# U.S. wage-price dynamics, before, during and after COVID-19, through the lens of an empirical econometric model. *

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6 May 2025.

**Abstract**

We specify a multiple-equation model with equilibrium-correction terms which connect inflation to the wage share and the functional income distribution, while not excluding a priori variables that are typically found in existing empirical U.S. Phillips curve models. We estimate the model equations using automatic variable selection with low Type-1 error probabilities on a sample with quarterly data that starts in the 1960s. Conditional on a relatively small number of location shift indicators, the price and wage equations have relatively constant parameters. The model's explanatory power is shown by dynamic simulations. Applied to the COVID-19 period, the model shows that wage growth was important initially but that other factors later also became important, in particular the broad increase in international prices. Out of sample simulation shows how well the model forecasts inflation since early 2023.

**JEL classification**: C32, C53, C54, E17, E27, E32, E37, E65.

## 1 Introduction

Even while COVID-19 was still a threat to public health and to the stability of national economies, price levels in many countries started to increase faster than had been usual since the 1990s. USA is a particularly interesting case, since it is easy to imagine that the policy response to U.S. inflation influences monetary policy decisions elsewhere in the world.

*Norwegian Research Council project number 324472. We would like to thank two reviewers for comments, both critical and constructive. Comments from Jennifer Castle, Steinar Holden, Amund A. Kordt, Bilal Sali and Borgar Løvold Ihle are also gratefully acknowledged. Earlier versions of the paper have been presented at CATE-BI workshop, October 2023, 45th Annual Meeting of the Norwegian Association of Economists, January 2024, Statistics Norway Research seminar, February 2024 and 26th Dynamic Econometric Conference, Oxford Martin School University of Oxford, April 2024.

In this paper we present a multi-equation econometric model with the purpose to analyse the drivers of inflation as well as the internal wage-price spiral dynamics of U.S. inflation.

Conceptually, the wage-price spiral captures the idea of a positive feedback process between product prices and wage compensation, see Blanchard (1987). Firms try to use mark-up pricing as a way to compensate for increased (variable) costs of production. They are also likely to succeed in this, to a degree that may depend on structural aspects of demand (e.g., price elasticities) and on the market form (monopolistic competition). On the worker side, one goal in individual pay negotiations, as well as in collective wage bargaining processes, is to seek compensation for increased costs of living. However, whether the degree of compensation is complete or partial can depend on both market forces and on institutions.

The econometric methodology we apply is based on cointegration and equilibrium correction models (EqCMs). The insight that equilibrium correction formulations can be an improvement on Phillips curve models of wage-price inflation goes back a long time and predates cointegration, e.g., Sargan (1980). However, wage and price EqCMs have never reached high popularity among modellers of U.S. inflation. The Phillips curve model, PCM, in its different varieties, continues to dominate.

The EqCM approach to wage modelling, WP-EqCM, is also well suited to test empirically the connection between the functional income distribution and the inflation process. In the PCM framework the connection is not direct, for example is the lagged wage share not an explanatory variable in the wage PCM. The disconnection can be plausible given that collective bargaining has come to play a minor role in the wage setting process in the U.S.. However, it may be possible that workers earn a share of rents in a system where an informally organized pool of workers bargain implicitly with long-time employers, cf. McDonald and Solow (1981). If rent sharing is a phenomenon in real world wage formation, it can be treated econometrically by the use of cointegration and WP-EqCM-wage equations. At the same time, our approach does not rule out finding a more standard U.S. Phillips curve empirically, as it is a special case.

Our work builds on Bårdsen and Nymoen (2009), where we modelled annual time series of U.S. wages and prices on a sample from 1962 to 2004. In that model, the typical U.S. wage Phillips curve was replaced by a wage growth equation that can be interpreted economically as consistent with rent sharing. In that way, the model captured that inflation is integrated in the process that determines the functional income distribution.

Although our approach is econometric, and the model is an empirical explanatory model, it is guided by economic theory of wage and price setting. In this respect, the recent paper by Bernanke and Blanchard (2024) is similar to ours. There are, however, differences in econometric method, choice of variables, and sample period. For example, the specification of our model is not tailor-made to fit the pandemic era. We are interested in testing whether relationships can have a degree of parameter constancy over a longer sample period, going back to the mid-1960s using quarterly data. Specifically, we investigate whether there has been a structural break in the data-generating process after COVID-19, which requires that we first establish a model based on a long, pre-COVID-19, data set.

The strength of standard inflation drivers, and the emergence of new ones, have been discussed and analysed in the pandemic era inflation literature. In the next few paragraphs we survey a selection of these offerings, focusing on the hypotheses they investigate and empirical results.

Cecchetti et al. (2023) use time series data dating back to the 1950s to analyse disinflations, including the post-pandemic period. Their preferred price PCM is a non-linear function of labour market tightness, indicating that while a hot and tightening labour market raises inflation, a slackening of an already cold labour market does not necessarily lower it. The results further highlight that the choice of sample period is crucial for the model's ability to explain pandemic-era inflation. Models incorporating data from the high and volatile inflation episodes of the 1960s and 1970s appear more effective in tracking recent inflation and disinflation than those based solely on the Great Moderation period. This aligns with findings that suggest a flattening of the Phillips curve during the Great Moderation, Blanchard (2016) and Hazel et al. (2022). However, other studies indicate that the curve may have steepened again when incorporating data from the pandemic era, Ari et al. (2023).

The instability of empirical U.S. Phillips curve was recognised long before COVID-19, see Del Negro et al. (2020) and the references therein. However, finding that the coefficient of the rate of unemployment is unstable in a simple model of wage inflation does not imply that the coefficient is unstable in a larger model. Castle and Hendry (2024) find that for a long historical sample of UK inflation, the unemployment rate has a stable negative slope coefficient in regression models that include all relevant explanatory variables.

From the wage-curve branch of the literature, Blanchflower et al. (2024) find empirically that the unemployment rate is not key to explaining wage growth data in the USA since the Great recession. Using panel data, they provide evidence supporting that other indicators of labour market pressure are more relevant: the non-employment rate, the under-employment rate and the inactivity rate.

The contribution by Ball et al. (2022) concludes that the increase in headline inflation resulted primarily from shocks to food and energy prices, but that labour market tightness had been an important factor of core inflation.

The influential study by Bernanke and Blanchard (2024), noted above, analyses inflation during the pandemic era using a model in which short- and long-term inflation expectations, along with labour market tightness, are the key drivers. The findings suggest that wage growth and labour market tightness contributed only modestly to inflation early in the pandemic. However, as restrictions eased, pent-up demand drove up the price level—given wages—by increasing demand for goods with inelastic supply. Energy prices alone accounted for much of the rise in overall inflation in late 2021 and the first half of 2022. The analysis conditions on relative food prices but, compared to the other studies mentioned, places somewhat less emphasis on food price inflation.

Closely related to short-term inelastic supply is the disruption of global supply chains, a key focus of several studies, e.g. Akinci et al. (2022), Bai et al. (2024), Comin et al. (2023), as well as CEA (2023). These contributions suggest that supply chain pressures may have been a primary driver of inflation toward the end of the pandemic and in its aftermath.

On the role of fiscal stimulus in building up latent demand pressure, Hagedorn (2023) gives theoretical arguments for inclusion of the change in federal transfers in a nominal demand augmented PCM (of the New Keynesian type), and reports empirical results which support that hypothesis. Related to this, Lorenzoni and Werning (2023) focus on the hypothesis that excess demand and scarce non-labour inputs may initially have pushed up the general price level and the subsequent wage-response. It does not follow that the wages and prices start to spiral out of control, though.

As mentioned earlier, existing studies have examined whether COVID-19 caused structural breaks in the wage Phillips curve, yielding mixed results. In our modelling work, we employed machine learning techniques to help identify structural breaks of the level-shift type. Conditional on a relatively small set of location shift indicators, the parameters of the price and wage equations remain largely stable, including the slope coefficient of the labour market tightness variable in the wage change equation. Notably, we do not find significant breaks after the first quarter of 2020—neither in the wage equation nor in any other equations of the model.

The model we propose is a block-recursive system, incorporating wages, consumer and producer prices, import prices, productivity, unemployment rate, and capacity utilization as interdependent endogenous variables. Oil prices, transfers, and global economic activity are treated as exogenous variables.

The set of variables used to explain wages and prices may appear relatively limited, omitting some factors highlighted as important in recent literature. This is partly due to data availability, as our goal was to estimate the wage-price model using a sample starting in the 1960s. However, we assess the explanatory power of additional variables in shorter samples (determined by data constraints), particularly inflation expectations and a global supply chain pressure indicator

Subject to the remark about location shifts above, dynamic simulation over the period 1980Q1–2020Q1 shows that the model tracks inflation well, even in periods where it predicts a more stable unemployment rate than observed in the data. While this may seem puzzling at first, it arises because import prices and productivity exert a stronger explanatory influence than the unemployment rate. This finding calls into question the assumed strong link between labour market pressure and inflation as a basis for disinflation policies.[1]

A second simulation focuses on the COVID-19 period and its aftermath. The results show that while worker compensation initially surged, the model effectively explains how inflation remained below 2 percent (annual change) in 2020. The primary factors driving this outcome in the model are a sharp increase in labour productivity and a decline in capacity utilization.

In the second year of the pandemic, rising inflation was largely driven by developments in goods markets—specifically, price increases given wages. In our model, this is captured by rising import and energy prices.[2]

The price shock of 2021 was substantial, and in our model, which incorporates a generic wage-price spiral, a significant share of inflation in 2022 and 2023 is attributed to the persistent effects of these shocks. Import price growth remained high through the first half of 2022 before declining sharply in the last two quarters of 2022 and into 2023.

Our empirical results highlight the importance of import prices, a factor that has received relatively little attention in recent studies. The modified Yellen (2017) model used in CEA (2023) examines the role of import price growth in U.S. inflation but finds it had little impact during the pandemic era. However, that model conditions inflation on growth in

[1] This interpretation is neither new nor unique; see Forder (2014) for a discussion of the policy implications of the empirical Phillips curve literature.

[2] As an aggregate model, ours does not explicitly represent shifts in demand composition (e.g., from services to durable goods) during the pandemic, which have been highlighted in existing studies, such as Guerrieri et al. (2023). However, since part of this demand shift was met by imports, it is reasonable to assume that its effects are reflected in imported inflation within our model.

relative import prices rather than on nominal import price growth, which may account for the difference in findings. Ultimately, this remains an empirical question.

The remainder of the paper is organized as follows. Section 2 presents the analytical framework, outlining a model typology in which the WP-EqCM, the Phillips curve, and the Bernanke and Blanchard model emerge as special cases. Section 3 details the operational definitions chosen to represent the theoretical variables and explains the empirical specification methodology. In Section 4, we use the full block-recursive model to simulate U.S. wage-price dynamics before, during, and after COVID-19, including an out-of-sample performance evaluation. Finally, Section 5 summarizes our findings.

# 2 Framework and stylized models

In the U.S., there is a long tradition of using Phillips curve models (PCMs) in inflation modeling Gordon (1997, 1998); Blanchard (2016). The model developed by Bernanke and Blanchard (2024) to analyse the causes of pandemic-era inflation belongs to this category.

Another approach also goes a long way back, to the error-correction models that Denis Sargan formulated early in the history of econometric modelling of wages and prices, Sargan (1964, 1980). During the 1990s, the econometrics of co-integrated variables was developed in ways that allowed long-run relationships containing real wages to be included as attractors in models of changes in wages and prices that belong to the class of equilibrium correction models, Bårdsen et al. (2005, Ch. 5).[3]

However, the difference between the two modelling traditions is not as large as it is sometimes made out to be, at least conceptually. As pointed out in Bårdsen and Nymoen (2003, 2009), EqCMs and PCMs have equilibrium correcting dynamics as a common feature. The economic interpretation is different though: The models have different implications for natural rate dynamics, e.g. Bårdsen and Nymoen (2009). By using the EqCM framework, we also capture the underlying two-way relationship between inflation and the functional income distribution in the economy, Nymoen (2021).

## 2.1 An encompassing framework

Equilibrium correction formulations can be used to include real wage ambitions of firms and workers in models of inflation. In practice, because of productivity growth, the operational definition of real wage ambition is typically a productivity corrected real wage, e.g., the wage share.

In countries where collective bargaining plays a significant role, the relationship between the functional income distribution, wage- and profit shares, and the wage formation is easy to recognise. However, as has been pointed out by Pencavel (1985) and others, wage setting models with unions as economic agents with real wage targets, may have a wider relevance than might be apparent at first, and it may be appropriate to imagine wage setting as the

[3]Hendry (1995, Ch. 7.10) made the point that the defining characteristic of EqCM dynamics is that it adjusts towards an equilibrium implied by the stability of the (homogeneous part) of the model equation, and to use the acronym EqCM for equilibrium-correction model instead than for error-correction model. We follow Hendry's convention.

outcome of a process of implicit bargaining. For example, a related concept is rent sharing, and evidence suggests that also non-union workers earn so called non-competitive rents, Carruth and Oswald (1989, Ch. 3), Blanchflower et al. (1996). Our framework encompasses both strong and weaker versions of the relationship between compensation and profitability.

In its turn, the functional income distribution has been shaped by the history of wage and price changes, often in response to changes in productivity and other factors that will affect the target value, unless it is followed by wage and price adjustments that aim at restoring the balance.

To put these ideas into model-equation form, we use two stylized equations for price and wage changes:

$$\Delta w_t = \psi_{wp1}\Delta p_t + \psi_{wp2}\Delta p_{t-1} + \psi^e_{wp1}\Delta p^e_t + \psi^e_{wp2}\Delta p^e_{t-1} + \psi_{wq}\Delta q_t + \psi_{wz}\Delta z_t$$
$$+ \mu_{w1}x_t + \mu_{w2}x_{t-1} - \theta_w \bar{\omega}^A_{wt-1} + \varepsilon_{wt}, \quad (1)$$
$$\Delta q_t = \psi_{qw}\,\Delta w_t + \psi_{qpi}\Delta pi_t + \psi_{qz}\,\Delta z_t + \theta_q \bar{\omega}^A_{ft-1} + \varepsilon_{qt}. \quad (2)$$

The wage level is denoted by $w$, consumer price by $p$, the price obtained by the producer by $q$, import prices $pi$, and productivity by $z$. $\varepsilon_w$ and $\varepsilon_q$ represent wage and price shocks.

Logs of variables, except possibly $x$, are denoted by lower case Latin letters, with differences (denoted by $\Delta$) representing approximate relative changes. In particular, $\Delta p^e_t$ denotes expected inflation. To simplify the notation, intercepts are assumed to be implicit in the equations.

The variable $x$ denotes labour market tightness. A convex functional form of the rate of unemployment, implying that labour market tightening puts more pressure on wages when unemployment is initially low than when the opposite is the case, goes back to the original curve of Phillips, see Forder (2014), Castle and Hendry (2024) among others. In practical modelling of U.S. wage Phillips curves, the linear functional form has however been quite standard. Interestingly, Bernanke and Blanchard (2024) make use of a non-linear functional with the unemployment and vacancy rate as arguments in their wage PCM. Cecchetti et al. (2023) use a convex functional form of the unemployment rate in their analyses of disinflations.

