# Department of Economics

## Modelling of the Inflation-Unemployment Tradeoff from the Perspective of the History of Econometrics

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## Abstract

This paper examines the history of econometrics through a particular case study — modelling the tradeoff between inflation and unemployment. It focuses on the questions of what econometric tools modellers would choose to model the tradeoff, how their choices helped shape the ways that they obtained, interpreted and theorised the empirical evidence and how their different concerns and the different problems that they encountered has fed back into the development of econometrics. The study reveals that much of the interaction between econometrics and economics involved modellers taking certain tradeoffs between theory and data, and their different positions generated disputes, factions as well as confusions. It also reveals that the history of modelling the tradeoff mirrors the evolving process of how the Cowles structural modelling paradigm in econometrics became consolidated, challenged, reformed or abandoned.

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This paper examines the history of econometrics through a case study — modelling the tradeoff between inflation and unemployment. The tradeoff, often referred to as the Phillips curve, has remained a vibrant research topic for half a century. Skimming through the literature, one is soon lost in a labyrinth of entangling economic and econometric issues and debates. Although the topic has been reviewed and surveyed periodically, little is available on the econometric side.[1]

The present study focuses on how econometrics was practised in modelling the tradeoff during the three decades after Phillips' 1958 seminal paper. The study is motivated particularly by a number of questions. What econometric tools were chosen by modellers to model the tradeoff? How did their choices help shape the ways that they obtained, interpreted and theorised the empirical evidence? How did their different concerns and the different problems that they encountered feed back into the development of econometrics? We start from a brief description of the original Phillips curve and its early extensions (see section 1); we then look at wage and price models developed almost in parallel to the Phillip curve (section 2) and the rise of the inverse Phillips curve led by Lucas nearly a decade later (section 3); subsequent research trends up to the late 1980s is outlined in section 4; the last section assesses the impact of the major works examined in sections 1-3 and the implications of modelling the Phillips curve on the history of econometrics.

## 1 Phillips Curve

The Phillips curve is named after a single-equation empirical model built by A.W.H. Phillips (1958).[2] The model relates wages negatively to unemployment. Based on a scattered diagram of the two time series using the UK annual data for the period 1861-1957

[1] The following is a list of reviews and surveys: Goldstein (1972), Lipsey (1978), Santomero and Seater (1978), Desai (1984), Gordon (1990; 2008), Berndt (1991, Chapter 10), Cross (1995), Leeson (2000), Mankiw (2001), Sims (2008); among them, Desai (1984) is the closest to the present discussion.

[2] For a more detailed historical account of the Phillips curve, see Wulwick (1987) and also the contributions by Klein, Laidler, Lipsey, Yamey in Leeson (2000).

net of the interwar period, Phillips conjectured a hyperbolic function between the growth rate of wages, *w*, and unemployment rate, *U*:

$$\left(\frac{\Delta w}{w} - a\right) = bU^{z} \tag{1}$$

where $\Delta$ denotes a difference, $(\Delta w / w - a)$ denotes the mean-adjusted wage rate and parameters *a*, *b*, *z*, are expected to satisfy $a > 0, b > 0, z < 0$. Equation (1) was transformed into a log-linear form for estimation:

$$\ln\left(\frac{\Delta w}{w} - a\right) = \ln(b) + z\ln(U) \tag{1′}$$

Phillips estimated (1′) by a novel procedure: he reduced the first 53 observations of the sample into 6 averages to estimate *b* and *z* while he chose the value of *a* by graphical inspection through trial and error (see Gilbert, 1976 for a detailed discussion on the procedure). Crucially, *z* was found to be significantly negative. The fitted equation was shown to give good forecasts of the subsequent sub-sample.

Phillips' econometric work was *ad hoc* and unorthodox if judged by the Cowles Commission structural modelling approach developed recently (see Qin, 1993; 2008). But that did not deter his model from being recognised almost immediately by Samuelson and Solow (1960), who helped to popularise the model among macroeconomists and make it known as the Phillips curve, eg via textbooks.

Phillips' econometric work was elaborated by Lipsey (1960). Apart from providing a theoretical explanation of the wage-unemployment trade-off, Lipsey carried out extensive statistical analysis to bring Phillips' model closer to 'standard statistical methods'. In particular, he proposed a different functional form to (1), introducing a reciprocal format for the unemployment variable:

$$\frac{\Delta w}{w} = a + b\frac{1}{U} + c\frac{1}{U^2}$$
$$\frac{\Delta w}{w} = a + b\frac{1}{U} + c\frac{1}{U^2} + d\frac{\Delta U}{U} \tag{2}$$

Model (2) was fitted to data with different samples/sub-samples and the results were compared mainly by $R^2$. The changing rate of unemployment, $d\frac{\Delta U}{U}$, in the second equation was added on the ground that the rate was normally uncorrelated with the level and thus deserved separate consideration. To verify its significance, Lipsey performed an auxiliary regression of the residuals from the first equation on the changing rate of unemployment, ie (parameters with 'hat' indicate estimates):

$$(2') \qquad \frac{\Delta w}{w} - \left( \hat{a} + \hat{b}\frac{1}{U} + \hat{c}\frac{1}{U^2} \right) = d\frac{\Delta U}{U}$$

Note that the above treatment was in tune with the specification bias analysis by Griliches (1957) and Theil (1957), though neither work was referred to in Lipsey (1960).

Lipsey also examined the possible effect of the cost of living on wages. This was initially tested via a scatter diagram between the residuals of the second equation in (2) and the real wage rate, i.e. money wage rate net of inflation, $\Delta p / p$, where $p$ stood for consumer price index (CPI). The examination led to an augmentation of (2) and further experiments with the following variations over different sample periods:

$$(3) \qquad \begin{aligned} \frac{\Delta w}{w} &= a + b\frac{1}{U} + c\frac{1}{U^2} + d\frac{\Delta U}{U} + e\frac{\Delta p}{p} \\ \frac{\Delta w}{w} &= a + b\frac{1}{U} + c\frac{1}{U^2} + e\frac{\Delta p}{p} \\ \frac{\Delta w}{w} &= a + b\frac{1}{U} + d\frac{\Delta U}{U} + e\frac{\Delta p}{p} \\ \frac{\Delta w}{w} &= a + b\frac{1}{U} + c\frac{1}{U^4} + d\frac{\Delta U}{U} + e\frac{\Delta p}{p} \end{aligned}$$

Lipsey stated in footnotes that no evidence of residual autocorrelation was found during the experiments though no specific tests were presented. In short, the experiments showed that inflation was significant but estimates of its parameter, *e*, were found to be far less than one to warrant the postulate of relating unemployment to real wage directly, and that the parameter estimates would vary with changing samples, casting doubt on the over-time constancy of the wage–unemployment tradeoff.

