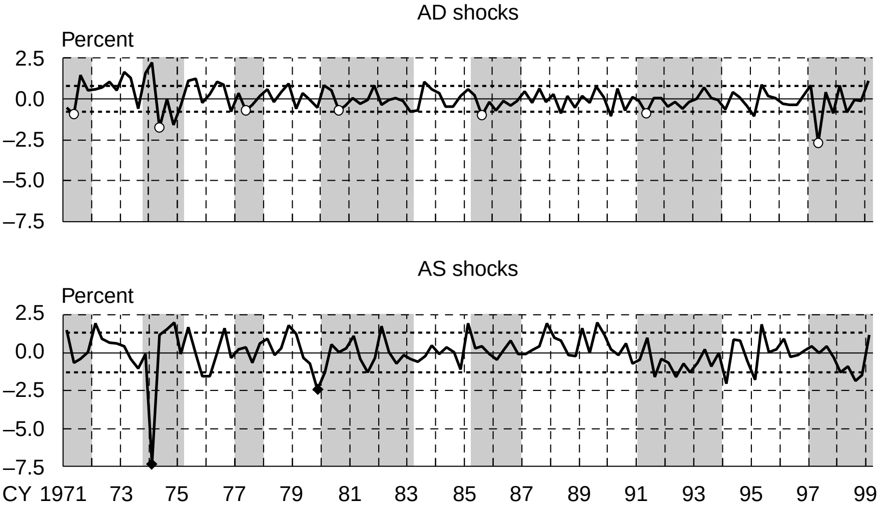
[19] The dynamic response of output due to an AD shock peaks at two quarters, remains stable until six quarters, and slowly diminishes until it disappears around 20 quarters. Variance decomposition of output shows that the contribution of AD shocks to output fluctuation is very small even at business cycle frequency. (For example, it is 19.9 percent after four quarters.) While this value is slightly larger than the value obtained by the previous studies for Japan, including Nishimura and Teruyama (1990) and Keating and Nye (1999), it is smaller than the value obtained by similar prior studies for the United States including Blanchard and Quah (1989), Galí (1992), and Shapiro and Watson (1988).

Figure 2 depicts the identified AS and AD shocks. Three features are notable: first, a negative AD shock of one standard deviation or greater is observed in the initial stage of all recessions. Second, a large and negative AS shock is observed during the two oil crises (1974/I and 1979/IV, respectively). Third, large and negative AS and AD shocks coincidentally take place during two recessions in the 1990s.

In summary, the results in this section support the plausibility of the assumptions made in the previous section. In addition, the dynamic properties of the identified structural VAR for the PD-PPD combination are generally compatible with the prediction of the AS-AD framework.

**Figure 2 Identified AS and AD Shocks**



Note: Each AS and AD shock is identified for the benchmark model. Shaded areas indicate recession based on the Cabinet Office's business cycle dates. Horizontal thick dotted lines indicate the one standard deviation band for AS and AD shocks.

## IV. Compatibility of the Historical Decomposition with Historical Episodes

The existing structural VAR applications that analyzed output fluctuation investigated the compatibility of their historical decomposition with major historical episodes such as business cycles or oil crises.[20] Their retrospective approach, I think, is informative for the evaluation of the empirical validity of the historical decomposition of the inflation rate as well.

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[20] See, for instance, Blanchard and Quah (1989), Blanchard and Watson (1986), Galí (1992), and Shapiro and Watson (1988).

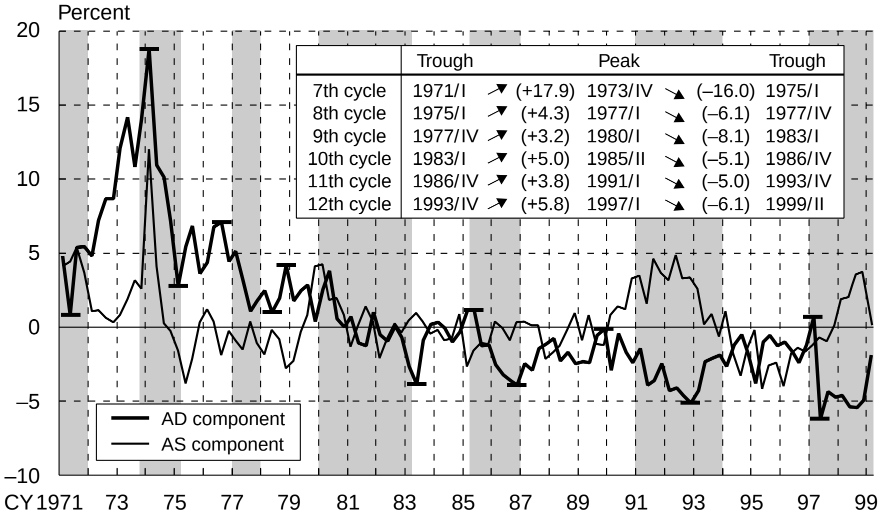
### A. Historical Decomposition and Business Cycles

Figure 3 depicts identified the inflation rate explained by AS shocks (hereafter, "AS component of inflation") and the rate of inflation explained by AD shocks (hereafter, "AD component of inflation").