$\bar{\omega}^A_{wt}$ and $\bar{\omega}^A_{ft}$ denote real wage target (i.e., ambitions) of the workers and the firm owners. In general, they will be only partly overlapping, as captured by the following identities:

$$\bar{\omega}^A_{wt} = (w_t - q_t - \iota z_t) + \varpi(p_t - q_t), 0 < \iota \leq 1, 0 \leq \varpi \leq 1, \quad (3)$$
$$\bar{\omega}^A_{ft} = (w_t - q_t - z_t). \quad (4)$$

$\bar{\omega}^A_{wt}$ in (3) denotes the real wage target of the worker side, and it can be rationalized by models of bargaining about nominal wages, Bårdsen et al. (2005, Ch. 5.2). $(p_t - q_t)$ denotes the wedge between the consumer real wage $(w - p)$ and the producer real wage $(w - q)$.

Consistent with how the variables have been defined, all coefficients in (1) and (2), with the exception of $\mu_{w1}$ and $\mu_{w2}$ (for $x_t$ and $x_{t-1}$), are non-negative.

Given the assumption that $pi$ is produced abroad, but consumed by U.S. households, we add a stylized identity which mimics how the consumer price index $p$, weighs together the price of domestic production $q$, and the price of imports, $pi$:

$$p_t = \phi q_t + (1 - \phi)pi_t,\ 0 < \phi < 1. \quad (5)$$

## 2.2 Model typology

The above equations represent a basic framework that contains different structures as special cases.

### a) WP-EqCM

The definitional trait of the WP-EqCM is that the two adjustments coefficients are positive: $\theta_w > 0$ and $\theta_q > 0$.

*SEM version of WP-EqCM*
When expectations are not explicit in the model, $\psi^e_{wp1} = \psi^e_{wp2} = 0$, we get a dynamic simultaneous equations model.

$$\Delta w_t = \psi_{wp1}\Delta p_t + \psi_{wp2}\Delta p_{t-1} + \psi_{wq}\Delta q_t + \psi_{wz}\Delta z_t + \mu_{w1}x_t + \mu_{w2}x_{t-1} - \theta_w \bar{\omega}^A_{wt-1} + \varepsilon_{w,t}. \quad (6)$$

$$\Delta q_t = \psi_{qw}\,\Delta w_t + \psi_{qpi}\Delta pi_t + \psi_{qz}\,\Delta z_t + \theta_q \bar{\omega}^A_{ft-1} + \varepsilon_{q,t}, \quad (7)$$

$$\bar{\omega}^A_{wt} = \Delta w_t - \Delta q_t - \iota\Delta z_t + \varpi(\Delta p_t - \Delta q_t) + \bar{\omega}^A_{wt-1}. \quad (8)$$

$$\bar{\omega}^A_{ft} = \Delta w_t - \Delta q_t - \Delta z_t + \bar{\omega}^A_{ft-1} \quad (9)$$

$$\Delta p = \phi\Delta q_t + (1-\phi)\Delta pi_t. \quad (10)$$

Because the model is stylized, and is not meant as a model that we would take to the data with an aim to estimate its parameters, we put the question about identification to one side for the time being, and will return to it in when we get to the econometric modelling.[4]

The "wage-price core" above can be supplemented with marginal equations. In the stylized model, assume that $pi_t$ and $z_t$ are generated as random-walks with drift:

$$\Delta pi_t = g_{pi} + \varepsilon_{pit},\ g_{pi} > 0, \text{ and} \quad (11)$$

$$\Delta z_t = g_z + \varepsilon_{zt},\ g_z > 0. \quad (12)$$

As noted, we define the import price as denoted in domestic currency. Hence, implicitly $pi_t$ is therefore the sum of the log of a price index denoted in foreign currency and the log of the nominal exchange rate index. The intercepts of the two random-walk equations are assumed to be positive, to make sure that the model is congruent with typical trend found for actual time series of nominal price levels and for average labour productivity.

In appendix A, the model (6)-(12) is formulated as a cointegrated VAR (with known coefficients).

For given initial conditions and exogenous time series $\epsilon_{wt}$ and $\epsilon_{pt}$, the model determines $\Delta w_t$, $\Delta q_t$, $\Delta p_t$, $\bar{\omega}^A_{ft}$, $\bar{\omega}^A_{wt}$, $\Delta pi_t$ and $\Delta z_t$.[5]

*WP-EqCM with adaptive expectations*

[4] That said, it is not difficult to think of interpretable restrictions on the wage equation that would make it identified. For example, restricting $\psi_{wq}$ and $\psi_{wz}$ to be equal, together with a dynamic homogeneity restriction, $\psi_{wp1} + \psi_{wp2} + \psi_{wq} = 1$.

[5] Closed form solutions in terms of the producer real wage, the relative price $(q-pi)$ and the unemployment rate were studied in Kolsrud and Nymoen (1998, 2014), and for the consumer real wage $w-p$ and $(p-pi)$ in Bårdsen and Fisher (1999).

When one, or both, of the expectations parameters $\psi^e_{wp1}$ and $\psi^e_{wp2}$ are not zero, the model requires a supplemental theory of expectations formation to become determined.

A main distinction is between model consistent rational expectations, and data based expectation formation. Two recent assessments of inflation expectations favour data expectations in combination with survey based measures, over models that adhere to the rational expectations hypothesis, see Coibion et al. (2018) and Rudd (2022).

Bernanke and Blanchard (2024) is an example of an analysis where rational expectations is put to one side, and instead make use of a subjective expectation scheme:

$$\Delta p^e_t = \delta\pi^*_t + (1-\delta)\Delta p_{t-1},\ 0 < \delta < 1, \tag{13}$$

where $\pi^*_t$ is defined as long-term inflation expectations, given by the equation:

$$\pi^*_t = \gamma\pi^*_{t-1} + (1-\gamma)\Delta p_{t-1},\ 0 < \gamma < 1. \tag{14}$$

These two equations are in the lineage of adaptive expectations models. Rewriting (14) as:

$$\pi^*_t - \pi^*_{t-1} = (1-\gamma)(\Delta p_{t-1} - \pi^*_{t-1})$$

is a particular special case of the adaptive expectations hypothesis, being first employed by Philip Cagan in his study of hyperinflation, Cagan (1956).

Equations (13) and (14) are compatible with the WP-EqCM and can be "added to" the multiple-equation model (6) -(12) without creating any internal logical inconsistency.

### b) PCM

The Phillips curve model is implied by the restrictions $\theta_w = 0$ and $\theta_q = 0$. In the same way as for the WP-EqCM, one can envisage a SEM form of the model, or a PCM with adaptive expectations, or even a mixed model.

When the restrictions $\theta_w = 0$ and $\theta_q = 0$ are imposed in (1) and (2), wage-price dynamics become disconnected from the functional income distribution. Moreover, since (11) and (12) imply that $w_t$, $q_t$ and $z_t$ are I(1), $\theta_w = 0$ and $\theta_q = 0$ entail that the wage share $(w_t - q_t - z_t)$ is I(1) as well.

Therefore, as pointed out by Bårdsen and Nymoen (2009), in order to have a PCM which is consistent with a dynamically stable functional income distribution, indirect equilibrium correction needs to be present in the model, for example in the form of a relationship between $x_t$ (e.g., interpreted as the rate of unemployment) and the wage share.

### c) The Bernanke and Blanchard model

As noted above, Bernanke and Blanchard (2024) is an important contribution to inflation modelling which focuses on the causes of the pandemic era inflation. Bernanke and Blanchard (B&B, hereafter) specify a stylized model with adaptive expectations that they use as a framework for an empirical model.

The stylized B&B model can be obtained as a special case of the framework above by applying the following restrictions:

$$\theta_w = \theta_q = 0,$$
$$\psi_{wp1} = 0,$$
$$\psi_{wq} = \psi_{qpi} = 0.$$

The first two restrictions are the most important, since they define the B&B model within the PCM category. The second restriction excludes contemporaneous cost of living effects from the wage equation. The third pair of restrictions is basically a consequence of the closed economy framework of the B&B-model.

As shown in the appendix, the wage and price equations of the stylized model in Bernanke and Blanchard (2024), B&B, can be written as:

$$\Delta w_t = \Delta p_t^e + \psi_{wp1}(\Delta p_{t-1} - \Delta p_{t-1}^e) + \psi_{wz}\Delta z_t + \mu_{w1}x_t + \mu_{w2}x_{t-1} + \varepsilon_{w,t}, \tag{15}$$
$$\Delta p_t = \Delta w_t - \Delta z_t + \Delta\varepsilon_{pt}. \tag{16}$$

The model consisting of (15) and (16), together with (13) and (14) has $\Delta w_t$, $\Delta p_t$, $\Delta p_t^e$ and $\pi_t^*$ as endogenous variables.[6]

Apparently, real wage ambitions are absent in this model. However, a real wage target is indeed present in the B&B model. The appendix shows that it has implications for the coefficients in equation (15): $\psi_{wp1} = \alpha$ if the B&B model is true, where $\alpha$ is the catch-up parameter in real wage ambitions. It may also be noted that $\mu_{w1} = \beta$, where $\beta$ is the labour market pressure coefficient, and that $\mu_{w2} = -\beta\alpha$.[7]

# 3 An empirical econometric model

Bårdsen and Nymoen (2009) used the model of Section 2.1 as their framework to model wage and price formation and US natural rate dynamics. In that study, $\theta_w$ and $\theta_q$ were estimated to be different from zero, and statistically significant. The estimated $\iota$ was positive, implying that a long-run relationship between the wage level and productivity, which is in part upheld through equilibrium correction of nominal wage changes. However, the estimated $\iota$ was also significantly less than one, implying that there is no equilibrium wage share coming from the process of wage formation.

In our 2009 study, we used annual times series, and the hourly compensation variable in manufacturing was used as the wage variable. In the present study, we use quarterly time series and the wage variable is compensation in the private business sector, which is a better operational definition of the concept of a macroeconomic wage cost variable. More than eighteen years of data are also added to the sample used by Bårdsen and Nymoen (2009), which ended in 2004.

In this section we discuss the empirical implementation of the model.

[6] $\Delta z_t$ as well, if the marginal random walk equation is included in the model.

[7] To make the wage-price dynamics of the B&B model comparable to the other models in the typology, we have included productivity in the wage ambitions, which implies $\psi_{wz} = \iota$.

Table 1: Variable definitions

| | Definition | Series-ID† | Unit‡ |
|---|---|---|---|
| Q | Price index, gross value added, nonfarm business | B358RG3Q086SBEA | Index |
| P | Price index personal consumption expenditures. | PCECTPI | Index |
| PI | Price deflator of imports of goods | A255RD3Q086SBEA | Index |
| W | Hourly compensation for all employed workers,nonfarm business | COMPNFB | Index |
| Z | Labour productivity, non-farm business | OPHNFB | Index |
| U | Unemployment rate | UNRATE | Percent |
| CAPU | Capacity utilization | TCU | Percent |
| PO | Oil price | WTISPLC | USD |
| TRA | Federal transfers | B087RC1Q027SBEA | Billion USD |
| WAC | World economic activity | IGREA | Index |
| INFCF | 1-year ahead expected inflation | EXPINF1YR | Percent |
| INFPF | 1-year ahead expected inflation | INFPGDP1YR | Percent |
| GSCPI | Global supply chain pressure index | | Index |

† FRED Economic Data. https://fred.stlouisfed.org/. Except:
INFPF : https://www.philadelphiafed.org/surveys-and-data/
GSCPI: https://www.newyorkfed.org/research/gscpi.html.
‡ 2005=1 for all indices, except IGREA and GSCPI which are centered at zero.
With the exception of $PO$, $TRA$ and $WAC$, all variable are seasonally adjusted.

## 3.1 The time series variables

The operational definitions of the variables used are given in Table 1. For some of the theoretical variables there is more than one operational definition to choose from. The consumer price variable, P, can be operationalized by one of the consumer price indices available, or by the deflator of personal consumption expenditure (U.S. Bureau of Economic Analysis). We decided to use the latter. It is the measure the majority of existing studies use, and it means that we can use data for the producer price, $Q$, and for price of imports, $PI$, from the same source.

The source of the wage and productivity series is the Labor Productivity and Costs (LPC) program of the Bureau of Labor Statistics (BLS), which reports labour productivity and compensation data for the non-farm business sector quarterly. Compensation includes "wages and salaries" and "supplements", cf. Champagne et al. (2016) for an analysis of the series' properties compared to the other main source of hourly wage, from the Current Employment Statistics. We model inflation jointly with the variables of the functional income distribution. One important argument for using LPC wage data is therefore that internal consistency in the measurement system is secured, as the productivity data comes from the same source.

The unemployment rate $U$ is included to represent the labour market tightness variable $x$

in the theoretical set-up. The main reason for not bringing in the vacancy rate at this stage, was simply to keep the number of endogenous variables in the model at a minimum. In the empirical wage model we rely on using a convex function of $U$ as a feasible and parsimonious representations of tightness,

Capacity utilization, CAPU, was included to test whether changes in the price mark-up on wage costs could be explained by conditioning on that variable.

Also included are variables that have been shown to be relevant conditioning variables in earlier other studies of aggregate wage and price dynamics in the U.S. economy, and variables rationalized by the recent literature on pandemic era inflation. This group includes oil-price (PO), world economic activity (WAC), and supply chain pressure (GSCPI) for global bottlenecks. We have included the variable $TRA$ (Federal transfers) in the data set because the literature has brought to attention the potential that the fiscal stimulus over the December 2019 to June 2022 period had become an inflation factor, di Giovani et al. (2023) and Hagedorn (2023) as noted above.

Finally, to test the role of inflation expectations in wage formation, we have included two measures of 1-year ahead inflation expectations. INFCF is the series used by Blanchard and Bernanke (2024), from the Cleveland Fed, i.e., Haubrich et al. (2012). The other, INFPF, is from the Survey of Professional Forecasters at the Philadelphia Fed.

Figure 1 shows plots of the one quarter changes (first row), and four quarter changes (second row) in the logs of $W_t$, $Q_t$ and $P_t$.

The correlations between the nominal changes are easiest to spot in the second row where the annual changes are plotted. In the first row, the considerable short-run variation is noticeable, in particular for wage changes. The variability of the wage change rates also appear to have increased over time, leading to heteroscedasticity as a characteristic in the time series for wages. One explanation may be that compensation per hour is affected by the changing composition of the employed, between sectors and professions. Another BLS series, the employment cost index, corrects for composition effects, which is a strength. However, the point about consistency with how productivity is measured is important in our model, where $z$ is an endogenous variable and is used together with $w$ to define the (log of) the wage share.