Formal statistical tests of the constancy by means of Chow tests were carried out by Perry (1964; 1966) when he modelled the Phillip curve using the US data. Perry also applied Durbin-Watson test for residual autocorrelation diagnosis. Perry followed Lipsey's model specification approach closely rather than that of Klein and Ball (1959) (see the next section), though he cited the latter work. Similar to Lipsey, Perry experimented with several variations of (3), and also with adding other variables, such as rates of productivity and profit rates. Following Dicks-Mireaux and Dow (1959) (see the next section), Perry explored fitting the model with disaggregate data, eg for the durable-goods industry and the nondurable-goods industry separately. Perry's main finding was in favour of modelling the tradeoff at disaggregate levels using multiple explanatory variables.

In short, the econometric side of the Phillips curve has been significantly formalised through the works of Lipsey and Perry. In particular, Lipsey's work helped to stimulate the research towards more explicit dynamic specification (eg see Desai, 1975), whereas Perry's work encouraged more disaggregate and micro data studies.

## 2 Price and Wage Modelling

Around the time Phillips was working on his 1958 paper at LSE, Klein was heading a project of building a quarterly UK econometric model at Oxford University (see Klein *et al*, 1961). One side-product of the project was a paper by Klein and Ball (1959) on modelling the price and wage relationship.

The Klein-Ball price and wage model was exemplary of the Cowles Commission paradigm – a four-equation SEM (simultaneous-equation model) for wage, price, earning to wage differential and work hours. The wage equation, key to the model, took a linear form

explaining annual wage change mainly by the annual average unemployment, the annual average inflation and a policy dummy $F$:[3]

$$\Delta w_t = \alpha_0 + \frac{\alpha_1}{4}\left(U_t + U_{t-1} + U_{t-2} + U_{t-3}\right) + \frac{\alpha_2}{4}\left(\Delta p_t + \Delta p_{t-1} + \Delta p_{t-2} + \Delta p_{t-3}\right) + \alpha_3 F_t \quad (4)$$

Note that (4) is defined by quarterly data, where $\Delta$ denotes annual difference, e.g. $\Delta w_t = w_t - w_{t-4}$. LIML (limited information maximum likelihood) was used in estimation since price endogenous (sample coverage 1948-1956). OLS estimates were also calculated and the results were 'hardly distinguishable' from those LIML estimates (see footnote on p474). Residual autocorrelation was checked by von Neumann ratio and Durbin-Watson test.

Among other things, a significantly negative parameter was estimated of the unemployment variable in (4). The finding corroborated the Phillips curve, in spite of the difference between (1) and (4) in terms of variable definition, choice of explanatory variables, functional forms, sample periods, data frequency and estimation methods. Klein and Ball actually compared their results to Phillips' (1958) briefly and disapproved of his nonlinear functional form. However, Klein later adopted the log-linear form in modelling wage and price (Klein, 1967).

An influential study which probably helped the wide adoption of the log-linear form was carried out by Dicks-Mireaux and Dow (1959). With UK quarterly data at hand, they postulated the following basic model between annual wage growth rate and annual inflation:

$$\ln(w_t) - \ln(w_{t-4}) = \alpha_0 + \alpha_1\left[\ln(p_t) - \ln(p_{t-4})\right] + \alpha_2 \ln(d_t) + \varepsilon_t \quad (5)$$

where $d>0$ denotes an index of the excess labour demand using primarily unemployment and vacancy data (see Dow and Dicks-Mireaux, 1958) and $\varepsilon$ is an error term. The model was estimated by two methods: the OLS and the method of quasi-differencing the variables

[3] The original equation also includes quarterly dummies; these are omitted here for simplicity.

proposed by Cochrane and Orcutt (1949) for correction of residual autocorrelation. The two sets of estimates were found not to differ significantly. Again, Durbin-Watson test was used for checking residual autocorrelation.

In fact, a considerable part of Dicks-Mireaux and Dow's study was devoted to verifying the 'precise form' of model (5) and its robustness. They experimented with different variations, including altering dynamic formulations via the time lags of the variables, e.g. using biannual difference instead of annual ones, and adding new variables such as the trade union effect. Moreover, they estimated the model with disaggregate data, e.g. data of sub-industry groups, in order to check the validity of the coefficient estimates of the aggregate model. Dicks-Mireaux and Dow also discussed, under the issue of identification, the validity of assuming the causal direction of price → wage. Their defence for the assumption was mainly built on the observed time lag in the data formation between price and wage changes. Meanwhile, they recognised the possibility of wage having feedback effect on price, but argued that the possibility implied a recursive system and that the second estimation method (i.e. the Cochrane-Orcutt method) should suffice such a system. Dicks-Mireaux and Dow acknowledged that price could be dependent on import costs and other factors, and related the issue to Klein-Ball's model (1959).

Notably, Dicks-Mireaux and Dow's discussion on identification covers the most important epistemic aspects of the issue – simultaneity and endogeneity, and their discussion on the latter including both the dynamic feedback formation and the variable coverage of a structural model. At the same time, however, they have circumvented totally the identification conditions formalised by the Cowles Commission.