The most striking feature of the historical decomposition is the procyclical swing of the AD component of inflation. During all six recessions since the 1970s, the AD components of inflation fall more than 5 percent. The magnitudes of the declines are particularly large in the recession following the two oil crises (the seventh and ninth cycle, respectively). Also, they rise during all six expansions since the 1970s. However, they do not rise more than 6 percent except for the seventh cycle (1972/I–1973/IV).

Moreover, after the first oil crisis, rises in the AD component of inflation during the expansions are consistently smaller, in absolute terms, than the falls in the AD component of inflation during the subsequent recessions. Since the AS component of inflation does not experience such a persistent decline throughout the estimation period, this implies that the disinflationary trend following the first oil crisis can be explained by the asymmetric falls in the AD component of inflation during the recessions compared to the rises during the expansions.[21]

**Figure 3 Historical Decomposition**



| | Trough | | Peak | | Trough |
|---|---|---|---|---|---|
| 7th cycle | 1971/I | ↗ (+17.9) | 1973/IV | ↘ (–16.0) | 1975/I |
| 8th cycle | 1975/I | ↗ (+4.3) | 1977/I | ↘ (–6.1) | 1977/IV |
| 9th cycle | 1977/IV | ↗ (+3.2) | 1980/I | ↘ (–8.1) | 1983/I |
| 10th cycle | 1983/I | ↗ (+5.0) | 1985/II | ↘ (–5.1) | 1986/IV |
| 11th cycle | 1986/IV | ↗ (+3.8) | 1991/I | ↘ (–5.0) | 1993/IV |
| 12th cycle | 1993/IV | ↗ (+5.8) | 1997/I | ↘ (–6.1) | 1999/II |

Note: Historical decomposition of the annualized quarterly inflation rate for the benchmark combination is shown. Shaded areas indicate recessions based on the Cabinet Office's business cycle dates. Horizontal bars on the elements of the AD component of inflation indicate peaks and troughs in each business cycle. Figures in parentheses indicate increases from the trough and decreases from the peak, respectively.

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[21] Although the AD shock is assumed to be mean-zero for the entire estimation period, it is not necessarily applied for the subperiod. In addition, as tested in the previous section, this result does not violate the assumption that shocks do not have serial correlation for the entire estimation period.

### B. Historical Decomposition and Major Historical Episodes

Next, I compare the historical decomposition to some of the major historical episodes after 1970.

#### 1. Two oil crises

The AS components of inflation rise sharply during the two oil crises (1974/I and 1979/IV, respectively). This is consistent with the interpretations of Bruno and Sachs (1985) and others who argued that the oil crises functioned as negative AS shocks.

The shape of the AD component of inflation during these two periods provides an interesting contrast. In the case of the first oil crisis, the AD component of inflation rises sharply before the crisis. On the contrary, in the case of the second oil crisis, the AD component of inflation is fairly stable before and after the crisis. In the second crisis, the rise of the AS component of inflation solely explains the rise of the observed inflation rate.

This finding is consistent with the conventional view that the first oil crisis was preceded by domestic inflation under the boom supported by the government's "Reconstruct the Japanese Archipelago" Plan, while Japan was able to avert domestic inflation in the second oil crisis.[22]

#### 2. "Bubble" period (11th expansion, 1986/IV–1991/I)

Turning next to the expansion of the so-called "bubble" period (the 11th expansion, 1986/IV–1991/I), the AD component of inflation hovers near zero percent even at the peak of the business cycle (1989/IV). Furthermore, the increase in the inflation rate from the previous trough is less than 4 percent, which is not significantly larger than that observed in other expansions. The AS component of inflation also hovers near zero percent until the end of 1989.

Okina, Shirakawa, and Shiratsuka (2001) argued that, as one possible assessment of the price development during this period, it is possible to conclude that inflationary concerns expressed by the Bank of Japan materialized with a time lag of about two to three years, since the CPI inflation rate exceeded 4 percent in the latter half of 1990.[23] Kousai, Ito, and Arioka (2000) argued that "an upward shift in the AS curve apparently increased output and contributed to the price stability despite approaching full employment." In other words, both AS and AD curves shifted to the right simultaneously, resulting in price stability and an increase in output. It should be noted that the historical decomposition here is not necessarily consistent with these past interpretations.[24]

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[22] See Ito (1992), for example, for this kind of conventional view.

[23] They also warned that this assessment boils down to the question of what can be regarded as a tolerable inflation rate, and there can be a variety of answers. They stated that the experience of the "bubble" period seems to suggest the importance of the assessment which emphasizes the sustainability of price stability over a fairly long period. Their understanding might suggest that some structural or temporal change in the shock propagation mechanism of price fluctuation occurred at this time. In this paper, I do not analyze further the source of the discrepancy between the past interpretations and the historical decomposition.

[24] As mentioned above, Okina, Shirakawa, and Shiratsuka (2001) have pointed out that inflationary concerns expressed by the Bank of Japan materialized with a time lag of about two to three years.