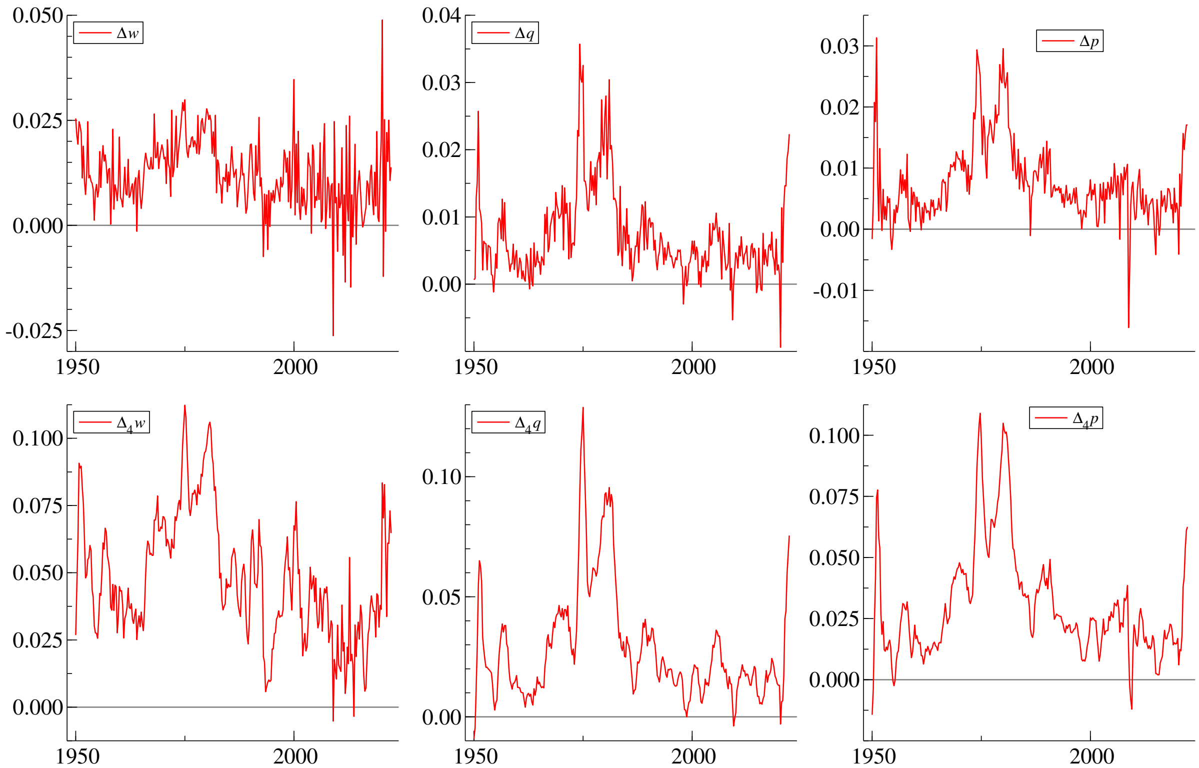


Figure 1: Wage and price change data. Units are relative change from the previous quarter (first row) and from the same quarter in the previous year (annual growth rate).

## 3.2 Empirical model specification

In the following we present model equations that retain the theoretical framework, in PCM or in EqCM form. However, as the framework is incomplete, it was not enforced without testing. Instead we employ structured variable selection, which starts from general a model with many more variables than in the theory model. The general unrestricted model (GUM) equations were specified as empirical generalisations of their theoretical counterparts and are therefore not identical for all equations.[8] For example, the treatment of Fiscal transfers follows from the understanding that the policy was directed towards consumers more than producers. This practical specification method at least leaves the researcher with a fighting chance of arriving at a final model which is a reasonable approximation to the unknown data generation process (DGP).

In brief, our approach has been to embed theoretical model equations in a statistical model with flexible dynamics (additional lags) and allowing for exogenous explanatory variables in the literature on U.S. wage and price inflation. We also make use of indicator saturation estimation, Johansen and Nielsen (2009), as implemented in *Autometrics* in the econometrics software package PcGive, Doornik and Hendry (2022a,b), following the approach of Hendry and Johansen (2015), by using a tight significance level (0.0001) when

[8] A detailed list of variables for each GUM can be provided if necessary.

testing for breaks, keeping the explanatory variables fixed, and then testing the variables using a looser significance level (typically 0.01).[9]

The coefficients of the retained indicator variables represent estimated departures from the modelled relationships which apply to the counterfactual situation where there are no breaks in deterministic terms. The final product of our modelling, we hope to show, is a parsimonious multiple-equation model, interpretable as an empirical implementation of the theoretical framework as well as a relevant explanatory model of U.S. wage and price inflation.

### The wage equation

As noted above, empirical U.S. wage equations have typically been specified as Phillips curves, the W-PCM defined above. Based on the theoretical framework and the broader literature on rent sharing, an alternative to the incumbent W-PCM equation is the W-EqCM where indicators of the functional income distribution play separate roles as explanatory variables of wage growth.

OLS estimates of the empirical wage equation are reported in equation (17). It is the model specification reached after starting from a General Unrestricted Model (GUM) with four lags, and by using the machine learning algorithm *Autometrics* with indicator saturation,cf. Castle et al. (2012), Hendry and Doornik (2014, Ch 19-20).[10] The model equation shows close correspondence with (6) in the stylized model. Changes in producer price ($\Delta q_t$), productivity ($\Delta z_t$) and consumption price index ($\Delta p_t$) index are explanatory variables, at different lags. The standard assumption that wage growth depends on labour market tightness is supported by the inclusion of the unemployment rate, in a non-linear form ($1/U$) and at lag three.

$$
\begin{aligned}
\Delta w_t \;=\; & -\underset{(0.052)}{0.2}\,\Delta w_{t-1} + \underset{(0.058)}{0.28}\,\Delta z_t + \underset{(0.092)}{0.31}\,\Delta q_{t-1} + \underset{(0.1)}{0.58}\,\Delta p_t \\
& + \underset{(0.0087)}{0.032}\,1/U_{t-3} - \underset{(0.016)}{0.084}\,[w-q-0.82z]_{t-1} \\
& + \underset{(0.0063)}{0.029}\,II_{2000(1)t} + \underset{(0.0045)}{0.022}\,DI_{2008(4)t} + \underset{(0.0045)}{0.017}\,DI_{2012(4)t} \\
& + \underset{(0.0067)}{0.048}\,II_{2020(2)} - \underset{(0.0018)}{0.0018}
\end{aligned}
\qquad (17)
$$

| | |
|---|---|
| OLS $1967(1)-2023(2)$ | $\hat{\sigma}100 = 0.62$ |
| AR 1-5 test: | $F(5,210) = 1.88[0.10]$ |
| ARCH 1-4 test: | $F(4,218) = 2.51[0.04]$ |
| Normality test: | $\text{Chi}^2(2) = 6.7[0.04]$ |
| Hetero test: | $F(16,207) = 2.34[0.003]$ |

What makes (17) different from a wage Phillips-curve, this is the variable $(w-q-0.82z)_{t-1}$. This is an EqCM-term, the estimated coefficient corresponds to the adjustment parameter

[9] The equations for producer prices and import prices use a final significance level of 0.025.

[10] Batch files with code that documents the specification is available, for this model equation and the others in the full model.

$\hat{\theta}_w$ in the theoretical equation (6). Conditional on cointegration, $\hat{\theta}_w$ is highly significant, with t-value $-5.2$.

We found that the significance of the wage EqCM-term depended on *not* forcing the coefficient of $z$ to be one, which would imply that it is the log of the wage share (as in the theory model). This result is the same as we discovered in our earlier analysis of an annual data set, 1967-2004, Bårdsen and Nymoen (2009). The interpretation is that, all things equal, a one percent increase in price and productivity go together with a smaller percentage increase in the wage level. Hence, nominal wage adjustments alone will not imply that the functional income distribution is stable and without a downward secular trend.

Below the estimated equation the sample period is reported in the first row, together with $\hat{\sigma}100 = 0.62$ which is the residual standard deviation in percent. The four last lines below the equation are standard tests of residual mis-specification: For autoregressive residual autocorrelation of order five; ARCH residual heteroscedasticity of order four; Departure from normal distributed error terms; and residual heteroscedasticity due to squares of regressors.[11] p-values for the tests are reported in square brackets.

The most significant test is the "Hetero test". It means that increased variability in the wage change data that we noted above is not well explained by the model equation (despite the inclusion of the dummies noted below). This gives a reason for using heteroscedastic standard errors to check that the robustness of the significance of the individual variables. We found that when heteroscedasticity consistent standard errors (HCSE) were used, the t-value of $\hat{\theta}_w$ changed only marginally, to $-5.9$. Statistical significance was also robust for the other economic explanatory variables in the wage equation.

The number of retained indicator variables in (17) is small, despite the long sample period (1967(1)-2023(2)): There are two impulse indicators, for 2000(1) and 2020(2) in the equation, and there are two differenced indicators, for 2008(4) and 2012(4).

$DI_{2008(4)t}$ is $+1$ in 2008(4) and -1 in 2009(1) can be associated with the financial crisis. All of the other indicators are also from the 2000's, when the variability of $\Delta w_t$ is higher than earlier in the sample period.

Of special interest to us is that there is a single indicator variable from the pandemic era, $II_{2020(2)}$ which is 1 in the second quarter of 2020, the first COVID-quarter. The job losses that occurred in late March and early April 2020 were unprecedented. As a consequence, unemployment rose sharply from 3.8 percent in 2020(1) to 13 percent in 2020(2). However, certain industries were hit harder than others, with the result that labour quality increased substantially. As shown by Stewart (2022), this composition effect can account for the main part of the sharp increases in average wage (compensation) and in labour productivity (see below) in the data for 2020.

The indicator variables in equation (17) are interpretable as location shifts. $DI_{2008(4)t}$ and $DI_{2012(4)t}$ give only short lived temporal shifts, while $II_{2000(1)t}$ and $II_{2020(2)t}$ imply a higher secular trend of the wage level (all other factors kept constant). Another type of structural break has to do with non-constant regression coefficients. With reference to the Great moderation and the Great recession, Blanchard (2016) and others suggested that the Phillips curve had become flatter, maybe returning to the slope that reigned during the

[11] The mis-specification and the other estimation results were obtained by PcGive 16, Doornik and Hendry (2022a).

1960s. That (emerging) consensus about a "flatter Phillips curve" became correlated with important monetary policy deliberations. At the Jackson Hole economic policy symposium in 2020, Federal Reserve Chair Jerome Powell spoke about a new medium-term monetary policy strategy, going for maximum employment as opposed to offsetting deviations from assessments of the natural rate, Powell (2020). However, after the pandemic the question has become whether the Phillips curve has become steeper, see Ari et al. (2023), Crump et al. (2024).

In practice, when we model real world data which is affected by changes both in the economy and in the measurement system, perfect constancy is rarely found. The practical question is instead whether the coefficients are constant enough to assess the explanatory power of the included variables.

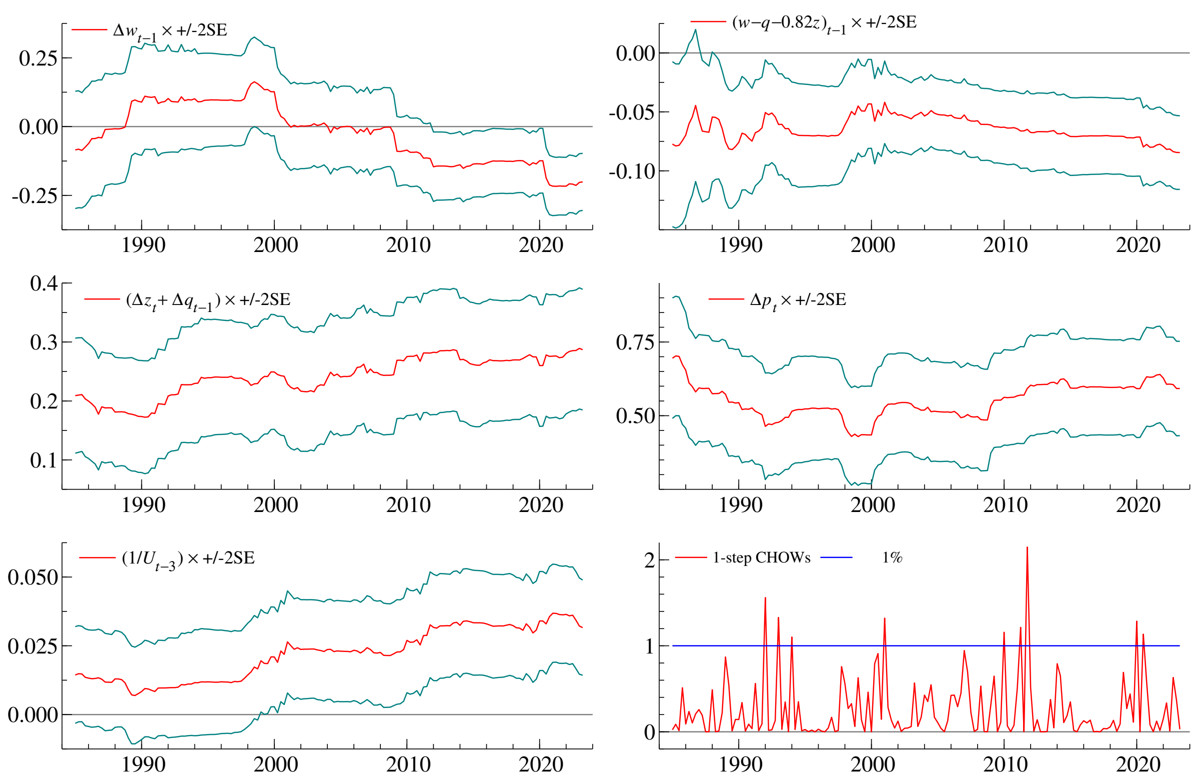


Figure 2: Recursive estimation results illustrating empirical coefficient constancy for the wage equation over the Great moderation, the Great recession and the Pandemic era.

Figure 2 illustrates relative coefficient constancy for the coefficients of equation (17). The first five plots are the coefficient estimates at each point in the shown sample period, together with their approximate 95% confidence intervals (±2SE on either side). In the sixth panel joint parameter constancy is illustrated by plotting the sequence of 1-step Chow tests, scaled by the 1 % critical values for rejecting a single null hypothesis of constancy.

The most fragile coefficient appears to be in the first panel, the coefficient of $\Delta w_{t-1}$. It is first positive (albeit insignificant), but shifts to zero at the start of the new millennium and then to the negative value it takes in (17), when the full sample is used. In the main we attribute this to the noticeably more jagged time series for $\Delta w_t$ after 2000, which is consistent with the change from positive to negative autocorrelation coefficient (conditional on the other variables in the model).

With regard to the debate about the changing wage responsiveness to labour market tightness, the fifth panel is of interest. Taken at face value, the tendency of the plotted recursive coefficient of $1/U$ goes in the opposite direction of the flattening of the Phillips curve hypothesis.[12] When uncertainty is taken into account, the tendency seen towards a larger coefficient is not a significant change, though.

Finally, since it is the $(w - q - 0.82z)_{t-1}$ variable that makes the wage equation stand out from the typical wage-PCM, it is of interest that the coefficient of the variable is quite stable over the whole period shown. Finding that wage equilibrium correction dynamics can be estimated with data from the Great moderation and earlier, is also consistent with our earlier modelling of annual wage-price data.

In appendix D additional results are reported which demonstrate that the empirical equation is robust when IV-estimation is used, which is consistent when the inclusion of contemporaneous explanatory variables represent a source of simultaneity bias in the OLS estimators.

Finally, we test the robustness of the interpretation that the dynamic specification is consistent with adaptive inflation expectations. If the hypothesis is not defensible, variables that measure expectations should change the estimation results for wage equation (17).

We first look at the results when we use the one-year inflation expectations series constructed by the Cleveland Fed, which was used by Bernanke and Blanchard in their empirical model. It is the variable *INFCF* in table 1 above. The series starts in 1982(1), so the sample is shorter than the sample used for the specification of the model, which means that we also get a test of robustness with respect to the exclusion of the information from the 1960s and 1970s.

The model in column 1 of table 2 is therefore equation (17) re-estimated on the sample that starts in 1982(2) (to allow one lag of the expectations variable). The results supplement the recursive graphs, and shows that with the exception of $\Delta q_{t-1}$, the explanatory variables retain their numerical and statistical significance.

One way that measured inflation expectations can matter for the results, are as instrumental variables for contemporaneous price inflation variables already in the equation. In column 2, the expectations variables $\text{INFCF}_t$ and $\text{INFCF}_{t-1}$ are used as instruments for the contemporaneous inflation variable $\Delta p_t$ in the model equation. Therefore, Sargan's test for instrument validity is reported at the bottom of the column, Sargan (1958,1964). The estimated coefficient of $\Delta p_t$, although somewhat reduced, can be said to be robust with respect to the change in estimation method.