A synergy of the Klein-Ball model and the Dicks-Mireaux-Dow model search approach was made by Sargan (1964). Intending initially to develop and compare estimation methods for SEMs with autocorrelated residuals, Sargan devoted the first part of

his paper to theoretical discussion on the relevant econometric techniques, including an IV (instrumental variables) estimator, its computation methods and a general way of testing residual autocorrelation. However, Sargan shifted his attention to model specification search when he came to applying his IV estimator. In the second part of his paper, Sargan closely examined the Klein-Ball model (4) and proposed to simplify it to:

(4′) $$w_t - w_{t-1} = \alpha_0 + \alpha_1 U_t + \alpha_2 \Delta p_t + \alpha_3 F_t$$

He then modified and extended (4′) to:

(6) $$w_t - w_{t-1} = \alpha_0 + \alpha_1 U_{t-1} + \alpha_2 \left(p_{t-1} - p_{t-4}\right) + \alpha_3 \left(w - p\right)_{t-1} + \alpha_4 F_t + \alpha_5 t$$

in order to take into consideration the real wage effect (*w*-*p*) and a possible time trend effect, *t*, as well as to circumvent simultaneity by lagging the unemployment and inflation variables. Note that the real wage effect was added by reference to Dicks-Mireaux and Dow (1959). Remarkably, the way this effect was specified in (6) introduced an error-correction mechanism (ECM) centred on an imposed long-run wage-price homogeneity ($\alpha_3 < 0$ was expected). Equation (6) was estimated by three methods, autoregressive LS, OLS and IV. Results of the first two were similar whereas those of the third showed much larger standard errors. Sargan thus abandoned the IV method as 'there seemed little point in trying to find a better set of instrumental variables' (p39).

The unimpressive IV estimates turned Sargan's subsequent attention fully to model specification search. The search was mainly judged by the criterion of achieving white-noise residuals. Sargan began the search by converting to the log-linear functional form following Dicks-Mireaux and Dow (1959), and experimented with adding new variables, such as a productivity index, and altering the lag lengths. The experiments ended in:

(6′) $$\ln\left(\frac{w_t}{w_{t-1}}\right) = \alpha_1 \ln\left(U\right)_{t-4} + \alpha_3 \ln\left(\frac{w}{p}\right)_{t-1} + \alpha_5 t + \alpha_6 \ln\left(\frac{w_{t-1}}{w_{t-2}}\right) + \alpha_7 \ln\left(\frac{w_{t-2}}{w_{t-3}}\right).$$

Sargan then examined the dynamic properties of the wage rate via transformation of (6′) into a weighted moving average of past unemployment and prices. The economic implication was discussed via the long-run static solution:

$$\ln\left(\frac{w}{p}\right) = -\frac{\alpha_1}{\alpha_3}\ln(U) - \frac{\alpha_5}{\alpha_3}t \tag{7}$$

embedded in (6′). Sargan's (1964) work was to become the prototype of the LSE school of dynamic specification approach fledged nearly two decades later (see section 4). Prior to that, however, his work has been relatively under heeded.

## 3 Inverse Phillips Curve

A new wave of interest in modelling the Phillips curve emerged around the turn of 1970, precursory of the rational expectations (RE) movement. Two aspects of the Phillips curve, at least, sustained the interest – the dynamic nature of the inflation-unemployment tradeoff and the interpretability of the unemployment variable as representing the real sector demand/supply gap. A dominant figure leading the new wave is R.E. Lucas.

Lucas first engaged himself in empirical studies of aggregate labour supply and demand with the main intention to discriminate between Keynesian employment theory versus the neoclassical theory. In a joint work with Rapping (see Lucas and Rapping, 1969a), a conventional SEM of labour demand and supply was set up and augmented by Phelps' (1967) expectations hypotheses. More precisely, adaptive expectations for price, $p$, and wage, $w$, were assumed which resulted in the labour supply equation taking a partial adjustment form (defined by employment, $L$, per household, $H$). The same form was assumed of the demand equation (defined by quality weighted employment per output, $Y$, where an index $Q$ was used to represent labour quality) on the simple justification that lagged employment and output had been empirically shown to be significant in demand equations. The labour demand-supply gap defined unemployment rate, $U$, resulting in an

inverse Phillips curve — unemployment being explained by wage rate and inflation,[4] as shown in the last equation of the following three-equation structural model:

$$
\begin{aligned}
&\underset{\text{labour demand}}{\ln\left(\frac{LQ}{Y}\right)_t} = \beta_{10} - \beta_{11}\ln\left(\frac{w}{Q}\right)_t + \beta_{12}\ln\left(\frac{LQ}{Y}\right)_{t-1} + \beta_{13}\Delta\ln(Y)_t + u_{1t} \\
&\underset{\text{labour supply}}{\ln\left(\frac{L}{H}\right)_t} = \beta_{20} + \beta_{21}\ln(w)_t - \beta_{22}\ln(w)_{t-1} + \beta_{23}\Delta\ln(p)_t + \beta_{24}\ln\left(\frac{L}{H}\right)_{t-1} + u_{2t} \\
&U_t = \beta_{30} - \beta_{31}\Delta\ln(w)_t - \beta_{31}\frac{\beta_{23}}{\beta_{21}}\Delta\ln(p)_t + \beta_{24}U_{t-1} + u_{3t}
\end{aligned}
\qquad (8)
$$

where $u_i$ were error terms and where most of the coefficients had expected signs or magnitude range conditions, eg $\beta_{31} > 0$ and $0 < \beta_{24} < 1$. Assuming wage endogenous, Lucas and Rapping estimated (8) by 2SLS (two-stage least squares) using annual US data of 1930-1965. They interpreted, as corroboration of their theoretical model, the relatively good fit of (8) and the basic confirmation of those significant coefficient estimates within their expected restrictions. In particular, the inflation variable in the unemployment equation was found significant, confirming to what was expected of a negative tradeoff. Interestingly, Lucas and Rapping stated that (8) was selected from estimations of a number of variants of their basic theoretical model, variants such as adding an interest rate variable, a wartime dummy and a time trend to one of the three equations at a time.

Subsequently, Lucas and Rapping extended the inverse Phillips curve in (8) by introducing alternative forms of the price expectations (1969b). In addition to the simple adaptive expectation scheme,[5] the RE hypothesis was postulated, which led to an ADL (autoregressive distributed lag) equation of unemployment:

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[4] Actually, Klein (1967) makes unemployment endogenous by adding an autoregressive unemployment equation, though without expectations theory to interpret the equation. However, a much earlier precedent to the inverse Phillips curve is Fisher's 1926 work (see Fisher, 1973).