### 3. Post-"bubble" period (11th recession and 12th cycle, 1991/I–1999/II)

There are two interesting features in the post-"bubble" period: first, throughout the period, the AD component of inflation has remained negative with the exception of 1997/I. Particularly large drops are observed during the recessions of the 11th and 12th cycle (1991/I–1993/IV and 1997/I–1999/II, respectively).[25] Second, the AS component of inflation experienced a relatively large countercyclical swing. It rises during the recession of the 11th cycle, falls during the expansion of the 12th cycle (1993/IV–1997/I), then rises again in the subsequent recession.

This implies that, while aggregate demand remained sluggish throughout the period, coincident negative AS shocks stabilized the price fluctuation. This also implies that the output drop was amplified by the coincidence of negative AS and AD shocks.[26]

The Bank of Japan (2000) has documented the large decline in aggregate demand during the recession of the 12th cycle as "The economy . . . underwent an unprecedented deterioration towards 1998 as both private consumption and business fixed investment declined," and the simultaneous drop in aggregate supply as "Japan's potential growth has slowed in the mid-to-long-term perspective . . . as existing capital stock became obsolete amid economic globalization and progress in IT (information technology)" and "[An] increased mismatch between demand and supply in the labor market . . . seemed to have lowered the equilibrium rate of the output gap." This interpretation is generally consistent with the historical decomposition in this paper.

To summarize, the following features are striking for the historical decomposition. (1) The AD component of inflation shows a procyclical swing. It rises during every expansion, while it falls during every recession since 1970. (2) Rises in the AD component of inflation during the expansions are consistently smaller than the falls in the AD component of inflation during the subsequent recessions. This explains the deflationary trend since the first oil crisis. (3) The AS component of inflation spikes temporarily during the two oil crises, while the AD component of inflation rises for the first crisis and falls for the second crisis. (4) The rise in the AD component of inflation during the "bubble" period is not significantly larger than that observed during the other expansions since 1970. (5) The coincidence of large and negative AS and AD shocks explains the combination of price stability and output stagnation during two recessions in the 1990s. (3) and (5) are compatible with the conventional view of that episode, while (4) is not. In addition, (5) suggests the need for further analysis of the supply side of the economy to understand the output and price development in the 1990s.

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[25] The peak and the trough dates of the 12th cycle are preliminary. Note that the end of the estimation period is 1999/I.

[26] See Figure 2 for identified shocks. Note that two shocks are assumed to be uncorrelated with each other. Blanchard and Watson (1986) and Galí (1992) argued that recessions are likely to be generated by concentration of a variety of negative shocks. Their argument and the historical decomposition here seem to be consistent.

## V. Robustness of the Historical Decomposition

In this section, I examine the robustness of the historical decompositions to the effects from sectoral shocks, alternative choices for price variables and assumptions for the lag lengths of VAR, and the long-run elasticity of output with respect to permanent changes in price due to AD shock.

### A. Effects from Sectoral Shocks

Bivariate decomposition has a limitation in disentangling more than three types of shocks with different dynamic effects on output and price. In addition, sources of these shocks are typically assumed to be aggregate factors.[27] However, besides AS and AD shocks, it is well known that short-run fluctuation in the observed inflation rate is also affected by sectoral shocks. For example, the sudden reduction in the *supply* of agricultural product by poor weather raises its relative price and the aggregate CPI sharply.[28] Therefore, it is necessary to examine whether these sectoral shocks commingle in identified AS or AD shocks and whether the contamination causes serious difficulty for the interpretation of the historical decomposition.

For the measure of the inflation rate explained by sectoral shocks, I use the asymmetry of the price change distribution defined by the difference between the changes in the headline CPI and 30 percent trimmed-mean CPI.[29] As shown in Figure 4, when some sectors face large shocks, prices of products for those sectors are likely to experience large *relative* price changes. Consequently, the price change distribution tends to skew and a divergence is likely to emerge between the changes in the headline CPI and the trimmed-mean CPI: the larger the skewness, the greater the divergence between the two. Focusing on this characteristic, this paper adopts the asymmetry of the price change distribution as a proxy for the inflation rate explained by the sectoral shocks.

Figure 5 depicts the inflation rate explained by the sectoral shocks and two identified components of inflation. It can be observed from the figure that the fluctuation in the asymmetry of the price change distribution resembles the fluctuation in the AD component of inflation.

The coefficients of correlation of the asymmetry of the price change distribution and two identified components of inflation are shown in Table 6. Asymmetry of the price change distribution has a stronger positive correlation with the AD component of inflation than with the AS component of inflation.

This evidence suggests that identified AD shocks are likely to commingle true AD shocks and sectoral shocks. This can take place if the output response to sectoral shocks is long-run neutral, given that the long-run neutrality of the AD

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[27] For example, the concept of aggregate demand in this paper is used in a broad sense that includes money demand, money supply, and IS shocks. See Blanchard and Quah (1989) and Faust and Leeper (1997) for discussion of the formal conditions for decomposing more than two AS and AD shocks into one AS and AD shock in a bivariate setup.

[28] In many countries, the "core CPI," which excludes certain volatile components from the CPI, is constructed to eliminate this effect.

[29] See Bryan and Cecchetti (1999), Mio (2001), Mio and Higo (1999), and Shiratsuka (1997) for details on the Japanese trimmed-mean CPI.