In column 3, the expectations variables are included as regressors in the model equation. Individually they are insignificant, and the test of joint significance, dubbed Subset-F in the table, also gets a high p-value (0.21).

[12]Differences of specification and interpretation of wage PCMs and EqCMs notwithstanding, this seems to be in line with the conclusion in Bernanke and Blanchard (2024) about the wage PCM curve being operative during the pandemic.

Table 2: Robustness check of wage model equation (17), with respect to inflation expectations, and omission of the 1960's and 1970's from the sample:

| | 1<br>OLS | 2<br>IVE | 3<br>OLS | 4<br>IVE | 5<br>OLS |
|---|---|---|---|---|---|
| $\Delta p_t$ | $0.46^{**}$ | 0.38 | $0.53^{**}$ | $0.73^{**}$ | $0.46^{**}$ |
| $\Delta w_{t-1}$ | $-0.23^{**}$ | $-0.22^{**}$ | $-0.25^{**}$ | $-0.22^{**}$ | $-0.23^{**}$ |
| $\Delta z_t$ | $0.35^{**}$ | $0.34^{**}$ | $0.33^{**}$ | $0.30^{**}$ | $0.27^{**}$ |
| $\Delta q_{t-1}$ | 0.19 | 0.23 | 0.07 | 0.20 | 0.18 |
| $1/U_{t-3}$ | $0.05^{**}$ | $0.05^{**}$ | $0.05^{**}$ | $0.05^{**}$ | $0.05^{**}$ |
| $[w - q - 0.82z]_{t-1}$ | $-0.11^{**}$ | $-0.10^{**}$ | $-0.09^{**}$ | $-0.11^{**}$ | $-0.09^{**}$ |
| $II_{2000(1)t}$ | $0.03^{**}$ | $0.03^{**}$ | $0.03^{**}$ | $0.03^{**}$ | $0.03^{**}$ |
| $DI_{2008(4)t}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ |
| $DI_{2012(4)t}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ | $0.02^{**}$ |
| $II_{2020(2)t}$ | $0.04^{**}$ | $0.04^{**}$ | $0.04^{**}$ | $0.05^{**}$ | $0.05^{**}$ |
| *Constant* | $-0.004$ | $-0.004$ | $-0.005$ | $-0.005$ | $-0.006^{**}$ |
| $INFCF_t$ | | | $-0.2$ | | |
| $INFCF_{t-1}$ | | | 0.2 | | |
| $INFPF_t$ | | | | | 0.01 |
| $INFPF_{t-1}$ | | | | | 0.10 |
| Sargan | | 3.0[0.08] | | 4.0[0.05] | |
| Subset-F | | 1.6[0.21] | | 2.7[0.07] | |

Column 1,2 and 3: Sample period 1982(2)-2023(2).
Column 4 and 5: Sample period 1970(3)-2023(2).
** = significant at 1 %. For Sargan and Subset-F, p-values in brackets.

As noted, $\Delta q_{t-1}$ is insignificant on the shortened sample, and the estimated coefficient becomes reduced when the expectations variable is included in the model equation (column 3). Hence, $\Delta q_{t-1}$ may be seen as a dubious explanatory variable in model equation (17).

While the central role given to the Cleveland Fed expectation measure in the Bernanke and Blanchard model also makes it very relevant for us, another measure from the Survey of Professional Forecasters allows robustness-testing of the wage equation (16) over a sample that starts in 1970(2). Since a plausible hypothesis is that expectations matter more during periods of high inflation, it also gives reason to think that adding more than ten years of data from that era will give a sharper test.[13]

Columns 4 and 5 in the table give the results when the Survey of Professional Forecasters measure, dubbed *INFPF*, is used. To some degree, the results are as expected. Tested as instruments for the contemporaneous inflation rate, $INFPF_t$ and $INFPF_{t-1}$ are valid instruments at significance levels higher than 5 % (column 4). Tested as omitted explanatory variables (column 5) the Subset-F test gets a p-value of 7 %. However, the overall impression about robustness of the wage equation (17) applies also for these estimations.

Clearly, not rejecting wage equation (17) as a parsimonious model of the link between wage growth and inflation, does not imply that it is the correct model and that models with explicit expectations variables are without real merit. However, the results in Table 2 give us some reason to put the expectations variables to one side, and keep the focus on how the parsimonious model performs when analysed jointly with the other empirical equations.

### Producer and consumer price equations

Also the GUM used in the specification of the equation for the producer price $q$ contained four lags of productivity $z$ and wage compensation $w$. In addition the general model contained variables that were not in the wage model: import price ($pi$), oil price ($po$) and capacity utilization ($capu$), all with lags.

The final empirical equation for $\Delta q_t$ in (18) has change in oil-prices (over two quarters, $\Delta_2 po_t$) and in productivity ($\Delta z_t$) as contemporaneous explanatory variables. The lagged change in the import price index ($\Delta pi_{t-1}$) and the second lag of the dependent variable

[13] We thank an anonymous reviewer for pointing this out to us.

$(\Delta_2 q_{t-2})$, were also retained as explanatory variables.

$$
\begin{aligned}
\Delta q_t \;=\;& \underset{(0.019)}{0.22}\;\Delta_2 q_{t-2} \;-\; \underset{(0.025)}{0.11}\;\Delta z_t \;+\; \underset{(0.008)}{0.036}\;\Delta pi_{t-2} \\
&+\; \underset{(0.00086)}{0.0076}\;\Delta_2 po_t \;+\; \underset{(0.011)}{0.031}\;\Delta capu_{t-2} \\
&-\; \underset{(0.01)}{0.1}\;[q_{t-1} - 0.69 w_{t-1} + 0.21(z-pi)_{t-1} \\
&\quad +0.04(po_{t-1} - (SI_{1972(1)t} + SI_{1986(2)t} + SI_{1999(1)t})] \\
&+\; \underset{(0.0028)}{0.012}\;\mathrm{II}_{1998(1)t} \;+\; \underset{(0.0017)}{0.018}
\end{aligned}
\qquad (18)
$$

| | |
|---|---|
| OLS $1967(4) - 2023(2)$ | $\hat{\sigma}100 = 0.28$ |
| AR 1-5 test: | $F(5, 210) = 0.62[0.68]$ |
| ARCH 1-4 test: | $F(4, 215) = 1.73[0.14]$ |
| Normality test: | $\mathrm{Chi}^2(2) = 4.17[0.12]$ |
| Hetero test: | $F(12, 209) = 2.69[0.0022]$ |

Parallel to the wage equation, there is an EqCM-term in (18), with a significant estimated coefficient $\hat{\theta}_q = -0.1$. The EqCM-variable contains the lagged wage level, the import price index, oil price and the productivity variable. The interpretation is that in a hypothetical steady state, the estimated long-run elasticity of the price $Q$ level with respect to $W$ is $+0.7$, $+0.2$ with respect to $PI$, and $+0.04$ with respect to the oil price. The estimated long-run elasticity with respect to a permanent productivity change is $-0.2$.

According to the hypothesis of normal cost pricing, the long-run elasticities of $W$ and $Z$ are equal with opposite signs. However, that hypothesis was not supported by the data when (18) was estimated. If it is enforced, the estimated $\hat{\theta}_q$ becomes $-0.006$, hence zero in practice.

The indicator variables in (18) are for periods and single quarters from the three last decades of the previous century. There are no dummies from the pandemic era in this equation.

Three of the indicators are step dummies that are restricted to be part of the EqCM-variable, implying that the mean of the hypothetical steady-state relationship for $q$ was shifted in 1972, 1986 and in 1999. A possible interpretation is that the breaks are related to major shifts in the global economy. For example, 1972 corresponds with the end of Bretton Woods. The Plaza accords were reached around 1986 while 1999 coincides with the end of the Russian crisis, or might be related to NAFTA or China's ascension to the WTO.[14]

[14] We are thankful to the reviewer who pointed this out to us.

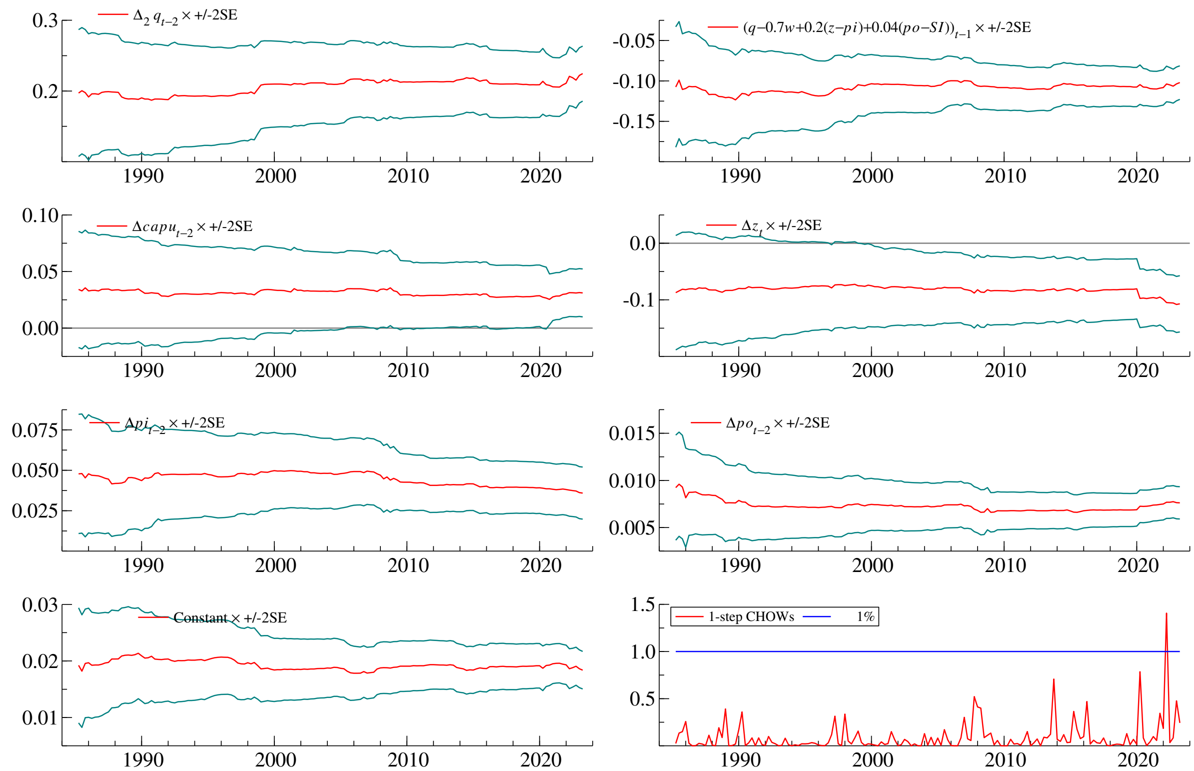


Figure 3: Recursive estimation results illustrating empirical coefficient constancy for the producer price equation over the Great moderation, the Great recession and the pandemic era.

Figure 3 shows the constancy of all the regression coefficients and the constant term. The high degree of parameter constancy over this 40-year period is striking. The pandemic era may still be an exception, since there is a significant Chow-test in 2022(2). It reflects a one-step forecast error, and can maybe be interpreted as a price-shock, although it was not retained by the automatic algorithm for detection of breaks. IV estimation results for the equation is shown in Appendix D. Coefficient estimates do not depend in any important way on the estimation method.

As noted above, several recent analyses of U.S. inflation has focused on the importance of supply side bottlenecks. The hypothesis about separate supply side shocks is logically consistent with our framework, i.e., as one interpretation of $\epsilon_t$ in (2). We do not have a long historical time series for supply chain pressure, but it is nevertheless of interest to test how the $\Delta q_t$ equation is affected when the equation is re-estimated on a sample from 1998(1)-2023(2) which is defined by the New York Fed's Global Supply Chain Pressure Index (GSCPI).

The results are given in Table 3, together with the coefficients estimates of equation (18) shown in column (a) as a reference. Column (b) shows that coefficient estimates of (18) change little when the 121 first observations have been dropped and the sample is 1998(1)-2023(2). However, we note that the coefficient of $\Delta pi_{t-2}$ becomes reduced compared to column (a), and that it is insignificant. The interpretation is therefore that inclusion of the high inflation years in the sample is important for robust estimation of the coefficient the variable representing imported inflation.

Column (c) shows the estimated $\Delta q_t$ equation when GSCPI is included. The estimated coefficient of GSCPI is tiny and insignificant (the t-value is 0.22). The better fit of the extended equation, measured by $\hat{\sigma}100$, is therefore not due to the supply side pressure index, but may in part reflect that the variance of inflation is smaller in this sample period.

In summary, the GSCPI measure does not add explanatory power to the $\Delta q_t$ equation, and hence does not change the analysis at this point. Other pressure indices or shortage measures could perform differently though, but a broader investigation is beyond the scope of this paper.

Table 3: Column (a): Coefficient estimates of $\Delta q_t$ equation (18). Column (b): $\Delta q_t$ equation re-estimated on the shortened sample 1998(1) - 2023(2). Column (c). $\Delta q_t$ equation augmented with the supply chain pressure index GSCPI.

| | (a)<br>Eq. (18)<br>1967(4)-2023(2) | (b)<br>Eq. (18)<br>1998(1) - 2023(2) | (c)<br>Eq (18) with GSCPI<br>1998(1) - 2023(2) |
|---|---|---|---|
| $\Delta_2 q_{t-1}$ | 0.22** | 0.29** | 0.29** |
| $\Delta z_t$ | -0.11** | -0.15** | -0.15** |
| $\Delta pi_{t-2}$ | 0.03** | 0.013 | 0.013 |
| $\Delta po_{t-2}$ | 0.008** | 0.008** | 0.008** |
| $\Delta capu_{t-2}$ | 0.031** | 0.036** | 0.035** |
| $ecm_{t-1}$ | -0.10** | -0.12** | -0.12** |
| $\text{II}_{1998(1)t}$ | 0.012** | | |
| Constant | 0.018 | 0.021** | 0.021** |
| GSCPI | | | 0.001 |
| $\hat{\sigma}100$ | 0.28 | 0.23 | 0.23 |

$ecm_{t-1}$ is the equilibrium correction variable detailed in (18)
** Significant at 5 % level

We now turn to the equation for the consumer price index $p$. In the stylized model, the link between producer and consumer price was represented by the identity (5) and, for the differenced variables, equation (10). Obviously, the stylized identities do not hold for the operational definitions of consumer and producer prices. Therefore, to represent the functional relationship between them, we model $\Delta p_t$ conditional on $\Delta q_t$ and $\Delta pi_t$, and other explanatory variables, including a lagged equilibrium correction variable.

The final equation is (19). It contains the main expected explanatory variables, namely import price growth ($\Delta pi_t$) and producer price inflation ($\Delta q_t$ and $\Delta q_{t-1}$).

The equilibrium adjustment variable has coefficient $\hat{\theta}_p = -0.04$ which is numerically smaller than in the two first equations, but still statistically significant conditional on cointegration. Since the producer and import price indices are in the adjustment term, the interpretation is that the secular trend in the consumer price index is correlated with both of them, but the weight on producer prices is much larger than on import prices.

Also note the "double difference", $\Delta\Delta_3 tra_t$, in the short-run part of the model, which indicate that transfers can given a separate impulse to inflation (over three quarters), but also that they tend to be cancelled out over the next few periods.