[5] A simple adaptive expectation of price amounts to assume: $\ln(p_t^*) = \lambda\ln(p_t) + (1-\lambda)\ln(p_t^*)$, where $p^*$ denotes permanent price.

$$
\begin{aligned}
\ln\left(p_t^*\right)_{\text{rational expectations}} &= \sum_{i=0} b_i \ln\left(p_{t-i}\right) + \sum_{j=1} a_j \ln\left(p_{t-j}^*\right); \qquad \sum b_i + \sum a_j = 1 \\
\Rightarrow \quad U_t &= \beta_0 + \sum_{i=0} \beta_{1i} \Delta \ln\left(w_{t-i}\right) + \sum_{i=0} \beta_{2i} \Delta \ln\left(p_{t-i}\right) + \sum_{j=1} \beta_{3j} U_{t-j} + u_t
\end{aligned} \tag{9}
$$

Annual US data of 1900-1965 were used and sub-sample estimates of the two alternative unemployment equations were obtained. The results rendered more support to the one in (9) than that in (8), and were interpreted in favour of the RE hypothesis. The long-run static solutions and accompanying significance test statistics (eg the hypothesis of $\sum \beta_{2i} = 0$) were then derived from the various subsample estimates of (9). The solutions suggested absence of significant long-run inflation-unemployment tradeoff. That was interpreted as endorsing the theories of a vertical long-run Phillips curve derived from the Phelps-Friedman expectations hypothesis.[6] Another major finding by Lucas and Rapping (1969b) was the lack of constancy in parameter estimates. This led to the view that empirical Phillips curves did not have much value to assist policy decisions.

Lucas' research forked, after his joint works with Rapping, in two directions which were to impinge enormously on both macroeconomics and macroeconometrics. The first direction was modelling of the output-inflation tradeoff, which bore close similarity to the inverse Phillips curve as unemployment was considered economically comparable to output gap. Again, Lucas' main interest was to test the long-run implications of the RE theory, eg Friedman's natural rate hypothesis (see Lucas, 1972; 1973). In terms of model (9), the natural rate was the rate at which the long-run tradeoff between unemployment and inflation was absent, which was also known as the non-accelerating inflation rate of unemployment (NAIRU).[7] The other direction was embodied by Lucas 1976 critique on the validity of using structural econometric models for policy purposes. Notably, the Phillips curve is the theme of the Carnegie-Rochester Conference volume in which the critique was

[6] The hypothesis is commonly seen as originated from (Phelps, 1967) and (Friedman, 1968).
[7] The literature on the natural rate hypothesis is vast; for general surveys, see (Cross, 1995), (Ball and Mankiw, 2002).

published. In the critique, Lucas used, as an example, an unemployment-inflation model similar to (9) to show that the coefficients of inflation ($\beta_{2i}$) in the unemployment equation would not remain constant if policy shocks occurred in the form of changing parameter values in $b_i$ or $a_j$ of the price equation. The example became the keystone to his general argument that few econometric structural models had invariant coefficients due to agents' RE behaviour under frequent policy shocks.

Interestingly, the econometrics that Lucas employed in his joint works with Rapping is basically the textbook approach, ie starting from a rigorously formulated theoretical model and using econometrics for the best estimates of those *a priori* defined structural parameters. After all, Lucas' primary motive of doing econometrics is to find empirical support to his *a priori* formulated theoretical models. Relative little attention is spared on the robustness of model specification, although he did notice that 'many coefficient estimates vary rather widely depending on which other variables are included' (Lucas and Rapping, 1969a; p747). The possibility that model mis-specification might be causing fragile and unstable coefficient estimates is unheeded. As his empirical studies accrue and theoretical interest evolves, however, Lucas' attachment to the textbook econometrics has rapidly loosened. Most of his subsequent studies simply use the OLS estimator. He seems to have become increasingly unsatisfied with the gap between what the textbook econometrics could deliver and what he has expected to achieve out of his theoretical interest. The dissatisfaction is reflected in his radical position of attacking Keynesian type of macro models in a state of 'econometric failure on a grand scale' (Lucas and Sargent, 1978).

The RE instigated theories and the related empirical studies explored by Lucas gave rise to new econometric issues and controversies. The job of providing better estimation methods for RE models was tackled relatively quickly and successfully (see eg Wallis,

1980), but the task of resolving other modelling issues turned out to be far more challenging and baffling (eg see Pesaran, 1987). As a result, modelling practice became greatly diversified from the mid/late 1970s onwards.[8]

## 4 Diversified Modelling of the Tradeoff

One macroeconomist who played a pivotal role in extending Lucas' work on modelling the output-inflation tradeoff is T. Sargent. Augmenting Fisher's theory of real interest rate by the RE hypothesis, Sargent (1973) deduced that a convenient way of testing the augmented theory was via the use of the natural rate of unemployment as a proxy for the output gap. Two tests were proposed. One utilised Granger (1969) causality test, ie testing whether unemployment could be significantly explained by, other than by on its own lags, the lagged variables that the RE hypothesis was conditioned upon. The other was to regress unemployment on two decomposed parts of inflation – the expected and the unexpected inflation, in order to check whether the former had any explanatory power. The latter test was more sophisticated as it involved formulating unobserved expectation variables and circumventing possible simultaneous-equations bias. Using quarterly US data of 1952-1970, Sargent obtained mixed results from the two tests. He played down the results of the second mainly from comparison of the relative over-sample constancy of the results. In a subsequent five-equation RE macroeconomic model that Sargent (1976a) postulated, the test of the natural rate hypothesis became solely relied on Granger causality test.

Further contemplation of the connection between RE-based structural models and the statistical VAR (Vector AutoRegression) model which underlay Granger causality test led Sargent to a new revelation – observational equivalence between the natural rate model based on Keynesian theories and the model based on classical theories (see Sargent, 1976b;

[8] In his account of the history, Gordon (2010) chooses 1975 as a demarcation year and describes the post-1975 period is a 'less well understood' period when macro theories forked in the road.

and also Qin, 2008b). Here, Sargent chose to represent the theoretical/structural models in a vector moving average (MA) form, eg:

$$\begin{pmatrix} y \\ z \end{pmatrix}_t = \sum_{i=0} \begin{pmatrix} A_i & B_i \\ 0 & D_i \end{pmatrix} \begin{pmatrix} \varepsilon_y \\ \varepsilon_z \end{pmatrix}_{t-i} \tag{10}$$

where $y$ could denote output and $z$, a policy instrument. Mathematical equivalence between an MA and a VAR led to Sargent's interpretation of the VAR:

$$\begin{pmatrix} y \\ z \end{pmatrix}_t = \sum_{i=1} \Pi_i \begin{pmatrix} y \\ z \end{pmatrix}_{t-i} + \begin{pmatrix} \varepsilon_y \\ \varepsilon_z \end{pmatrix}_t ; \quad \Pi = f(A, B, D) \tag{11}$$

being the 'reduced form' of (10). Sargent showed that both Keynesian models and the classical models shared (11) as their reduced forms and hence might not be empirically differentiable or identifiable. Note that Sargent's choice of treating (10) as a structural model amounts to regarding the dynamics of $y$ being driven by the output shock, $\varepsilon_y$, and the policy shock, $\varepsilon_z$; such a model was distinctly different from what was taught in econometrics textbooks but reminiscent to the Slutsky-Frisch impulse-propagation scheme.