**Figure 4 The Asymmetry of the Price Change Distribution**

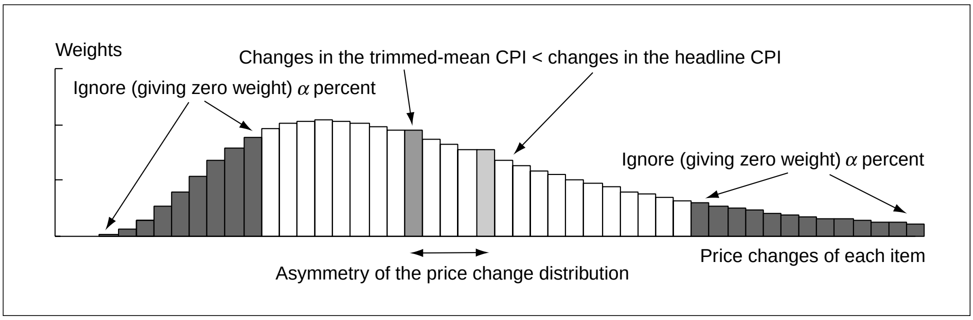
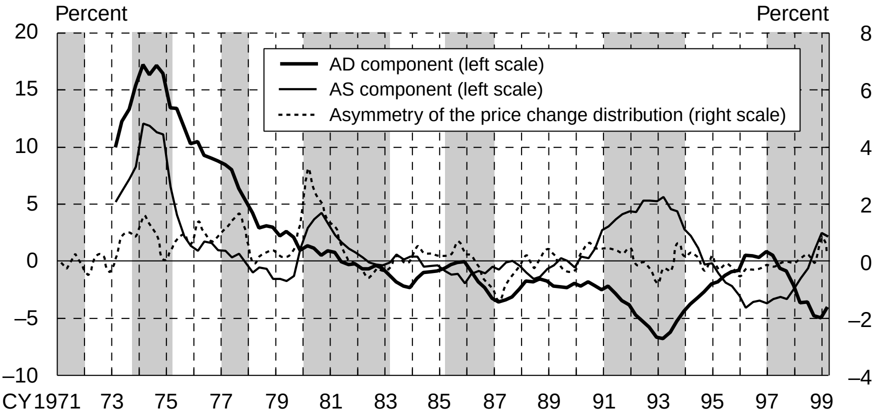


**Figure 5 Asymmetry of the Price Change Distribution and Historical Decomposition**



Note: Four-quarter moving average of the historical decomposition of the annualized quarterly inflation rate is shown. To match the definition to the asymmetry of the price change distribution, historical decomposition for PD-CPI combination is shown. Historical decompositions of PD-CPI and PD-PPD combinations are compared in Figure 6. Asymmetry of the price change distribution is calculated by subtracting the 30 percent trimmed-mean CPI (trimming 15 percent from each tail of the price change distribution) from the changes in the headline CPI. Shaded areas indicate recessions based on the Cabinet Office's business cycle dates.

**Table 6 Coefficients of Correlation**

| | Full sample | |
|---|---|---|
| | AD component | AS component |
| Asymmetry of the price change distribution | 0.765 | 0.392 |

| | Excluding oil crises | |
|---|---|---|
| | AD component | AS component |
| Asymmetry of the price change distribution | 0.584 | 0.175 |

Note: All coefficients of correlation are computed based on the series indicated in Figure 5. The second row of the table denotes the coefficients of correlation of the sample period from which 1973/I–1975/IV and 1979/I–1981/IV are excluded.

shock is an identifying restriction. If this is the case, it might cause some difficulty for the interpretation of the historical decomposition, since sectoral shocks are dominated by sectoral *supply* shocks and can be regarded as temporary AS shocks as argued in Balke and Wynne (2000), Ball and Mankiw (1995), Mio (2001), Mio and Higo (1999), and Shiratsuka (1997).[30]

Assuming that sectoral shocks represent the sectoral *supply* shocks, I go back to Figure 1 to see which of the two shocks, namely, the true AD shock and sectoral shock, dominates the identified dynamic response of price due to the AD shock. It strongly suggests that the true AD shock dominates the sectoral shock, since the identified dynamic responses of output and price to identified AD shock are positively correlated. This cannot be the case when the sectoral shock dominates the true AD shock, since dynamic responses of output and price to the identified AD shock should be negatively correlated in that case. Hence, this contamination would not do serious damage to the *qualitative* interpretation of the historical decomposition based on the AS-AD framework.

However, this contamination does affect the *quantitative* interpretation through two possibilities. The first possibility is that the *positive* identified AD shock is the linear combination of the *positive* true AD shock and the *negative* sectoral shock. In this case, the identified dynamic response of price (output) to the AD shock *overestimates* (underestimates) the dynamic response of price (output) to the true AD shock, since the *negative* sectoral shock *amplifies* (mitigates) the dynamic response of price (output) to the true AD shock. The second possibility is that the *positive* identified AD shock is the linear combination of the *positive* true AD shock and the *positive* sectoral shock. In this case, the identified dynamic response of price (output) to the AD shock *underestimates* (overestimates) the dynamic response of price (output) to the true AD shock, since the *positive* sectoral shock *mitigates* (amplifies) the dynamic response of price (output) to the true AD shock.