However, a particular feature of the model is that the transfer variable ($tra$) also modifies the estimated long-run relationship. This effect must to a large extent be attributed to the COVID period. As shown above, transfers to the public rose sharply up to a level not seen before in our sample period, before falling back. An implication of the equation is that the huge transfers may have driven a temporary wedge between the estimated trend in consumer prices and the "determinants" of the trend: domestic producer prices and prices of imports.

$$\begin{aligned}\Delta p_t = \; & \underset{(0.028)}{0.47}\ \Delta q_t + \underset{(0.014)}{0.089}\ \Delta_2 q_{t-2} + \underset{(0.0044)}{0.099}\ \Delta pi_t + \underset{(0.0012)}{0.0031}\ \Delta\Delta_3 tra_t \\ & - \underset{(0.0046)}{0.04}\ [p_{t-1} - 0.96 q_{t-1} - 0.04 pi_{t-1} - 0.04 tra_{t-1}] \\ & + \underset{(0.0011)}{0.0057}\ (II_{1973(3)t} - II_{1974(2)t}) \\ & - \underset{(0.0015)}{0.0079}\ II_{1975(1)t} - \underset{(0.001)}{0.0046}\ DI_{1975(2)t} - \underset{(0.0013)}{0.0092}\end{aligned} \tag{19}$$

| | |
|---|---|
| OLS 1968(1) – 2023(2) | $\hat{\sigma}100 = 0.15$ |
| AR 1-5 test: | $F(5, 208) = 1.71[0.13]$ |
| ARCH 1-4 test: | $F(4, 214) = 1.86[0.12]$ |
| Normality test: | $\text{Chi}^2(2) = 10.75[0.0046]$ |
| Hetero test: | $F(22, 199) = 2.26[0.0016]$ |

The results so far can be summarized as giving empirical evidence of joint dependency between wage and price setting, and that the interaction takes two forms: between the respective growth rates and through the adjustment of growth rates to the lagged wage and price levels. Significant explanatory factors are the oil price, the price of imports, labour market tightness and how productivity evolves. In addition come the effects of transfers on consumer prices, which may have been numerically significant during the COVID-era.

### Productivity equation

The productivity equation (20) is a generalization of the simple autoregressive process (12) in the theory framework. In the empirical version, the productivity growth rate is affected negatively by import price changes ($\Delta pi_t$), which may reflect that value added reacts faster than hours worked when there is a price shock. The rate of unemployment also has statistical explanatory power, with the expected positive sign.

$$
\begin{aligned}
\Delta z_t \quad = \quad & \underset{(0.047)}{0.24}\ (\Delta w_t - \Delta q_t) \ - \ \underset{(0.016)}{0.073}\ \Delta pi_{t-1} \ + \ \underset{(0.0018)}{0.0081}\ u_t \\
& - \ \underset{(0.016)}{0.1}\ [z_{t-1} - 1.2(w-q)_{t-1} + 0.07 pi_{t-1}] \ - \ \underset{(0.0032)}{0.01}
\end{aligned}
$$

| | | |
|---|---|---|
| OLS 1967(4) – 2023(2) | $\hat{\sigma}100 = 0.67$ | (20) |
| AR 1-5 test: | $F(5, 213) = 1.1650[0.3275]$ | |
| ARCH 1-4 test: | $F(4, 215) = 1.7108[0.1487]$ | |
| Normality test: | $\mathrm{Chi}^2(2) = 4.7536[0.0928]$ | |
| Hetero test: | $F(10, 214) = 2.2884[0.0227]$ | |

The estimation results show that the rate of unemployment has a significant and positive coefficient. It is an important effect to have in the model, as it is one way of representing a consequence of the dramatic job loss during the first year of the pandemic, which was to increase the quality of labour and hence to lift average labour productivity, see Stewart (2022).

Another noteworthy explanatory variable is the EqCM-term with estimated coefficient $\hat{\theta}_z = -0.1$. As the coefficient is statistically significant, it implies a long-run relationship between productivity, the real-wage $(w - q)$ and the level of the import price index $pi$. The long-run elasticity of $(w - q)$ is 1.2, much smaller for $pi$. The non-homogeneity that $pi$ represents may be difficult to rationalize in economic terms, but it helps the identification of the long-run wage equation in particular, since the EqCM term in (6) excludes the import price index.

We now get to the more marginal equations of the model, for import price $(pi)$, rate of unemployment $(U)$, and capacity utilization $(CAPU)$.

**Import price equation**

In a detailed empirical analysis of the drivers of U.S. import price inflation in the period from 2018(1)-2023(1), Amiti et al. (2024) found that global shocks dominated for most of the pandemic period. After the middle of 2022, when global import price inflation subsided, they found that idiosyncratic U.S. demand and supply components gained in importance.

In model equation (21), the price of energy, represented by the oil-price $po_t$, fits into that picture, since the price of oil and other energy forms increased sharply when the economies opened up and Russia invaded Ukraine. It was a global shock.

$$
\begin{aligned}
\Delta pi_t \quad = \quad & \underset{(0.043)}{0.45}\ \Delta pi_{t-1} \ + \ \underset{(0.006)}{0.092}\ \Delta po_t \ - \ \underset{(0.0063)}{0.022}\ \Delta po_{t-2} \\
& - \underset{(0.012)}{0.074}\ II_{2008(4)t} \ - \ \underset{(0.015)}{0.036}\ (pi - 0.18 po)_{t-1} \ - \ \underset{(0.0096)}{0.023}
\end{aligned}
$$

| | | |
|---|---|---|
| OLS 1981(1) – 2023(2) | $\hat{\sigma}100 = 1.1$ | (21) |
| AR 1-5 test: | $F(5, 159) = 2.53[0.03]$ | |
| ARCH 1-4 test: | $F(4, 162) = 1.38[0.24]$ | |
| Normality test: | $\mathrm{Chi}^2(2) = 0.60[0.74]$ | |
| Hetero test: | $F(8, 160) = 2.14[0.08]$ | |

**Unemployment rate and capacity utilization equations**

In the model, the unemployment rate influences the inflation process through wage-setting, and in a non-linear manner. Our goal is not to develop a comprehensive model for unemployment but to propose a modified autoregressive model for the unemployment rate, which can be incorporated into the system for dynamic (multi-step) forecasting. The same reasoning applies to the endogenization of capacity utilization, which is necessary as it appears in the product price equation.

$$
\begin{aligned}
U_t = \; & \underset{(0.025)}{1.5}\, U_{t-1} - \underset{(0.026)}{0.47}\, U_{t-2} - \underset{(0.014)}{0.06}\, U_{t-4} \\
& + \underset{(1.5)}{3.5}\, \Delta(w-q)_{t-4} - \underset{(0.00038)}{0.0014}\, \Delta_2\, WAC_{t-1} \\
& + \underset{(0.12)}{0.94}\, \left(II_{1975(1)t} - II_{1975(3)t} + II_{1980(2)t}\right) \\
& - \underset{(0.096)}{0.47}\, \left(SI_{1981(3)t} - SI_{1982(4)t}\right) + \underset{(0.19)}{8.8}\, DI_{2020(2)t} \\
& + \underset{(0.057)}{0.28}
\end{aligned}
\tag{22}
$$

| | |
|---|---|
| OLS 1969(1) – 2023(2) | $\hat{\sigma} = 0.207$ |
| AR 1-5 test: | $F(5, 203) = 0.50530[0.77]$ |
| ARCH 1-4 test: | $F(4, 210) = 1.0470[0.38]$ |
| Normality test: | $\text{Chi}^2(2) = 1.4442[0.49]$ |
| Hetero test: | $F(32, 185) = 2.1827[0.007]$ |

$$
\begin{aligned}
CAPU_t = \; & \underset{(0.041)}{1.4}\, CAPU_{t-1} - \underset{(0.062)}{0.35}\, CAPU_{t-2} - \underset{(0.039)}{0.14}\, CAPU_{t-3} \\
& + \underset{(4)}{18}\, \Delta_3 z_t + \underset{(0.0012)}{0.0069}\, \Delta_2\, WAC_t - \underset{(3.9)}{14}\, \Delta_2(w-q)_{t-2} \\
& - \underset{(0.48)}{9.5}\, DI_{2020(2)t} + \underset{(1.1)}{3.6}
\end{aligned}
\tag{23}
$$

| | |
|---|---|
| OLS 1981(4) – 2023(2) | $\hat{\sigma} = 0.60$ |
| AR 1-5 test: | $F(5, 154) = 1.7300[0.13]$ |
| ARCH 1-4 test: | $F(4, 159) = 3.3265[0.01]$ |
| Normality test: | $\text{Chi}^2(2) = 2.7125[0.25]$ |
| Hetero test: | $F(32, 185) = 2.8809[0.007]$ |

**The complete model: A block-recursive system**

Taken as a whole, the above model equations imply a block recursive system: In the first block $po_t$, $WAC_t$ and $tra_t$ are determined (from given initial conditions). In the second block, $w_t$, $q_t$, $p_t$, $z_t$, $u_t$ and $CAPU_t$ are jointly determined, conditional on $po_t$, $WAC_t$ and $tra_t$.

Within sample simulations can be conditioned on historical values of oil price, world activity and transfers, which exploits the explanatory power of these three exogenous variables. For analyses of responses to shocks and to forecast,the estimated equations for *po* and $WAC_t$ found in the appendix are included in the model. It goes without saying that those equations are rudimentary. In an operational setting, one could attempt to forecast *po* and $WAC_t$ jointly, following the approach of e.g., Kilian and Murphy (2014), Baumeister and Killian (2015).

Figure 4 summarizes the dependencies in the model.

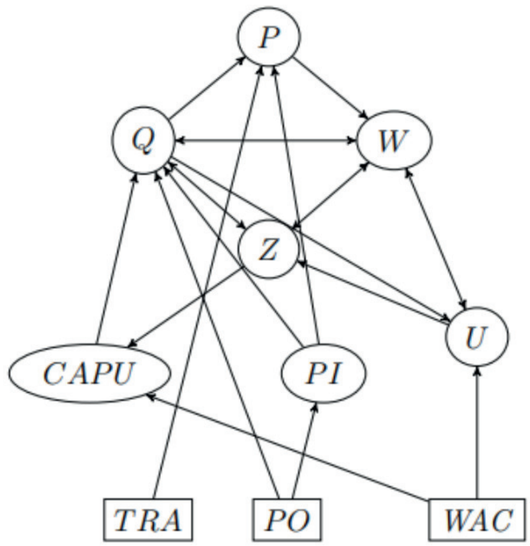


Figure 4: Dependencies between the variables in the empirical wage-price model. $W$ (wage), $Q$ (producer price), $P$ (consumer price), $PI$ (price of imports), $U$ (unemployment rate), $CAPU$ (capacity utilization), $Z$ (labour productivity), $PO$ (oil-price), $WAC$ (world economic activity) , $TRA$ (transfers).

# 4 Simulating the model

In this section we illustrate the properties of the empirical model with the aid of simulation experiments.

## 4.1 Dynamic responses

One way to quantify the dependencies that Figure 4 represents, is to simulate a scenario where there is a shock to the model equations for the import price index and for the oil price. Simulated responses are shown in Figure 5.

The plots in the figure show the dynamic responses to a joint shock to the error terms in the two equations (namely (21) and (37)). In the scenario, the shock hits in 2020(1). As the two first plots show, the two variables immediately deviate from their baselines by 10 percentage points, and this effect lasts for the rest of 2020. Subsequently, the effects go away rather quickly, as a result of the dynamic specification of these two marginal equations in the model.

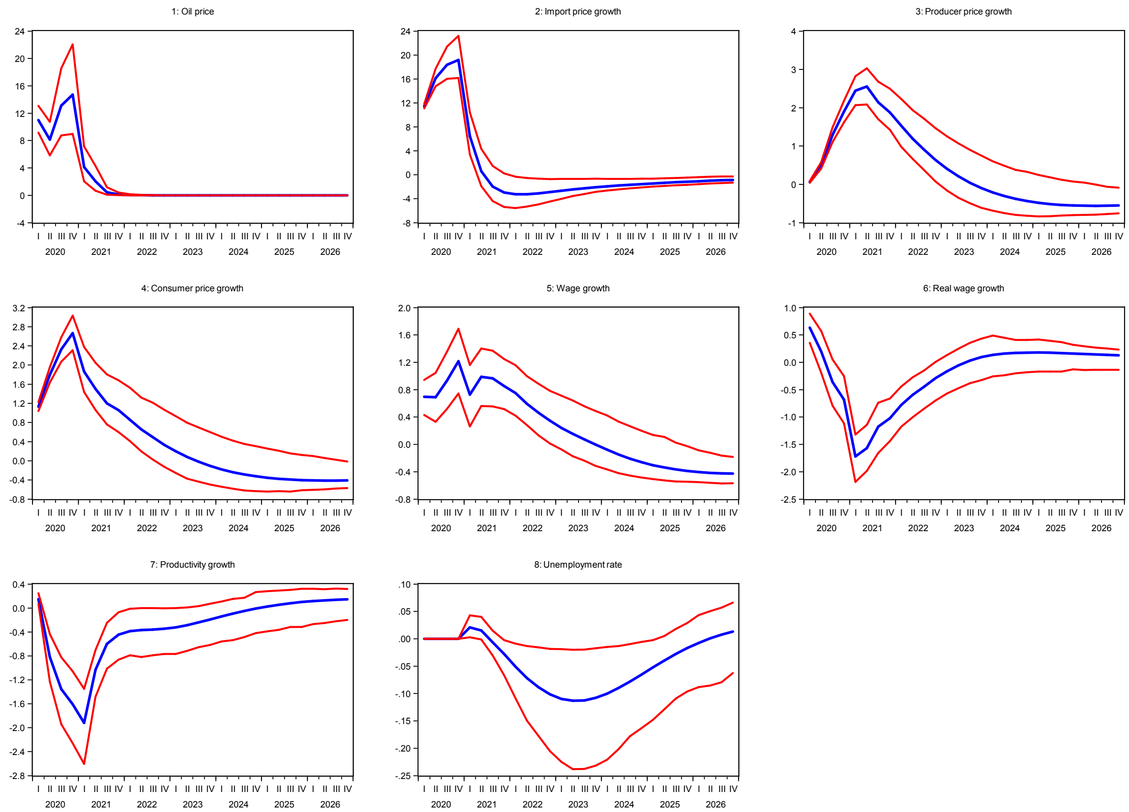


Figure 5: The effects to key variables of the full model of an impulse of 0.1 to import price and oil price equations. All variables except the unemployment rate are annual changes (four quarter relative changes). Deviations of shock-simulation from baseline-simulation. Units on all the vertical axes are percentage points. 95 % uncertainty bounds in dashed lines (bootstrap).

The responses of the variables that are at the core of the wage-price spiral, in panels 3 to 6, are much more persistent. However, after about twelve quarters, the responses of $\Delta q$, $\Delta p$, $\Delta w$ and $\Delta(w-p)$ are no longer significantly different from zero.

The responses in the third row (panels 4, 5 and 6) can also be compared to the inflation, wage growth and real wage responses of the stylized models in Appendix B. The empirical responses have most in common with the theoretical WP-EqCM responses in Figure 9 in the appendix.

## 4.2 Before COVID-19: The Great Moderation and the Great Recession

Figure 6 shows dynamic simulation results for the period 1980(1)-2020(1), conditional on the actual values of the exogenous variables $po_t$, $WAC_t$ and $tra_t$ and the estimated structural breaks (impulses and step) in the empirical model documented immediately above.