A good example of having a structural model as (10) was the four-equation model of money growth and unemployment built by Barro (1977; 1978) (see also Barro and Rush, 1980). In Barro's model, output, price and unemployment dynamics were assumed to be mainly driven by unanticipated money growth, which was defined as the residuals of the money growth equation:

$$\varepsilon_{mt} = \left(\frac{\Delta m}{m}\right)_t - \left[\sum_{i=1} \hat{a}_i \left(\frac{\Delta m}{m}\right)_{t-i} + \hat{b}\left(\frac{\Delta U}{U}\right)_{t-1} + \hat{c} Z_t\right] \tag{12}$$

where $m$, $U$ and $Z$ denoted money, unemployment and exogenous fiscal variable respectively; the estimated coefficients are denoted by hat. Both the current and the lagged $\varepsilon_m$ were found significant in explaining unemployment and output:

$$
\begin{aligned}
U_t &= \alpha_1 + \sum_{i=0} \beta_{1i} \varepsilon_{m_{t-i}} + \gamma_1 z_{1t} + \upsilon_{1t}; \quad \Rightarrow \quad \overline{U} = \alpha_1 \\
\ln(y_t) &= \alpha_2 t + \sum_{i=0} \beta_{2i} \varepsilon_{m_{t-i}} + \gamma_2 z_{2t} + \upsilon_{2t}; \quad \Rightarrow \quad \Delta \ln(\overline{y}) = \alpha_2
\end{aligned} \tag{13}
$$

where $t$ is a deterministic time trend. In model (13), the two explained variables were simply assumed to grow at constant rates, $\alpha$, 'naturally' in the long run or in an equilibrium state, ie when $\varepsilon_m$ and other exogenous shocks ($z$) were absent. Among other things, Barro's model stimulated much interest in testing the relationship between unanticipated monetary shocks and the natural rate hypothesis, ie whether it was the unanticipated shocks alone which would drive output to deviate from its 'natural rate'.

In view of econometrics, models such as (13) evoked two representation issues, albeit little heeded by macroeconomists, namely how one could justify that the theoretical entities of unanticipated shocks, such as monetary shocks, real supply shocks, were equivalent to model-derived residuals; and what the justification was in representing the anticipated long-run movement by a constant rate. Econometric efforts to resolve the issues led to a renewed interest in latent-variable models (eg see Geweke and Singleton, 1981), and in the NBER (National Bureau of Economic Research) business cycle research tradition of decomposing the permanent and transitory components of variables by their time-series properties (eg see Qin, 2010).[9] Research along these lines helped fostering, well into the 1990s, the revival of factor models and the use of time-series filters to define latent theoretical entities, such as time-varying NAIRU.

Apart from those measurement issues, econometricians were also confronted with the demand for better or sharper tests to discriminate competing theoretical models. Various attempts emerged. For example, Pesaran (1982) utilised Cox's non-nested testing procedure to evaluate Barro's model results against the Keynesian alternative; Ilmakunnas and

[9] Later, similar time-series approach was extended to multiple series and applied to the study of the long-run output-inflation tradeoff (eg Geweke, 1986; and also King and Watson, 1994).

Tsurumi (1985) and Leamer (1986) applied Bayesian methods to evaluate the output-inflation tradeoff and the unemployment-inflation tradeoff. Unfortunately, statistical uncertainty in the empirical results was repeatedly found to be too large to sustain a clear verdict between rival theories in spite of the tool refinement. To a large extent, the evidence reinforced Sargent's 'observation equivalence' (1976b).

An alternative modelling route to circumvent 'observation equivalence' was to drop the theorists' stance of 'pretending to have too much *a priori* economic theory', a route explored by Sargent and Sims (1977) and evolved into the VAR approach (see Qin, 2008b). Applied macroeconomists were particularly attracted to the VAR approach by its facility of impulse response analysis through model simulation, as it made shock-based business cycle models such as (10) empirically operational, and also by its continued allegiance to the general equilibrium tradition. But one fundamental problem cropped up: how should modellers sequence the contemporaneous shocks when these terms were correlated with each other? In his 1980 paper, Sims simply followed the inverse Phillips curve in ordering the triangle shock matrix of his six-variable VAR model, ie letting the contemporaneous wage and price shocks precede that of unemployment. However, it was soon shown by Gordon and King (1982) that the reverse ordering in accordance to the Keynesian school could work equally well. Gordon and King also highlighted another problem of the VARs – the results would often vary considerably when the VARs were altered in terms of what variables were included.

The inclusiveness of macro evidence motivated some empirical researchers to go for micro evidence from disaggregate data, leading to a boom in labour economics (eg see Oswald, 1985; Pencavel, 1985). Meanwhile, there came a rising interest in time-series methods, stimulated considerably by the RE movement. Apart from the VAR approach, there were numerous studies on the compatibility between the properties of observed single

time series and the corresponding time-series process *a priori* assumed in RE-based models, such as the autoregressive scheme of the monetary instrument implied in (10) and the ADL structure for inflation in (9). These studies revealed the wide existence of non-stationary features in economic variables. For example, Altonji and Ashenfelter (1980) showed, by means of various tests including then newly developed Dickey-Fuller unit-root test, that aggregate wage rates exhibited significant random walk properties; Nelson and Plosser (1982) examined a range of macroeconomic time series and found that, for most of them, the nonstationary process with a random drift was a better characterisation than the stationary one with a deterministic trend. Such findings severely undermined those RE-based models which disregarded nonstationarity and attributed transitory shocks as the only source of dynamics.