A combination of the assumption that the positive sectoral shock produces a negative price response with the evidence that asymmetry of the price change distribution and the AD component of inflation have a positive correlation suggests that the first possibility is likely. But the analysis here does not tell how this contamination is *quantitatively* important. Thus, there is a need to expand the model to disentangle the inflation rate explained by sectoral shock, especially when focusing on the quantitative aspect of the historical decomposition.[31]

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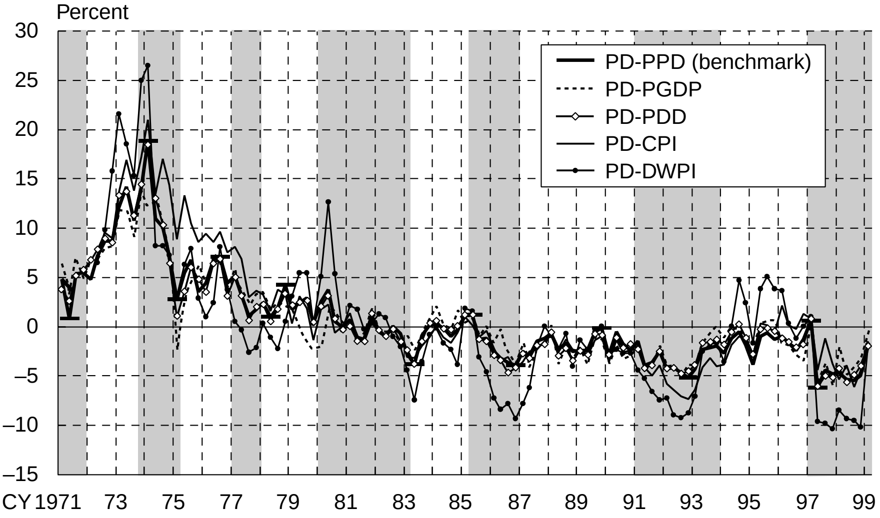
30. These studies analyzed the fluctuation of the inflation rate focusing on the information of the cross-sectional price change distribution. Among these, Mio (2001) estimated the Phillips curve using the asymmetry of the price change distribution as a proxy for controlling the temporary supply shock effect and obtained a fairly robust relationship. This result suggests that the asymmetry of the price change distribution is a good proxy for the effect of temporary supply shock to the price. See Blanchard and Fischer ([1989], chapter 10.3) for an analysis of dynamic output response to the temporary AS shock.

31. Quah and Vahey (1995), who originally proposed the structural VAR approach to measure core inflation, strongly opposed the approach developed by Bryan and Cecchetti (1994) and others, who aimed to measure core inflation focusing on cross-sectional data, due to the lack of an economic theoretical foundation. Thus, Quah and Vahey (1995) and their followers thus far viewed the two approaches as substitutes. However, the result here implies, as opposed to their view, that the two approaches should be integrated.

## B. Alternative Choices for the Price Variable

Historical decompositions for the AD component of inflation for different price variables are expected to be at least qualitatively similar if the identified shocks and dynamic responses are similar among different output-price combinations. Figure 6 presents five identified AD components of inflation using five price variables. While the AD component of inflation for DWPI experiences a larger swing than the other four variables, the timing and magnitude of peaks and troughs generally coincide with each other. This implies that similar AD shocks and dynamic responses are being identified regardless of the price variable used. The benchmark historical decomposition is robust to the alternative choices of the price variable.

**Figure 6 Historical Decompositions for Five Output-Price Combinations**



Note: Historical decomposition of the annualized quarterly inflation rate for five price variables is shown. PD is fixed as the output variable for all of the five combinations. Shaded areas indicate recessions based on the Cabinet Office's business cycle dates. Horizontal bars on the elements indicate peaks and troughs in each business cycle for the benchmark.

## C. Assumption for the Lag Length

When long-run restrictions are used for identification of the model, the lag length of VAR also plays a role of identifying restriction.[32] Hence, when one cannot pin down the lag length of VAR from prior information, the robustness of the historical decomposition for alternative assumptions for the lag length of the VAR should be checked.

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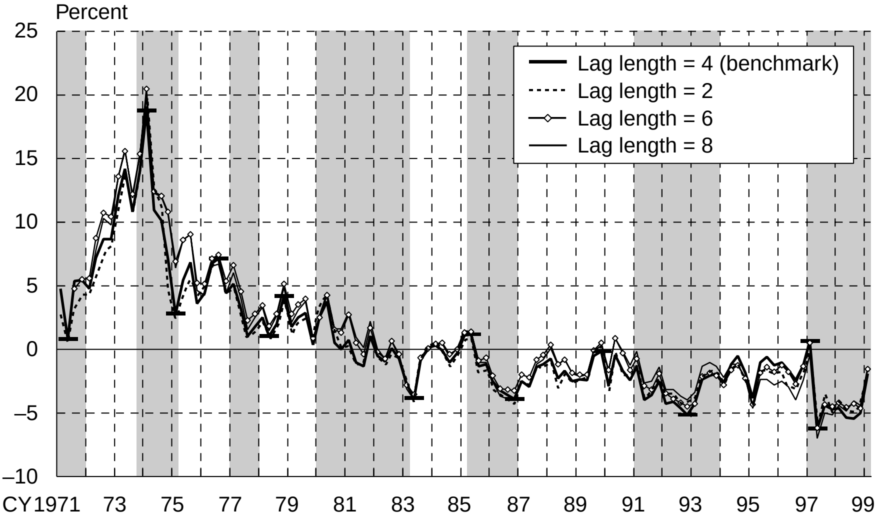
[32] See Faust and Leeper (1997) for details.