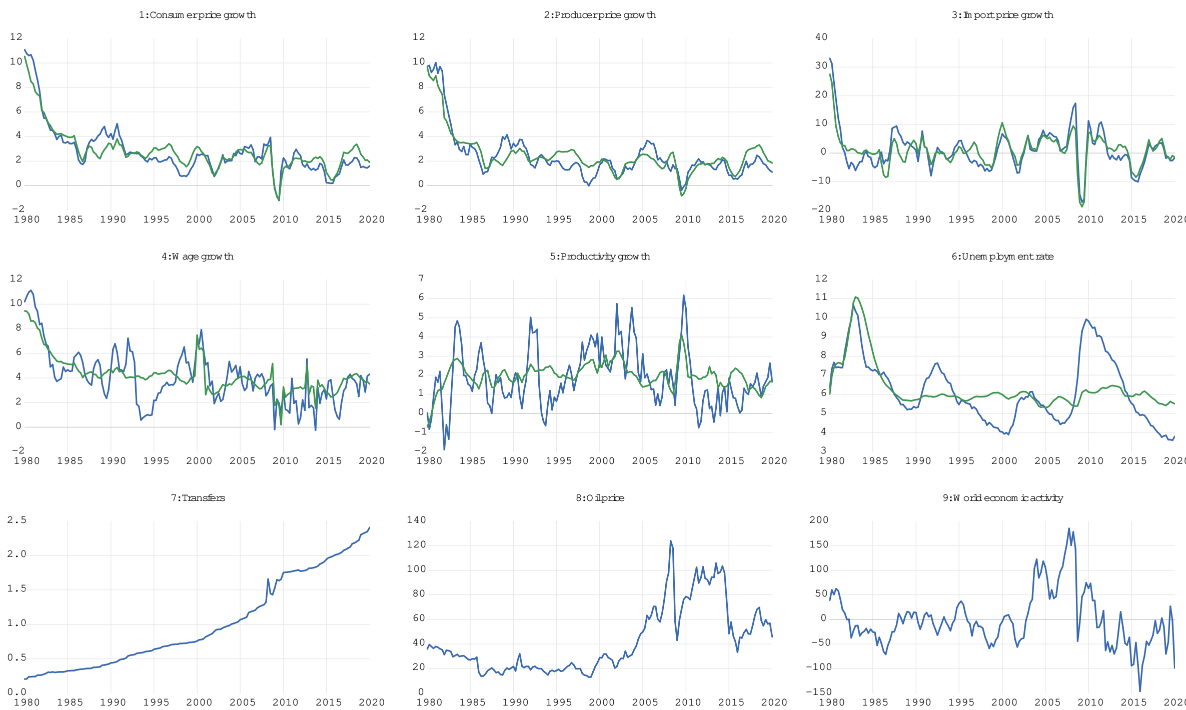


Figure 6: Dynamic model simulation 1980(1)-2020(1), conditional on $WAC$, $PO$, and $TRA$. The blue line graphs show actuals, the green (dashed) lines show simulated values. Units are percent. The five first panels show four quarter changes. Panel six shows the rate of unemployment. The third row shows the exogenous variables (raw data). Units are billion USD ($TRA$), USD ($PO$) and index units ($WAC$).

The two first panels show how well the model explains the two (price) inflation variables, $\Delta_4 p_t$ and $\Delta_4 q_t$ over the four decades long simulation period. As the estimated equations for $\Delta p_t$ and $\Delta q_t$ above document, there is a limited number of indicator variables for breaks in this period. As just noted, in the $\Delta q_t$ equation (18) there are shifts in the mean of the long-run relationship in 1972(1), 1986(1) and in 1999(1). A change in the mean of a long-run relationship can be interpreted as a change in the steady-state growth rate of the affected endogenous variable. Hence, one interpretation of how well the model simulation fits for price inflation during the Great moderation is that it represents a lowering of price expectations, or others developments that had the same effect, by the step-dummies just mentioned.

In the $\Delta p_t$ equation (19) there are only short-run fluctuations in 1973-1975 captured by differenced indicators.

Since, in the model, the price inflation is conditional on the relative change in the import price index (but not the other way round) the plot that shows actual and simulated $\Delta_4 pi_t$ in Figure 6 gives additional insight. According to equation (21), the import price index depends on the oil-price, and on a single impulse indicator in 2008(4). It can be noted how fast $\Delta_4 pi_t$ came down in the early, 1980s. Domestic inflation was reduced more gradually as the two first plots show. The next surge in U.S. import inflation happened in the pandemic era, and therefore it is of interest to see whether a similar adjustment pattern can be found for that period (see §4.3 below).

The fourth plot shows the simulation results for annual wage growth. Compared to the first three plots, the model does a poorer job in explaining wage inflation. Although the secular reduction in inflation during the Great Moderation is explained, the model fails to account for the persistent low nominal wage growth in 1993-1995. The model tracks wage growth better during the Great recession, albeit aided by two differenced indicator variables, in 1980(4) and 2012(4), cf. (17).

The last plots in the second row show that the explanatory power of the model is a good deal weaker for productivity growth (plot 5) and unemployment (plot 6). However, the simulated productivity growth rate appears to be unbiased, implying that the simulated productivity level does not drift too far from the actual, which would have damaged the simulated values for wage and prices through the EqCM-terms of the model.

Unemployment is not very well explained after 1990, where the solution graph appears to give a near constant rate, despite conditioning on the variation in world economic activity ($WAC$), which is an exogenous variable in this simulation. Viewed together with the price and wage plots, it is notable that inflation and wage growth are tracked rather well also in periods where the model produces large errors for the unemployment rate. In this way, the model simulation can be said to indicate a weaker association between labour market pressure and inflation than often seems to be taken for granted when policy measures are discussed. One reason for this model property is easy to spot: the non-linear functional form in the wage equation. The conventional view may still be correct, though. And it goes without saying that explaining unemployment better would not have done anything but good for how well the model explains inflation.

## 4.3 COVID-19 and after

The job losses that occurred in late March and early April 2020 were unprecedented. As a result unemployment rose from 3.8 percent in 2020(1) to 13 percent in 2020(2). However, certain industries were hit harder than others, with the result that labour quality increased substantially. As Stewart (2022) convincingly explains, this composition effect can account for the main part of the sharp increases in average wage (compensation) and in labour productivity in the data for 2020(2).

The cause of these dramatic changes was the forced and voluntary steps that were taken to protect public health. Hence, in economic modelling terms it was a huge shock form outside. In our model, it is captured by the indicator variable which is $+1$ in 2020(2) and zero elsewhere. It appears in two equations of the model: The wage equation (17) and the unemployment equation (22). Interestingly, the algorithm we used did not include it in the productivity equation.

In order to check the model's explanatory power in the pandemic era, we therefore condition the simulation on 2020(2) and solve for the period 2020(3)-2023(2). Since there are no indicator variables in any of the equations, the only forcing variables are the three exogenous variables: transfers ($TRA$) , oil price ($PO$), and world economic activity ($WAC$).

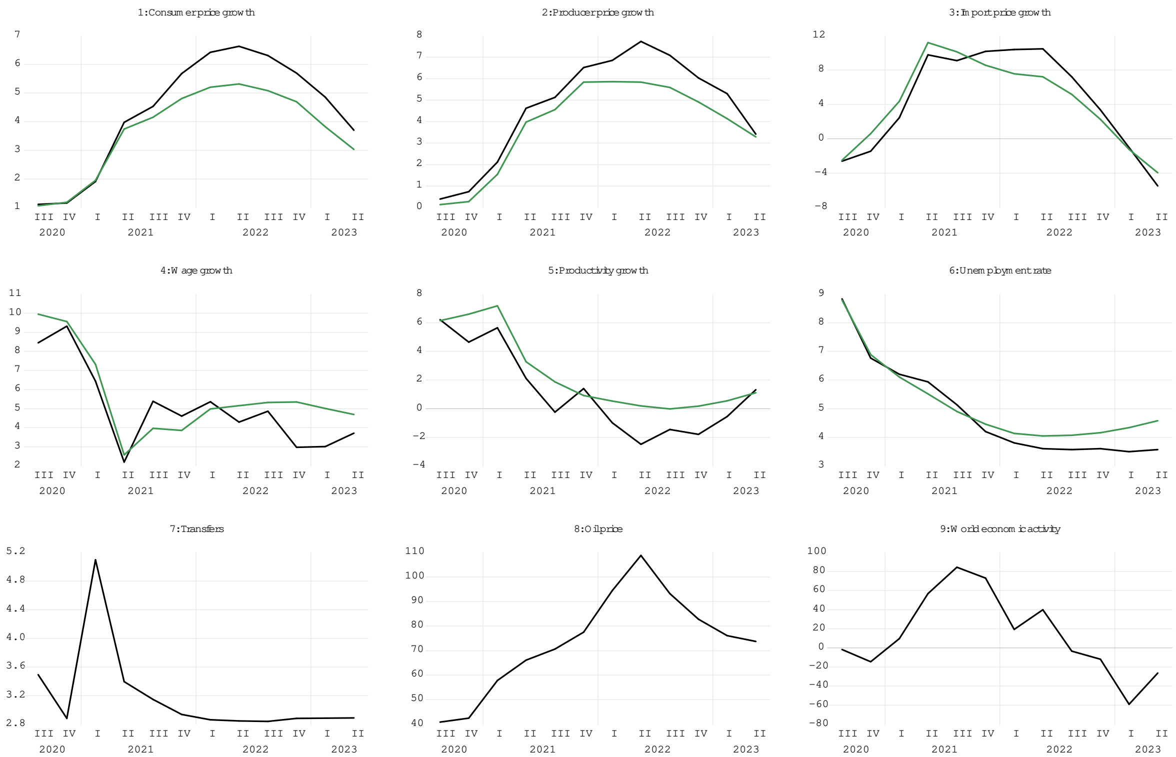


Figure 7: Dynamic model simulation 2020(3)-2023(2), conditional on $TRA$, $PO$ and $WAC$. The line graphs show actuals, the dashed (green) lines show simulated values. Units: see Figure 6.

.

The plots in the first row in Figure 7 show that for five quarters, from 2020(3) to 2021(3) the model simulation tracks the increase in both domestic price inflation and in imported inflation. The outside inflationary forces became strong towards the end of 2020. The price of petroleum products started on a steep rise that peaked in 2022(2) after the Russian invasion of Ukraine. However, the price shock was broad, as the increase in import price growth to ten percent shows (third panel in first row).

Attention has been drawn towards the fiscal stimulus over the December 2019 to June-2022 period, di Giovani et al. (2023) and Hagedorn (2023). As shown above, the increase in transfers is an explanatory variable of consumer price inflation in our model. The plotted series for transfers in the third row shows that this shock hit in 2021(1). Because of the dynamics of prices and wages, the effects of the transfers-shock are likely to affect the simulated values for at least the rest of 2021.

The model also explains wage growth well during the first phase of the pandemic (first plot in the second row), and it is interesting to note that wage growth and price inflation moved in opposite directions. Technically, this is made possible in the model because of the important role that initial conditions play for the model solution when they are far removed from long-run equilibrium values, a condition almost certainly met in this case. In terms of economic interpretation, the reduction in wage inflation is also consistent with the large composition effects becoming less dominant for wage growth as we move away from the first quarter of the pandemic.

The model also gives a reasonably good explanation of wage growth in 2022, but for consumer and producer price inflation there is a gap between actual and simulated values. For consumer price growth the largest difference is 2022(2) when actual inflation was 6.6 percent, while the simulated rate became 5.0 percent. The "missing inflation" may be seen as an accumulation of small but systematic errors (estimated constant terms are the usual suspects). However, this does not rule out the possibility that the inflation that the model misses can be due to other factors. For example, like other authors have done, one can test out using a food price index as an explanatory variable in the consumer price equation. However, strong exogeneity cannot be taken for granted for such a variable. Hence, it may lead to developing a larger model when the purpose is to obtain dynamic responses and to forecast.

## 4.4 Out of sample simulation

We can now add the five quarters from 2023(3) to 2024(3) to the data set with the specification and estimation sample which ended in 2023(2). It is of interest to check the model performance for the extended data period. Especially since the impression is that since early 2023, inflation has fallen faster than expected.

Figure 8 shows the (quasi) forecasts when we use the same method as above and condition on knowing the true paths of the three exogenous variables over the solution period. The layout of the panels are therefore the same as the two previous figures.

Since we mimic actual forecasting, each of the figures includes line graphs (dotted) which represent forecast uncertainty bounds, together with the actuals and the simulated forecasts.

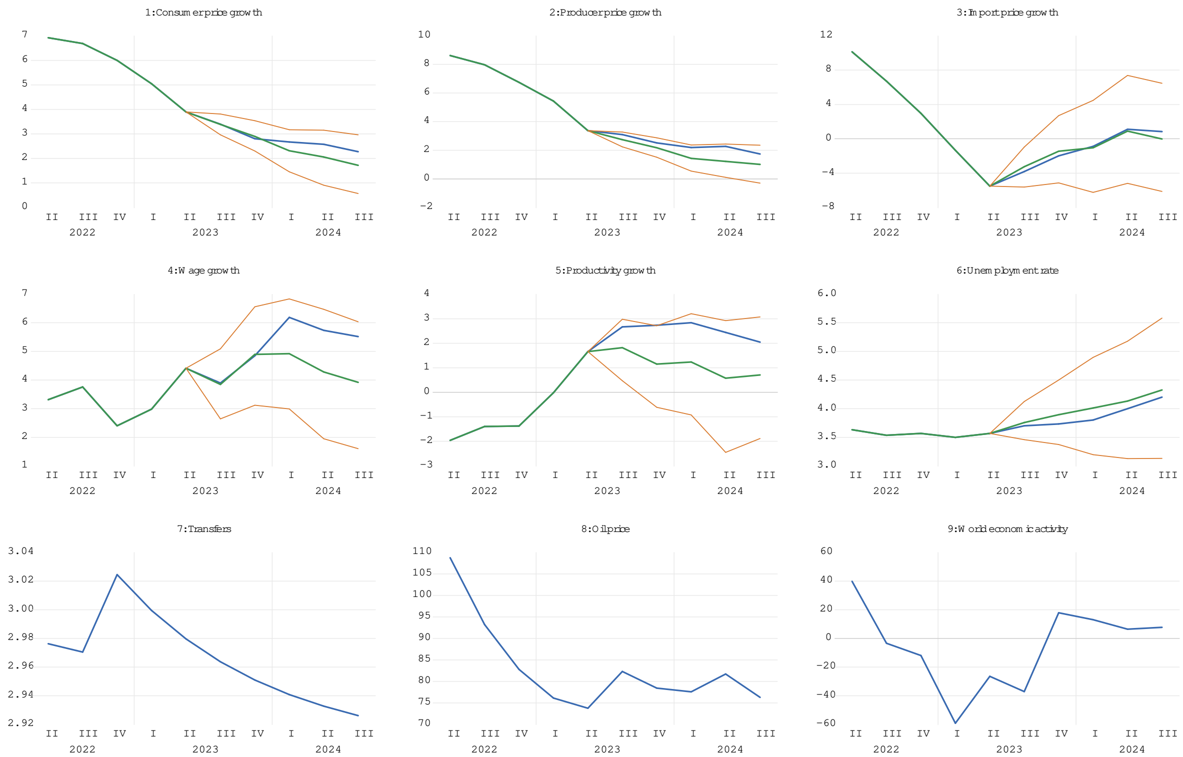


Figure 8: Dynamic model simulation 2023(3)-2024(3) conditional on $TRA$, $PO$ and $WAC$. The green line graphs show actuals, including the five last quarters of the estimation sample. The dashed lines (blue) are the point forecasts and the dotted (red) lines represent uncertainty bounds (90 %). Units: see Figure 6.