From a macroeconomic stance, however, an obvious route to remove the incompatibility was to build models which would generate those frequently observed time-series features. The route was pioneered by Kydland and Prescott (eg see their 1982 paper), and grew into a methodological enterprise known as the 'real business cycle' (RBC) model and/or 'computable general equilibrium' (CGE) model approach. Empirically, the approach relied on model simulation, using as a key model selection criterion the closeness of the features of synthetic data from RBC simulations to actual data features (eg see Qin, 2010).

Back in the econometric circle, the rise of time-series econometrics was further boosted by a resurgence of Sargan's 1964 modelling approach (see Dawson, 1981; Hendry and Wallis, 1984; Hendry, 2003), due notably to its ECM form, which was greatly popularised by the empirical study of Davidson *et al* (1978) (see also Hendry, 1983). The resurgence culminated in the birth of cointegration theory (see Granger and Weiss, 1983;

Engle and Granger, 1987),[10] which bridged formally the gap between the long-run relationship of a set of non-stationary variables and the equilibrium relationship expected of these variables by theory. However, the resurgence went beyond ECM and cointegration. There arose to prominence the LSE school of dynamic specification approach (see Pagan, 1987; Gilbert and Qin, 2006). The LSE school shared with the VAR approach in promoting a data-instigated strategy in determining the dynamic shape of a model. But unlike the VAR approach, the LSE school stayed away from treating model-derived residuals as unanticipated structural shocks.

## 5 Modelling the Tradeoff in Retrospect

From a historical angle, the belated resurgence of Sargan's 1964 price-wage model is particularly interesting. Apart from the long time lag, two related aspects are worth pondering. The first is the irony that Sargan has devoted most of his econometric effort into developing estimators and tests whereas what brings him enduring and far-reaching impact is the empirical ECM in his 1964 paper. The second is the recurrence of disillusionment in rigorous use of estimation methods; Sargan's abandonment of his own IV estimator for the simple OLS in his 1964 paper is a perfect case, which was, in fact, preceded by numerous cases resulting in the rehabilitation of OLS towards around the turn of 1960 (see Waugh, 1961; and also Gilbert and Qin, 2006); but the experience did not end with Sargan and has been repeated by many other modellers including Lucas, as shown in section 3. Indeed, the radical position by Lucas and Sargent (1978) conveys the same disillusionment of the Cowles Commission econometrics as voiced by applied econometricians nearly two decades earlier, only the disillusionment is veiled by their macroeconomists' stance and textbook econometrics upbringing. What is it which has deterred the profession from

[10] Both papers cited Sargan (1964) and the Sargan type wage equation was used as the first example of ECM in by Granger and Weiss (1983).

learning from these repeated experiences? And more broadly, how has the evolution of applied modelling impacted on the development of econometrics?

In order to better address these questions, a citation database is constructed based on 26 major works of modelling the inflation-unemployment tradeoff during the three decades from (Phillips, 1958). Over 4000 citations are collected from JSTOR (for the pre-1970 period) and Web of Science (for 1970-2005).[11] These citations are classified in line with the JEL (Journal of Economic Literature) system. Class 'C' (i.e. where 'econometrics' is classified) is further categorised into 'applied', 'theoretical' and 'educational' three types. Among the 'applied' category, a sample of 125 papers is selected to link the econometrics citations in their references into the database. The sample includes major empirical works cited in various literature surveys, plus some drawn from *Economica* and *Journal of Political Economy*, two major journals for papers on the tradeoff.

Let us first examine the patterns of citations of the key papers discussed in sections 1-3. The papers are grouped by sections − Group A comprising (Phillips, 1958; Lipsey, 1960; Perry, 1964; 1966), Group B (Dicks-Mireaux and Dow, 1959; Klein and Ball, 1959; Sargan, 1964) and Group C (Lucas and Rapping, 1969a; 1969b; Lucas, 1972; 1973). The total citation counts are given in the table at the bottom of Figure 2. Their time series are plotted in the upper left panel of Figure 1. The next three panels in Figure 1 plot the indices of topic transfer (ITT) (see Mann *et al*, 2006), as defined by:

$$ITT(G)_t = \frac{\text{Number of citations of } (G) \text{ from Topic } i \text{ by time } t}{\text{Number of citations of } (G) \text{ by time } t} \tag{14}$$

where $G$ is designated to one of the three groups in turn and topic $i$ to 'C' (econometrics), 'E' (macroeconomics) and 'J' (labour economics) categories respectively.[12] Discernibly

[11] The 26 root works are mostly from the reference of this paper. A few citations by papers in books and conference collections are added, but the database is primarily made of journal papers. Citations of non-research nature such as book reviews are filtered out.

[12] Note that any one paper can be classified to more than one topic, eg Lucas and Rapping (1969b) falls into all the three topics here, whereas Lucas (1972) falls into 'econometrics' and 'macroeconomics' only.

from the ITT series, the dissemination rates of group A move in a similar manner under the three topics; the rate of group B is the highest under 'econometrics' but its rate under 'macroeconomics' remains rather low; in contrast, group C dominates 'macroeconomics' but its popularity in 'econometrics' and 'labour economics' is short-lived. Figure 3 plots the citations under the 'theoretical' category within 'econometrics'. The citation counts from major econometrics/statistics journals are listed below. These statistics show that group A has hardly enticed the imagination of theoretical econometricians directly, that group C's success with them is transitory in the early 1980s, and that only group B has managed to maintain certain visibility over the 35-year span, due solely to Sargan's 1964 paper.[13] These suggest that theoretical econometric research has not been very close to applied issues.

What about the other side of interaction, ie how much have modellers of the tradeoff been attracted to theoretical econometrics works? Figure 3 graphs the summary statistics of the reference links of the sample of 125 papers, which are further divided into three sets. The graphs show that the reference counts are on the increase over time. A scan of the reference list reveals that the references are relatively up to date and are mainly on tests, eg Chow test, Ramsey test, autocorrelation tests as well as exogeneity tests, the last is most noticeable from the middle and bottom left panels, where Granger (1969) causality paper topped the citation counts; in contrast, references on estimators are few and far between. One might infer that many applied modellers would refer to textbooks on estimation matters. Indeed we see a steady reliance on textbooks from the right-side panels, though there is a sign of weakening and more lagged reliance in the 1980s set. Interestingly, the top count in that set is Box and Jenkins (1976) time-series book. On the whole, the sample evidence suggests that applied economists have been fairly knowledgeable and receptive of econometrics and become increasingly so since 1970s.