Figure 7 indicates four AD components of inflation identified for VARs that have two, four, six, and eight lags. As shown in the figure, there are no apparent differences among the historical decompositions. The historical decomposition is robust to the alternative assumption for the lag length of the VAR.

**Figure 7 Historical Decompositions for Various Lag Lengths of VAR**



Note: Historical decomposition of the annualized quarterly inflation rate identified for four alternative lag length of VARs (two, four, six, and eight lags) is shown. Shaded areas indicate recessions based on the Cabinet Office's business cycle dates. Horizontal bars on the elements indicate peaks and troughs in each business cycle for the benchmark.

## D. Assumption for the $\gamma_{yD}$

When the long-run elasticity of output with respect to permanent changes in price due to AD shock $\gamma_{yD}$ is used for the identifying restriction, it is common to assign a value of zero for it given the long-run neutrality of AD shocks. However, some empirical evidence indicates that the zero-restriction for $\gamma_{yD}$ might not be relevant.[33] Hence, it is valuable to examine the robustness of the historical decomposition to the alternative $\gamma_{yD}$. Here, I assume the alternative $\gamma_{yD}$ as 0.27. This is a parameter estimate for $\gamma_{yD}$ when a short-run restriction $\beta_{0,12} = -3.92$, which is estimated by West (1993), is imposed as the identifying restriction.[34]

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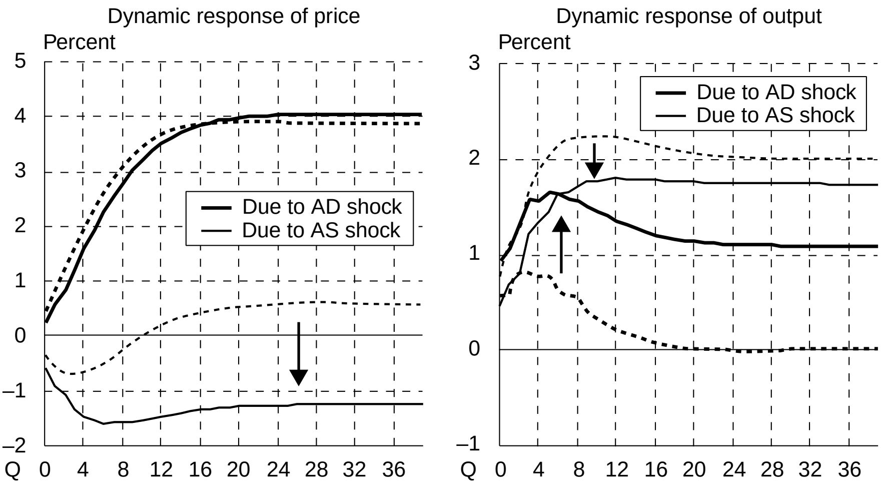
33. For example, Bullard and Keating (1995) estimate a structural VAR using zero restriction for the long-run elasticity of price with respect to permanent exogenous changes in output due to AS shock $\gamma_{pS}$ for identification. They reported the point estimate of $\gamma_{yD}$ for Japan as about 1.5 and its 90 percent confidence interval as about 0 to 3. In addition, Miyao (2000) estimated a four-variable structural VAR using short-run restrictions and also reported that the point estimate of the long-run elasticity of output with respect to permanent exogenous changes in money due to monetary shock as 0.6 to 0.8 and its standard deviation as 0.5.

34. $\beta_{0,12}$ can be regarded as the slope of the short-run AS curve. See King and Watson (1997). I use West's parameter estimate because its standard deviation is very small. Lowering $\beta_{0,12}$ to about –30, which is the parameter estimate of Iwabuchi (1990), however, does not significantly affect the result shown below.

This causes two major changes in identified dynamic properties of price. First, as shown in Figure 8, the long-run dynamic response of price due to an AS shock turns from positive to negative and becomes compatible with the prediction in Table 3. As a result, the long-run elasticity of price with respect to permanent changes in output due to an AS shock $\gamma_{pS}$ declines from 0.290 to –0.718.

Second, the contribution of the AS shock to the forecast error variance in the short run sharply increases. For example, as shown in Table 7, the four-quarter-ahead forecast error variance of price explained by an AS shock rises from 16.4 percent to 55.4 percent. However, it declines to 12.6 percent after 36 quarters, indicating that the AD shock dominates the price fluctuation in the long run for both assumptions in $\gamma_{yD}$.[35]

**Figure 8 Changes in the Identified Dynamic Responses**



Note: Each dynamic response indicates the cumulative percentage deviation of price and output in response to AS and AD shock normalized at one standard deviation. Dotted lines indicate results for $\gamma_{yD} = 0$, while unbroken lines indicate results for $\gamma_{yD} = 0.27$.