Panels 1. and 2. show that the inflation forecasts for the second half of 2023 were quite precise, but that inflation was higher than the model forecasts in 2024. Import price growth was well forecasted, as panel 3. shows. Panel 4. shows that also wage growth in 2024 was under-predicted by the model. Interesting to see though, there are no forecast failures for the nominal growth rates.

Productivity (panel 5) is under-predicted for the length of the forecast horizon, so it appears to be the weakest link in the chain. Re-estimation of the productivity equation with 2023(3)-2024(3) in the sample showed that the estimated constant term became reduced compared to equation (20). Therefore, as often found when forecast errors are analysed, a non-constant intercept appears to be a main culprit.

# 5 Conclusion

We have specified an empirical model of U.S. inflation which is built around a wage-price spiral core. In the model, producer prices and productivity are related to wage adjustments both in the short and in the long run, where the wage level is related to factors influencing industrial prosperity — the ability to pay in the firms that set wages ("rent sharing"), giving room for effects from both consumer and producer prices. Although the wage equation is therefore distinct from a wage Phillips curve, it includes other explanatory variables that are well known from studies of U.S. wage Phillips curves. The wage equation was tested for omission of the inflation expectation variable that Bernanke and Blanchard focus on, and it was found to be robust. This does not imply that a consolidated approach, with endogenous expectations, should not be attempted in further work.

The wage equation we have reported is not consistent with the view that wages became less responsive to labour market tightening during the Great Moderation and the Great Recession. Hence, empirical results about structural change in the direction of less wage responsiveness may be relative to the use of Phillips curves which are linear in the rate of unemployment and which omit the lagged wage-share (or other indicators of rent-sharing).

The model equation for producer prices includes an import price index and the price of oil in addition to wage costs and productivity. Over the sample, this equation was shown to have a high degree of parameter constancy. Since it is a quite simple relationship it is easy to think of possible omitted variables. A measure of supply chain pressure is perhaps the most topical after the pandemic. Although we did not find this factor to be statistically significant, when we tested, it should not be put to one side, given that other studies have concluded otherwise.

Dynamic model simulation showed that the model explained quite well the long-term behaviour of wages and prices over the four decades that include the Great Moderation and the Great Recession. The simulated fit of the model for this long period was aided by the relatively few, but still significant, location shifts that are included in the core equations. Those location shifts have the double interpretation as structural breaks, but also as conditioning factors that robustify the estimation of the derivative coefficients in the model equations that determine the dynamic multipliers and impulse responses.

The estimated equation for the producer price index is an example. It contains three step-dummies (for breaks in 1972(1), 1986(2) and 1999(1)) which helps the dynamic simulation of the complete model stay "on track". However, as Figure 3 showed, the coefficients of the economic explanatory variables in the equation are quite constant over the sample. As we see it, this type of constancy increases the relevance of the model for comparative dynamics.

Judged by the within sample dynamic simulation results, the complete model explained wage growth well during the first phase of the pandemic, as well as giving a reasonably good explanation of wage growth in 2021 and 2022. In the model, this would have been difficult to attain unless the model tracked productivity reasonably well, which it does. Keeping import price inflation in the model seems to reduce the need for a large domestic price shock to explain inflation in 2021 and 2022, although there was a considerable gap between actual and simulated inflation in 2022, which invites further modelling and development of the framework.

The model performed quite well when simulated out of sample, which also encourages further work, for example ways to make operational methods that can help protect model forecasts against the damages caused by intercept changes near the forecast origin.

# A Cointegrated VAR representation of WP-EqCM and PCM

In this appendix we consider only the SEM versions of WP-EqCM and PCM in section 2.1, as the addition of adaptive expectation does not contribute to the discrimination between the two models in the typology.

Using matrix notation, a multiple-equation model that encompasses the WP-EqCM and PCM can be formulated as:

$$\boldsymbol{A}_{s\,0}\Delta\boldsymbol{y}_t = \boldsymbol{\alpha}_s\boldsymbol{\beta}'\boldsymbol{y}_{t-1} + \sum_{i=0}^{p-1}\boldsymbol{A}_{s\,i+1}\Delta\boldsymbol{y}_{t-1-i} + \boldsymbol{C}_s\boldsymbol{D}_t + \boldsymbol{\varepsilon}_{st}, \tag{24}$$

where the vector $\boldsymbol{y}_t$ has five elements:

$$\begin{aligned} y_1 &= q, \\ y_2 &= w, \\ y_3 &= x, \\ y_4 &= pi, \\ y_5 &= z. \end{aligned}$$

The consumer price index $p$ is not included as an element in $\boldsymbol{y}_t$ because it has been substituted by the use of the definition (5). However, when a solution for $\boldsymbol{y}_t$ has been found, the associated solution for inflation $\Delta p_t$ is obtained by using the differenced version of (5), namely $\Delta p_t = \phi\Delta q_t + (1-\phi)\Delta pi$.

The matrix with contemporaneous coefficients is denoted $\boldsymbol{A}_{s0}$. The wage equation (1) was specified with $\Delta p_{t-1}$ as an explanatory variable, implying $p = 2$ in (24). Inclusion of longer lags than in the stylized model is unproblematic and is covered by the notation used in (24).

$\boldsymbol{D}_t$ represents deterministic terms and can include the intercept terms in the equations above, but also deterministic trend, seasonal dummies, impulse indicators and step-dummies. As mentioned in the main text, for some of the estimated equations, step-dummies can be restricted to be in the cointegration space.

$\boldsymbol{\alpha}_s$ is the $(5 \times 3)$ matrix with equilibrium correction coefficients. Row 4 and 5 consists of zeros while the upper $(3 \times 3)$ partition is diagonal with $-\theta_q$, $-\theta_w$,$-\theta_x$ as adjustment coefficients in the main diagonal. Compared to the main-text the only undefined symbol in $\boldsymbol{\alpha}_s$ is $\theta_x \geq 0$, which is introduced to encompass the two model types.

*WP-EqCM*

To simplify we consider the case of non negative adjustment coefficients, which puts the possibility of cobweb-type dynamic responses to one side. The WP-EqCM is defined by:

$$0 < \theta_w < 1,\ \ 0 < \theta_q < 1,\ \ 0 < \theta_x < 1.$$

For consistency with the notation used in the main text for the coefficients of $x_t$ and $x_{t-1}$ in the wage equation (6), we can define:

$$(\mu_{w1} + \mu_{w2}) = \upsilon\theta_w,\ \upsilon \leq 0,$$

in this model. The matrix $\boldsymbol{\beta}$ with the coefficients of the cointegration relationships is:

$$\boldsymbol{\beta} = \begin{pmatrix} 1 & -(1-\varpi(1-\phi)) & 0 \\ -1 & 1 & 0 \\ 0 & \upsilon & 1 \\ 0 & -\varpi(1-\phi) & 0 \\ 1 & -\iota & 0 \end{pmatrix}. \tag{25}$$

Subject to invertibility of $\boldsymbol{A}_{s0}$ the reduced form is:

$$\Delta \boldsymbol{y}_t = \boldsymbol{\alpha}\boldsymbol{\beta}'\boldsymbol{y}_{t-1} + \sum_{i=0}^{p-1} \boldsymbol{\Gamma}_i \Delta \boldsymbol{y}_{t-1-i} + \boldsymbol{C}\boldsymbol{D}_t + \boldsymbol{\varepsilon}_t, \tag{26}$$

where the matrices are:

$$\begin{aligned} \boldsymbol{\alpha} &= \boldsymbol{A}_{s0}^{-1}\boldsymbol{\alpha}_s \\ \boldsymbol{\Gamma}_i &= \boldsymbol{A}_{s0}^{-1}\boldsymbol{A}_{si} \\ \boldsymbol{C} &= \boldsymbol{A}_{s0}^{-1}\boldsymbol{C}_s \\ \boldsymbol{\varepsilon}_t &= \boldsymbol{A}_{s0}^{-1}\boldsymbol{\varepsilon}_{st} \end{aligned}$$

In the case of $p = 2$ the reduced form (26) becomes:

$$\boldsymbol{y}_t = (\boldsymbol{\alpha}\boldsymbol{\beta}' + \boldsymbol{I} + \boldsymbol{\Gamma}_1)\boldsymbol{y}_{t-1} - \boldsymbol{\Gamma}_1\boldsymbol{y}_{t-2} + \boldsymbol{C}\boldsymbol{D}_t + \boldsymbol{\varepsilon}_t, \tag{27}$$

The solution for $\boldsymbol{y}_t$ can be obtained by recursion forward from known initial conditions, $\boldsymbol{y}_0$,$\boldsymbol{y}_{-1}$, known values of $\boldsymbol{D}_t$ and by random numbers from the distribution of $\boldsymbol{\varepsilon}_t$ for $t = 1, 2, ..., T$.

The WP-EqEM solution for the wage share will in general be stable, while joint stability of the wage share and the wedge is more fragile, Kolsrud and Nymoen (2014),

In the specification above, $x_t$ as an autonomous $I(0)$ series. However, no inconsistency follows if we alternatively assume a two-way relationship between wage and price formation and $x_t$. For example, with suitable specifications of $\boldsymbol{A}_{s0}$ and $\boldsymbol{A}_{s1}$, the $x_t$ equation can include $\Delta p_t$ an $\Delta p_{t-1}$ (to mimic monetary policy responses to inflation). Another possibility is to assume that $x_t$ equilibrium corrects, for example with respect to the cointegration relationship $(w - q - z)_{t-1}(\equiv \bar{\omega}^{A}_{ft-1})$.

*PCM*

The defining assumptions for the PCM are:

$$\theta_w = 0, \;\; \theta_q = 0, \;\; 0 < \theta_x < 1.$$

Consistency with the notation for the coefficients of $x_t$ and $x_{t-1}$ in the wage equation is secured by applying the following definitions:

$$\mu_{w1} = \mu^{pcm}_{w1} \;\text{ and }\; \mu_{w2} = \mu^{pcm}_{w2}.$$

$-\mu^{pcm}_{w1}$ is element in the $\boldsymbol{A}_{s0}$ matrix in the PCM version of the model, while $\mu^{pcm}_{w2}$ is element in $\boldsymbol{A}_{s1}$ in this version.

Without making further assumptions $\boldsymbol{\beta}'$ is $(1 \times 5)$ vector with 1 in the third row and zeros elsewhere and $\boldsymbol{\alpha}$ is $(5 \times 1)$ with the adjustment coefficient of $x_t$ as the third element (the others are zero).

With this structure, the PCM-solution for the wage share will in general be unstable, Kolsrud and Nymoen (2014). However, there are possibilities for indirect equilibrium correction in wage-formation that may contribute to stabilization. For example if $x_t$ is assumed to depend on the lagged wage share, the stability properties will also be changed.

# B Bernanke and Blanchard's inflation model

## B.1 Model specification

The stylized model in Bernanke and Blanchard (2024), B&B, has four equations. Two of them are for short term and long term inflation expectations, given by (13) and (14) above.

The third equation connects the expected real wage $w_t - p^e_t$ to real wage ambitions, $\omega^A_t$, and a labour marked tightness variable $x_t$:

$$w_t - p^e_t = \omega^A_t + \beta x_t + \iota z_t,\ 0 < \iota \leq 1. \tag{28}$$

Trend productivity is implicit in the B&B model, where the wage level can be interpreted as trend-corrected. For easier comparison with the other models, we have include productivity, $z_t$, explicitly as a variable.[15]

$\omega^A_t$ is given by the equation:

$$\omega^A_t = \alpha\omega^A_{t-1} + (1-\alpha)(w_{t-1} - p_{t-1} - \iota z_{t-1}) + \epsilon_{wt}, 0 < \alpha < 1. \tag{29}$$

The term $\epsilon_{wt}$ is interpreted as the wage-shock variable. Note that in a hypothetical steady-state situation, setting $\epsilon_{wt} = 0$ for simplicity:

$$\omega^A = w - p - \iota z,$$

saying that the real-wage target is a (stable) wage share in steady state, if $\iota = 1$.

## B.2 Dynamic properties

(28) and (29) implies the wage equation:

$$\Delta w_t = \Delta p^e_t - \alpha\Delta p^e_{t-1} + \alpha\Delta p_{t-1} + \iota\Delta z_t + \beta(x_t - \alpha x_{t-1}) + \epsilon_{wt} \tag{30}$$

Inflation expectations are modelled by (13) and (14) in the main text.

(13) and (14) endogenize inflation expectations, not actual price level change. The complete their model, B&B start from the static price level equation:

$$p_t = w_t - z_t + \epsilon_{pt}$$

[15] The sign of the coefficient $\beta$ depends on the operational definition of $x_t$.

where $\epsilon_{pt}$ is in this context interpreted as a price-level shock. However, they use the differenced version as their model equation for price setting:

$$\Delta p_t = \Delta w_t - \Delta z_t + \Delta \epsilon_{pt} \tag{31}$$

(13),(14), (30) and (31) determine $\Delta w_t$, $\Delta p_t$,$\Delta p_t^e$ and $\pi_t^*$ from given initial conditions and conditional on exogenous time series for $x_t$, $z_t$,$\epsilon_{wt}$ and $\Delta \epsilon_{pt}$.

The model can be written as a two equation model after elimination of $\Delta p_t^e$ and $\Delta w_t$ by substitution (using (13) and (31)).

$$\pi_t^* = \gamma \pi_{t-1}^* + (1-\gamma)\Delta p_{t-1} \tag{32}$$

$$\begin{aligned}\Delta p_t = {} & \delta \pi_t^* - \alpha\delta\pi_{t-1}^* + (1-\delta+\alpha)\Delta p_{t-1} - \alpha(1-\delta)\Delta p_{t-2} \\ & + (\iota - 1)\Delta z_t + \beta(x_t - \alpha x_{t-1}) + \epsilon_{wt} + \Delta\epsilon_{pt}\end{aligned} \tag{33}$$

The companion form is:

$$\begin{pmatrix} \pi_t^* \\ \Delta p_t \\ \pi_{t-1}^* \\ \Delta p_{t-1} \end{pmatrix} = \begin{pmatrix} \gamma & 1-\gamma & 0 & 0 \\ \delta(\gamma-\alpha) & \alpha - \delta\gamma + 1 & 0 & \alpha(\delta-1) \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} \pi_{t-1}^* \\ \Delta p_{t-1} \\ \pi_{t-2}^* \\ \Delta p_{t-2} \end{pmatrix} + \begin{pmatrix} 0 \\ f(t) \\ 0 \\ 0 \end{pmatrix} \tag{34}$$

where $f(t)$ in the non-homogenous part is given by:

$$f(t) = (\iota-1)\Delta z_t + \beta(x_t - \alpha x_{t-1}) + \epsilon_{wt} + \Delta\epsilon_{pt} \tag{35}$$

The eigenvalues of the companion matrix:

$$r_1 = 1; r_2 = 0; r_3 = \gamma(1-\delta), r_4 = \alpha. \tag{36}$$

The vector time series does not have a (globally asymptotically) stable solution, due to the real root of unity, Nymoen (2020, p 144).

Sali (2024) shows that when the system is written with variables in levels, it is a cointegrated I(2) system. Interestingly, the choice of using (31) and not the original equation in levels is consequential. Sali shows that in this case, differencing a static model equation increases the degree of integration from $d = 0$ to $d = 2$, not to $d = 1$.

That the solution for all admissible structures, values of $\alpha$,$\delta$,$\gamma$, does not imply that the values of the three model parameters are unimportant for the implied response functions with respect to an inflation shock. B&B show that a structure they dub weak feed-back, $\alpha = 0.2$, $\delta = 0.9$, $\gamma = 0.94$, gives a response function for inflation with rapidly diminishing values. Another structure, called strong feed-back($\alpha = 0.6$, $\delta = 0.7$, $\gamma = 0.9$), gives responses that decline more slowly. Hence, the different structures have important implications for the degree of inflation persistence.