[13] It is however difficult to assess the secondary impact since the present database does not present citation trees.

Having analysed the citation statistics, we are now back to the issue of what historical assessment we can make of the impact of applied modelling on the development of econometrics. From a broad perspective, the development exemplifies the consolidation process of the Cowles Commission paradigm and the subsequent reforms that it evoked (see Qin, 2008a). As described in Section 2, Klein was avant-garde in applying the SEM approach to modelling the price-wage relationship in the late 1950s. It takes roughly a decade for SEMs to be widely adopted, as shown from Goldstein's 1972 survey and also the joint study by Lucas and Rapping (1969a). It is nevertheless noticeable from the papers of group C that the faith in the SEM-based structural approach was so established that there was almost no trace of *ad hoc* data-instigated model specification. Moving from groups A to C, we discern the consolidation process in that macroeconomists were tuned up in using econometrics as a measurement toolbox to serve their endeavour in postulating more sophisticated theoretical models.

To a large extent, the consolidation process is driven primarily by the need, from mainstream economists, of theory corroboration on the part of econometrics. This explains why group B has much lower dissemination rates than that of its contemporary group A in spite of the relatively advanced econometric techniques used by the group. For most economists, the inflation-unemployment tradeoff bears far more economic significance than the wage-price relationship (see eg Gordon, 1990); the Phillips curve was particularly attractive because of its simple and heuristic model form, its appealing forecasting capacity, its close policy relevance and its rich macroeconomic interpretability. The technical aspect is merely secondary. Once the inflation-unemployment relationship is brought to parallel with the inflation-output tradeoff, the Phillips curve becomes well grounded on the macroeconomic tradition of having a simple but complete model representation within the general equilibrium paradigm. The RE movement led was aimed essentially at making the

dynamic aspect of that model more complete. Econometrics was, after all, regarded as providing the service of measured proofs of that model. Econometric works were thus selected mainly for their usefulness to the service.

Econometrically measured RE models have, however, resulted in more contentious than conclusive findings. Interpretations from different angles and intentions fostered diversification of research agendas. While those strongly theory-minded largely abandon econometrics for the simulation-based CGE approach, economists who still practise econometrics also become divided in how much they are willing to let go of the structural approach. Some let go of the constancy of structural parameters for time-varying parameter models; others let go of structurally parametric models or for random shock models or dynamic factor models; there are also others who let go of the general equilibrium tradition for data-instigated single-equation models with loose theoretical guidance. Applied economists have become increasingly willing to abandon textbook econometrics and let data speak more, although it is not yet a prevailing position to forgo the general equilibrium tradition and embrace empirical models explicitly with partial and incomplete structural interpretation.

The diversification reflects an 'externalisation' of econometric research agendas in that attention has been increasingly shifted from devising measurement instruments for parameters within a model to devising other tools for testing, evaluating and revising the model as a whole (see Gilbert and Qin, 2007). The externalisation challenges the passive corroboration role conventionally expected of econometrics. Fundamentally, it is the ultimate need to tackle applied issues that drives the externalisation, inducing econometrics to break the straitjacket of theory confirmation.

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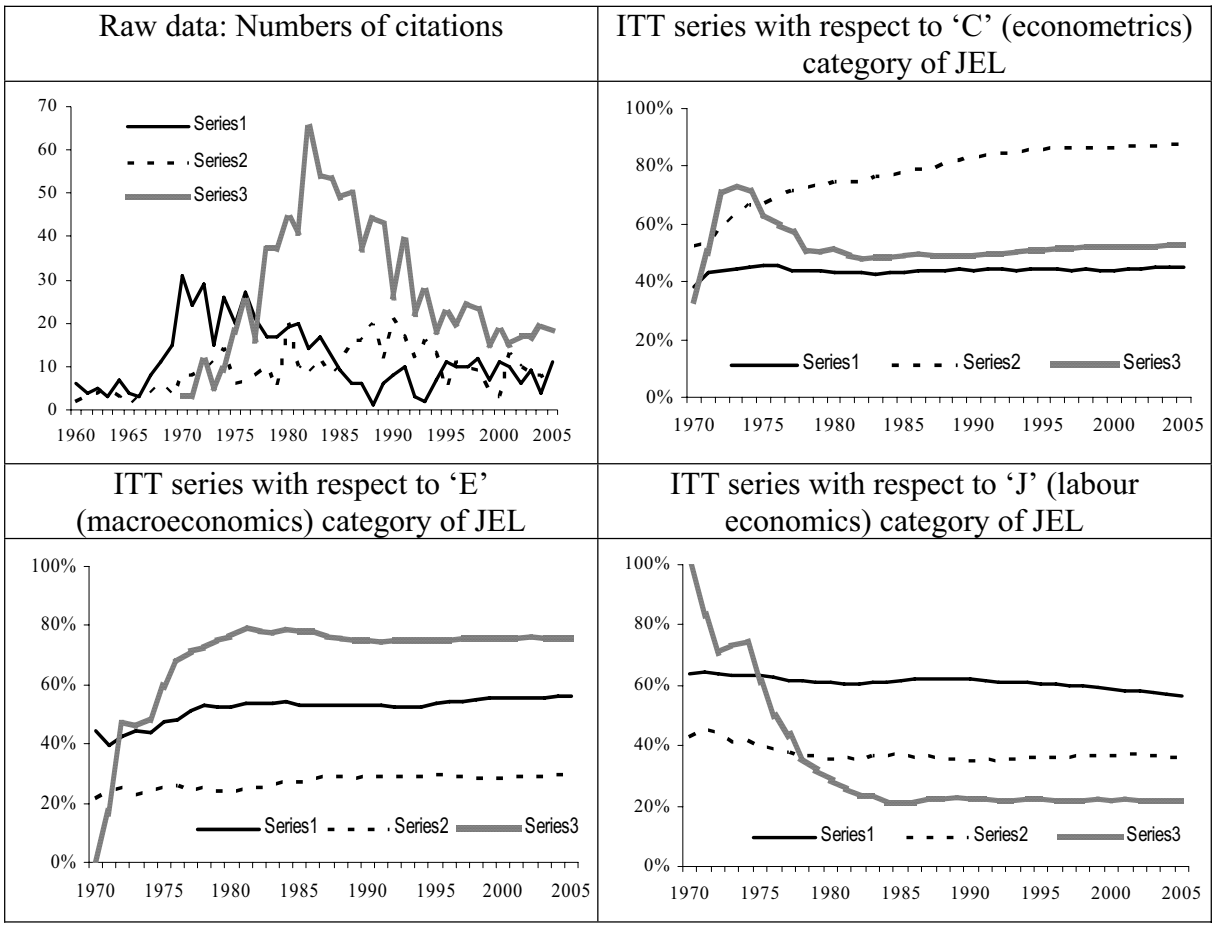
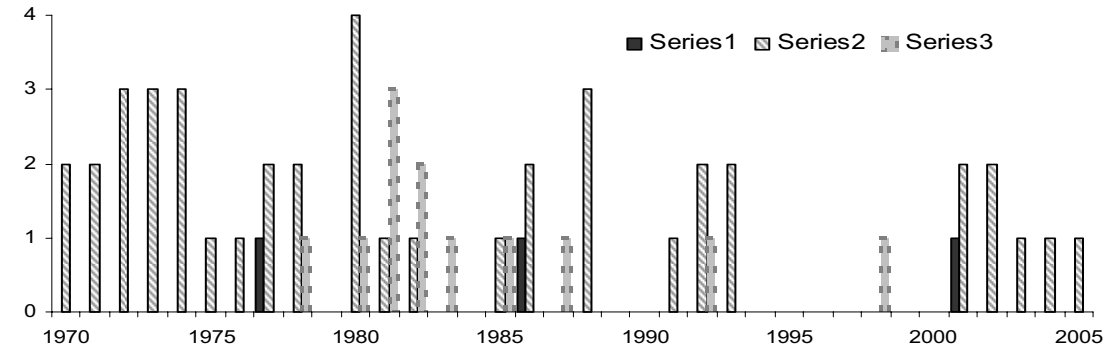
Figure 1. Citation Series and ITT Series