**Table 7 Changes in the Results of Forecast Error Variance Decomposition**

| | Price | | Output | |
|---|---|---|---|---|
| | AD shock | AS shock | AD shock | AS shock |
| 0 quarter | 14.2 (55.9) | 85.8 (44.1) | 80.7 (34.8) | 19.3 (65.2) |
| 4 quarters | 44.6 (83.6) | 55.4 (16.4) | 65.7 (19.9) | 34.3 (80.1) |
| 8 quarters | 63.5 (93.9) | 36.5 (6.1) | 56.1 (12.3) | 43.9 (87.7) |
| 12 quarters | 73.9 (97.1) | 26.1 (2.9) | 49.6 (8.3) | 50.4 (91.7) |
| 36 quarters | 87.4 (97.8) | 12.6 (2.2) | 36.5 (2.9) | 63.5 (97.1) |

Note: Values in the table indicate the percentage contribution of each type of shock to the forecast error variance of the output and price fluctuation. Figures in parentheses indicate results for $\gamma_{yD} = 0$, while figures to the left of the parentheses indicate results for $\gamma_{yD} = 0.27$.

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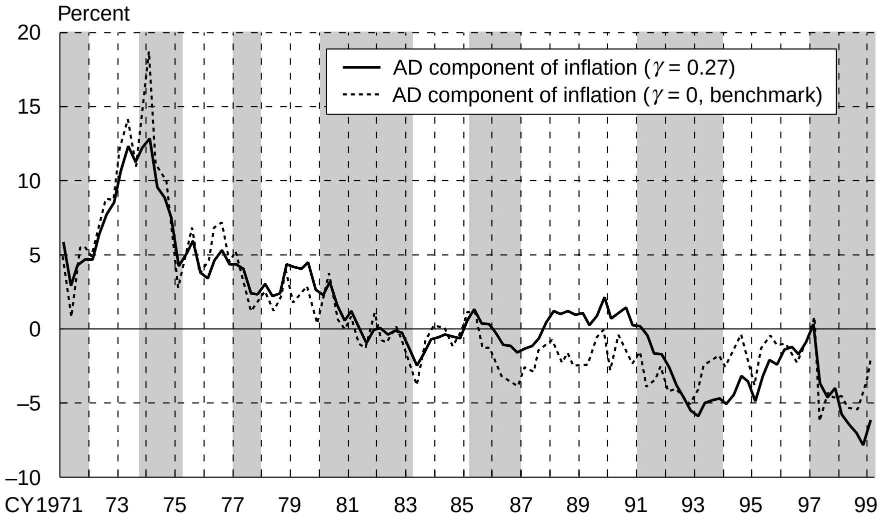
[35] For the case of $\gamma_{yD}$, by assumption, dynamic response of output with respect to the AD shock does not converge to zero. As a result, the forecast error variance of output explained by the AD shock sharply rises for all time horizons.

Finally, Figure 9 provides a comparison of the historical decomposition for two assumptions, namely, $\gamma_{yD} = 0$ and $\gamma_{yD} = 0.27$. There is no qualitative difference between the two cases. However, minor quantitative discrepancies arise at certain periods. First, from the beginning of the recession of the 10th cycle (1985/II–1986/IV), AD components of inflation for the two assumptions start to diverge persistently. For the case of $\gamma_{yD} = 0.27$, the AD component of inflation peaks at 2.2 percent, while for the case of $\gamma_{yD} = 0$ it hovers near zero at the end of 1989. This is somewhat closer to the interpretation of Kousai, Ito, and Arioka (2000), who stated that "an upward shift in the AS curve apparently increased output and contributed to the price stability despite approaching full employment." Nonetheless, the rises in AD components of inflation from the trough (1986/IV) to peak (1989/IV) are 3.7 percent for the case of $\gamma_{yD} = 0.27$ and 3.8 percent for the case of $\gamma_{yD} = 0$, indicating that there is no significant difference in the magnitude of the identified positive AD shocks in this period between these two cases. Secondly, the troughs in two recessions in the 1990s become deeper for the case of $\gamma_{yD} = 0.27$ than for the case of $\gamma_{yD} = 0$ by roughly 2 to 3 percent.

To summarize the analysis in this section, the historical decomposition is *qualitatively* robust to the sectoral shocks, alternative choices for the price variable and assumptions for the lag length of the VAR, and the long-run elasticity of output with respect to permanent changes in price due to AD shocks. Nevertheless, it also should be noted that historical decomposition can be *quantitatively* affected by these factors. It might be necessary to expand the model to deal with these limitations.

**Figure 9 Historical Decompositions for Alternative Assumptions on $\gamma_{yD}$**



Note: Historical decomposition of the identified annualized quarterly inflation rate with the assumption of $\gamma_{yD} = 0$ (dotted line) and $\gamma_{yD} = 0.27$ (solid line) is shown. Shaded areas indicate recessions based on the Cabinet Office's business

## VI. Conclusion

In this paper, I estimate a bivariate output-price structural VAR model for Japan to decompose the inflation rate time-series into two components, explained by AD and AS shocks. The following three points are the main findings.

First, dynamic properties of the identified model are generally consistent with the predictions of the conventional AS-AD framework.