What the structures have in common is that the values of the response functions converge to a positive value, which is largest in the strong feed-back case. The positive responses, even long after the shock happened, are implied by a common feature, namely the unit root mentioned above, which transforms any temporary shock to a non-zero long-run response.

Since the model is dynamically unstable conditional on the $x$ variable, which can be the rate of unemployment, an interpretation is that the long-run Phillips curve is vertical. Hence, in order to bring the long-run response down to zero, increased $x$ is required. The interpretation is also that the catch-up and expectation structures determine how costly a disinflation becomes.

## B.3 Comparison with WP-EqCM

To make the dynamic properties of WP-EqCM and B&B as comparable as possible, we assume that expectation formation is the same in the two models. We therefore set $\psi_{wp1} = \psi_{wp2} = 0$ in the WP-EqCM model. Finally we simplify the WP-EqCM so that it too is a closed economy model ($\phi = 1$ and $\psi_{qpi} = 0$).

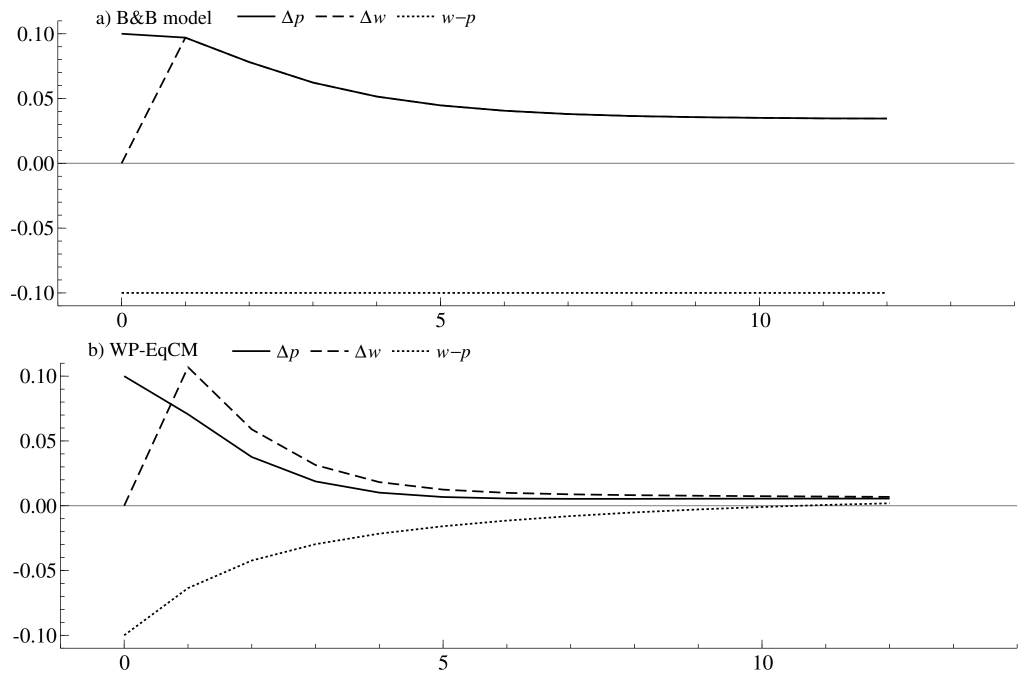


Figure 9: Inflation responses to a 1-period shock to $\Delta p_t$ in the stylized Bernanke and Blanchard model and the stylized WP-EqCM model (lower panel). Strong feed-back in expectation formation in both models.

Because of the three parameters $\theta_w$,$\theta_p$ and $\psi_{qw}$ in the WP-EqCM model, the dynamic responses to an inflation shock will be different from the B&B model responses. Figure 9 gives an illustration for the case with strong feed-back and EqCM-parameters $\theta_w = 0.1$,$\theta_p = 0.15$ and $\psi = 0.8$.

The figure shows that the instantaneous responses are identical. In particular, because of the lagged inflation expectations, there is no wage response in the period when the inflation shock hits and increase inflation by 0.1. However, the dynamic responses are different for the two models. In the B&B model, starting in the first period after the shock, the inflation responses are identical to the wage responses. This is a consequence of the somewhat over-stylized price equation in that model. The implication is that the real wage $w - p$ is never compensated for the initial reduction, and is permanently reduced by 0.1.[16]

In the EqCM version the responses show that wage earners are able to catch-up over time so that the real wage is brought back to its initial level (note that firms are still able to roll 0.8 of each "round of" wage increases). Therefore dynamic response in wage inflation is

[16]The real wage response does not depend on the values of any of the three parameters $\alpha$, $\delta$,$\gamma$.

higher than in price inflation for a long time. However, this is not associated with a run-away wage-price spiral in this model. Instead, the long-run inflation responses are lower than for the PCM-model.

# C Empirical equations for oil price, and world economic activity

**Oil price**

$$\begin{aligned}\Delta po_t = \; & \underset{(0.045)}{0.27}\, \Delta po_{t-1} + \underset{(0.00012)}{0.00051}\, \Delta_4\, WAC_t + \underset{(0.065)}{0.53}\, \mathrm{DI}_{1974(1)t} \\ & + \underset{(0.089)}{0.29}\, \mathrm{II}_{1979(3)t} - \underset{(0.089)}{0.55}\, \mathrm{II}_{1986(1)t} \\ & + \underset{(0.089)}{0.45}\, \mathrm{II}_{1990(3)t} + \underset{(0.063)}{0.26}\, \mathrm{DI}_{1990(4)t} + \underset{(0.089)}{0.29}\, \mathrm{II}_{1999(2)t} \\ & + \underset{(0.063)}{0.21}\, \mathrm{DI}_{2003(1)t} - \underset{(0.063)}{0.53}\, (\mathrm{DI}_{2008(4)t} - \mathrm{DI}_{2009(1)t}) \\ & + \underset{(0.036)}{0.28}\, (\mathrm{SI}_{2014(3)t} - \mathrm{SI}_{2015(1)t} + \mathrm{DI}_{2015(2)t} - \mathrm{DI}_{2016(1)t}) \\ & - \underset{(0.063)}{0.48}\, \mathrm{DI}_{2020(2)t} + \underset{(0.0061)}{0.011}\end{aligned} \qquad (37)$$

| | |
|---|---|
| OLS 1969(1) − 2023(2) | $\hat{\sigma} = 0.09$ |
| AR 1-5 test: | $F(5, 200) = 1.5[0.19]$ |
| ARCH 1-4 test: | $F(4, 210) = 3.42[0.85]$ |
| Normality test: | $\text{Chi}^2(2) = 7.20[0.03]$ |
| Hetero test: | $F(29, 188) = 3.21[0.00]$ |

**World economic activity**

$$
\begin{aligned}
WAC_t \; = \; & \underset{(0.029)}{0.91}\; WAC_{t-1} - \underset{(0.022)}{0.17}\; (WAC_{t-5} - WAC_{t-6} + WAC_{t-7}) \\
& + \underset{(12)}{52}\; \mathrm{DI}_{2015(3)t} + \underset{(14)}{86}\; \mathrm{DI}_{2019(3)t} \\
& + \underset{(14)}{69}\; \mathrm{DI}_{2019(4)t} + \underset{(13)}{56}\; \mathrm{DI}_{2020(3)t} - \underset{(19)}{216}\; \mathrm{II}_{2008(4)t} \\
& - \underset{(5.4)}{29}\; \mathrm{SI}_{2004(2)t} - \underset{(9.9)}{33}\; \mathrm{SI}_{2008(3)t} + \underset{(9.6)}{66}\; \mathrm{SI}_{2009(4)t} \\
& + \underset{(17)}{65}\; \mathrm{SI}_{2011(4)t} - \underset{(17)}{65}\; \mathrm{SI}_{2012(1)t} + \underset{(6.2)}{23}\; \mathrm{SI}_{2013(4)t} \\
& - \underset{(6.2)}{23}\; \mathrm{SI}_{2016(1)t} - \underset{(11)}{40}\; \mathrm{SI}_{2020(3)t} + \underset{(11)}{40}\; \mathrm{SI}_{2021(2)t} \qquad (38) \\
& + \underset{(3.3)}{6.1} - \underset{(3.3)}{19}\; \mathrm{Seasonal}_t - \underset{(3.2)}{5.9}\; \mathrm{Seasonal}_{t-1} \\
& - \underset{(3.3)}{18}\; \mathrm{Seasonal}_{t-2}
\end{aligned}
$$

| | |
|---|---|
| OLS 1970(1) − 2023(2) | $\hat{\sigma} = 16.55$ |
| AR 1-5 test: | $F(5, 192) = 1.84[0.11]$ |
| ARCH 1-4 test: | $F(4, 206) = 3.88[0.005]$ |
| Normality test: | $\mathrm{Chi}^2(2) = 1.21[0.55]$ |
| Hetero test: | $F(27, 186) = 0.64[0.92]$ |

The dummies in the two equations can be used to test the relative invariance and super exogeneity of the model equations that condition on oil price and world economic activity, see Engle and Hendry (1993) and recent applications of semi-automatic tests e.g., Castle et al. (2023) among others.

For example, when the 15 dummies in the oil-price equation are added to the $\Delta q_t$ equation (18) in the main text, the estimate of the coefficient of $\Delta_2 po_t$ becomes 0.0082, which is insignificantly larger than 0.0076 in (18). The coefficients of the other explanatory variables are (also) practically unchanged, strengthening the interpretation of relative invariance. However, the joint test, interpretable as a super exogeneity test, is significant at the 2.5 % level: F(15,200) = 1.7844 [0.0389]. Inspection shows that the only dummy the impulse indicator for 1974(1), which could therefore be included in the conditional model without altering the interpretation. The joint test of the 14 other dummies gives; F(14,200) = 1.3765 [0.1672].

Applying the same testing method to the import price equation (21), as well as to the unemployment equation (22) and the capacity utilization equation (23) with respect to the dummies in the WAC equation (38), yields similar evidence of relative invariance, while also suggesting that a small number of quarter-specific indicators could be included in the conditional model equations.

# D IV estimation of the model equations for wage, price and productivity

The structure of the multiple equation model shows that $\Delta z_t$ is an endogenous explanatory variable in wage equation (39). The only other contemporaneous explanatory variable in the equation is $\Delta p_t$, which is pre-determined given the structure of the complete model. However, other structures that would imply endogeneity of $\Delta p_t$ is probably also data admissible.

To investigate robustness with respect to estimation method, equation (39) shows IV-estimation results when $\Delta z_t$ and $\Delta p_t$ have been instrumented by six explanatory variables in the two respective model equations. Five of the instrument are lagged, only $\Delta pi_t$ is contemporaneous.

$$\begin{aligned}
\Delta w_t = & -\underset{(0.06)}{0.23}\ \Delta w_{t-1} + \underset{(0.17)}{0.40}\ \Delta z_t + \underset{(0.10)}{0.28}\ \Delta q_{t-1} + \underset{(0.12)}{0.67}\ \Delta p_t \\
& + \underset{(0.009)}{0.032}\ 1/U_{t-3} - \underset{(0.016)}{0.084}\ [w - q - 0.82z]_{t-1} \\
& + \underset{(0.0065)}{0.03}\ II_{2000(1)t} + \underset{(0.0047)}{0.023}\ DI_{2008(4)t} + \underset{(0.0045)}{0.017}\ DI_{2012(4)t} \\
& + \underset{(0.0083)}{0.046}\ II_{2020(2)} - \underset{(0.0018)}{0.0018}
\end{aligned} \tag{39}$$

| | |
|---|---|
| IVE 1967(1) − 2023(2) | $\hat{\sigma}100 = 0.63$ |
| Sargan-IV: | $\chi^2(4) = 4.06[0.40]$ |
| Additional instruments : | |
| $(z - 1.2(w - q) + 0.07pi)_{t-1}, \Delta pi_t, \Delta pi_{t-1}$ | |
| $(p - 0.96q - 0.04pi + tra)_{t-1}, \Delta q_{t-2}, \Delta q_{t-3}$ | |

The results show that the coefficients of $\Delta p_t$ and $\Delta z_t$, the two endogenous explanatory variables, are somewhat inflated compared to the OLS estimates, as often is the case. The specification test (4 over-identifying instruments) is insignificant, in support of the validity of the instruments.

In the price equation (18), $\Delta z_t$ is an endogenous explanatory variable. The IV estimates in (40) shows only minor deviations from the OLS estimates reported in the main text.

$$
\begin{aligned}
\Delta q \;=\; & \underset{(0.021)}{0.22}\ \Delta_2 q_{t-2} - \underset{(0.077)}{0.20}\ \Delta z_t + \underset{(0.009)}{0.033}\ \Delta pi_{t-2} \\
& + \underset{(0.0011)}{0.0069}\ \Delta_2 po_t + \underset{(0.011)}{0.027}\ \Delta capu_{t-2} \\
& - \underset{(0.01)}{0.11}\ [q_{t-1} - 0.69 w_{t-1} + 0.21(z - pi)_{t-1} \\
& \qquad + 0.04(po_{t-1} - (SI_{72(1)t} + SI_{86(2)t} + SI_{99(1)t})] \\
& + \underset{(0.003)}{0.013}\ \mathrm{II}_{98(1)t} + \underset{(0.002)}{0.019}
\end{aligned} \tag{40}
$$

IVE 1967(4) − 2023(2) $\hat{\sigma}100 = 0.69$
Sargan-IV: $\chi^2(5) = 4.43[0.49]$
Additional instruments :
$(w - 0.82z - q)_{t-1}, \Delta w_{t-1}, \Delta q_{t-1}, (1/u)_{t-3}$
$(z - 1.2(w - q) + 0.07pi)_{t-1}, \Delta pi_{t-2}$

When it gets to the productivity growth equation, the complete model implies that $\Delta(w-q)_t$ is an endogenous explanatory variable. In the IVE-estimation, we de-restricted $\Delta(w-q)_t$ to better see the robustness of the two endogenous explanatory variables with respect to IV-estimation. The results in equation (41) show that both variables are significant. Although there is a difference in the magnitudes of the two coefficients, the more concise representation $\Delta(w-q)_t$ is defensible also based on these results.

$$
\begin{aligned}
\Delta z_t \;=\; & \underset{(0.12)}{0.23}\ \Delta w_t \underset{(0.18)}{-0.34}\ \Delta q_t - \underset{(0.021)}{0.058}\ \Delta pi_{t-1} + \underset{(0.0018)}{0.0081}\ u_t \\
& - \underset{(0.016)}{0.1}\ [z_{t-1} - 1.2(w-q)_{t-1} + 0.07 pi_{t-1}] - \underset{(0.0032)}{0.01}
\end{aligned} \tag{41}
$$

IVE 1967(4) − 2023(2)$\hat{\sigma}100 = 0.67$
Sargan-IV:$\chi^2(5) = 1.02[0.96]$
Additional instruments :
$(w - 0.82z - q)_{t-1}, \Delta q_{t-1}, (1/u)_{t-3}$
$(p - 0.96q - 0.04pi + tra)_{t-1}, \Delta_3 \Delta tra_t, \Delta_2 \Delta q_2,$
$(q_{t-1} - 0.69w_{t-1} + 0.21(z - pi)_{t-1}$
$+0.04(po_{t-1} - (SI_{72(1)t} + SI_{86(2)t} + SI_{99(1)t})\qquad)$

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