Note: Series 1, 2 and 3 are formed by citations of groups A, B, C respectively. Group A: (Phillips, 1958; Lipsey, 1960; Perry, 1964, 1966); Group B: (Dicks-Mireaux and Dow, 1959; Klein and Ball, 1959; Sargan, 1964); Group C: (Lucas and Rapping, 1969a; 1969b; Lucas, 1972; 1973).

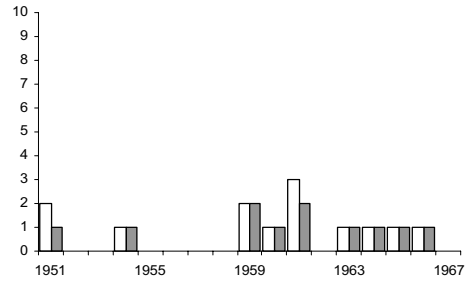
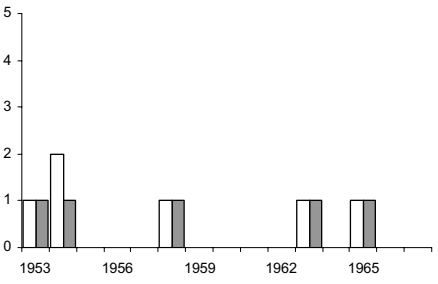
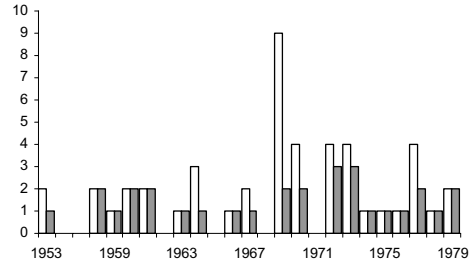
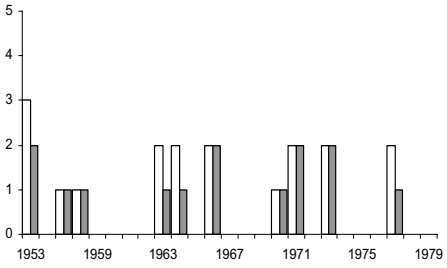
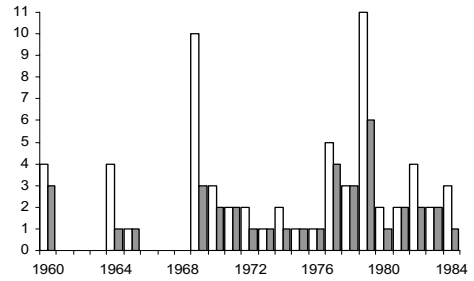
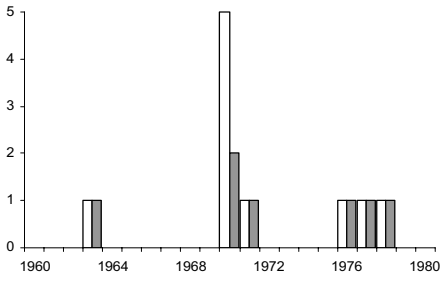
Figure 2. Citations by theoretical econometrics papers




Self-citations are removed from the counts. Series 1, 2 and 3 are formed by citations of groups A, B, C respectively.

| Citations by Major Econometrics Journal (1960-2005) | Citations | | |
|---|---|---|---|
| | Group A | Group B | Group C |
| Econometrica | 7 | 20 | 19 |
| Journal of the American Statistical Association | 2 | 7 | 1 |
| Econometric Theory | 0 | 6 | 1 |
| Journal of Econometrics | 0 | 5 | 3 |
| Journal of the Royal Statistical Society | 2 | 5 | 0 |
| Share of the total citations | 1.7% | 10.3% | 2.4% |
| Total citations | 537 | 417 | 984 |

Figure 3. References to Econometrics Works of a Sample of 125 Papers

| Base: | Cited theoretical econometrics works | Cited textbooks |
|---|---|---|
| Set A: 16 papers (1959-1969) | Total count = 13   | Total count = 6   |
| Set B: 66 papers (1970-1979) | Total count = 47   | Total count = 18   |
| Set C: 43 papers (1980-1989) | Total count = 63   | Total count = 10   |

* Self-citations are excluded. Clear bars indicate the raw counts and the grey bars are the counts net of the duplicated papers.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