Second, the historical decomposition is generally compatible with the conventional view of the major Japanese historical episodes since 1970. The following features are especially striking: (1) the AD component of inflation shows procyclical swings, rising during every expansion while falling during every recession since 1970. (2) Rises in the AD component of inflation during the expansions are consistently smaller than the falls in the AD component of inflation during the subsequent recessions; this explains the deflationary trend since the first oil crisis. (3) The AS component of inflation spikes temporarily during the two oil crises, while the AD component of inflation rises for the first crisis and falls for the second crisis. (4) The rise in the AD component of inflation during the "bubble" period is not significantly larger than that observed during the other expansions since 1970. (5) The coincidence of large and negative AS and AD shocks explains the combination of price stability and output stagnation during two recessions in the 1990s. (3) and (5) are compatible with the conventional view of that episode, while (4) is not. In addition, (5) suggests the need for further analysis of the supply side of the economy to understand the output and price development in the 1990s.

Third, the historical decomposition is qualitatively robust to the sectoral shocks, alternative choices for the price variable, and assumptions for the lag length of VAR and the long-run elasticity of output with respect to permanent changes in price due to AD shocks.

My approach using a simple and small bivariate model seems to have succeeded in explaining the *qualitative* features of the Japanese inflation rate for the past 30 years and is useful to decompose the observed inflation to AS and AD components. However, it seems to have a limitation in disentangling sectoral *supply* shocks and AD shocks, which are expected to have different dynamic effects on output and price. The analysis here does not tell how the contamination *quantitatively* affects the result. Thus, there is a need to expand the model to disentangle the inflation rate explained by sectoral shock, especially when focusing on the *quantitative* aspect of the historical decomposition.

## APPENDIX: ESTIMATION METHOD

In this appendix, I illustrate the re-parameterization of equation (4) to estimate it by the IV method. The procedure shown here is a simple variant of the procedure proposed in King and Watson (1997), who estimated a bivariate output-money structural VAR to test the long-run neutrality of money.

Recall that $\alpha_{jk}(L)$ is the $j$, $k$-th ($j$, $k$ = 1, 2) element of $\alpha(L)$ and the long-run restriction $\gamma_{yD} = -\alpha_{12}(1)/\alpha_{11}(1)$, the upper block of the structural VAR equation (4), can be re-parameterized as equation (A.1).

$$\Delta y_t = -\alpha_{12}(1)\Delta p_t + \varphi(L)\Delta^2 p_t + (1 - \alpha_{11}(1))\Delta y_{t-1} + \zeta(L)\Delta^2 y_t + \varepsilon_t^S, \qquad \text{(A.1)}$$

where

$$\varphi(L) = -\frac{(\alpha_{12}(L) - \alpha_{12}(1))}{1 - L},$$

$$\zeta(L) = 1 - \frac{\alpha_{11}(L) - \alpha_{11}(1)L}{1 - L}.$$

Next, rewrite $\gamma_{yD} = -\alpha_{12}(1)/\alpha_{11}(1)$ to yield equation (A.2).

$$\gamma_{yD} - (1 - \alpha_{11}(1))\gamma_{yD} = -\alpha_{12}(1). \qquad \text{(A.2)}$$

Substituting the left-hand side of equation (A.2) to the first term of equation (A.1) yields equation (A.3).

$$\Delta y_t - \gamma_{yD}\Delta p_t = (1 - \alpha_{11}(1))(\Delta y_{t-1} - \gamma_{yD}\Delta p_t) + \varphi(L)\Delta^2 p_t + \zeta(L)\Delta^2 y_t + \varepsilon_t^S. \qquad \text{(A.3)}$$

Equation (A.3) can be estimated by the IV method using $\Delta y_t - \gamma_{yD}\Delta p_t$ as the left-hand side variable, $\Delta y_{t-1} - \gamma_{yD}\Delta p_t$, $\Delta^2 p_t$, $\Delta^2 p_{t-1}$, . . . , $\Delta^2 p_{t-p+1}$, $\Delta^2 y_{t-1}$, $\Delta^2 y_{t-2}$, . . . , $\Delta^2 y_{t-p+1}$ as right-hand side variables and $\Delta p_{t-1}$, $\Delta p_{t-2}$, . . . , $\Delta p_{t-p}$, $\Delta y_{t-1}$, $\Delta y_{t-2}$, . . . , $\Delta y_{t-p}$ as instrumental variables.

On the other hand, estimation of the lower block of equation (4) requires using estimated residual for the upper block of equation (4), i.e., $\hat{\varepsilon}_t^S$, as the instrumental variable of $\Delta y_t$ since $\Delta y_t$ and $\varepsilon_t^D$ are correlated. The lower block of equation (4) can be estimated by the IV method using $\Delta p_{t-1}$, $\Delta p_{t-2}$, . . . , $\Delta p_{t-p}$, $\Delta y_t$, $\Delta y_{t-1}$, $\Delta y_{t-2}$, . . . , $\Delta y_{t-p}$ as explanatory variables and $\Delta p_{t-1}$, $\Delta p_{t-2}$, . . . , $\Delta p_{t-p}$, $\hat{\varepsilon}_t^S$, $\Delta y_{t-1}$, $\Delta y_{t-2}$, . . . , $\Delta y_{t-p}$ as instrumental variables.

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