Implications and New Developments of Staggered Wage and Price Setting Models

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CONTENTS

Abstract

This chapter focusses on models of economic fluctuations based on nominal rigidities that are due largely to staggered wage and price setting. After many years, many critiques, and many variations, this type of model is still the most common method of incorporating nominal rigidities into empirical macroeconomic models, especially those used for policy analysis. The chapter builds on my earlier chapter in the *Handbook of Macroeconomics, Volume 1* (Taylor (1999)) which reviewed original research papers that had already spawned a vast literature by that time. This paper is a combination of an exposition and a survey. Using a “canonical” model it reassesses from a longer vantage point the more fundamental characteristics and implications of the research, surveys the enormous amount of new research, and considers possible directions of future research.

1. Introduction

This chapter reviews the role of wage and price rigidities in models of economic fluctuations. It focusses on rigidities based on staggered wage and price setting which after four decades in use and many variations constitutes a common method of incorporating nominal rigidities in empirical macroeconomic models used for policy analysis.

The chapter builds on my earlier *Handbook of Macroeconomics* chapter (Taylor, 1999) which reviewed many original research papers that had already spawned a vast literature by that time. Both an exposition and a survey, it reassesses from a longer vantage point the more fundamental characteristics and implications of the research, and it surveys new research since that first *Handbook* chapter. The chapter also reviews critical research such as that of Chari, Kehoe, and McGrattan (2000) and the responses from Woodford (2003) on the empirical macroeconomic power of staggered price setting derived from microeconomic foundations, and the complementary critical work by Golosov and Lucas (2007) on state-dependent pricing and more recent work of Alvarez and Lippi (2014) and Kehoe and Midrigan (2010) which again finds greater persistence and impacts of policy shocks as in the mainline staggered contract model.

In my 1999 review I wrote that "one of the great accomplishments of research on wage and price rigidities in the 1980s and 1990s is the bolstering of case studies and casual impression with the evidence from thousands of observations of price and wage setting collected at the firm, worker or union level." The same could be said of the new research on micro data since then except that it is far greater, a virtual explosion including the studies in the US by Bils and Klenow (2004), Klenow and Kryvtsov (2008), Nakamur and Steinsson (2008) and the ECB surveys in Europe. The chapters in the *Handbook of Monetary Economics* by Klenow and Malin

(2011) and in this *Handbook of Macroeconomics* by Basu and House (2015) review this empirical work, so I do not provide a detailed review here, except to point out how the research has helped to calibrate parameters and discriminate between models.

2. Origins

When you look through graduate level textbooks in macroeconomics and monetary theory you find that the chapters on modern macro models with nominal rigidities begin with the idea of staggered contracts or staggered wage and price setting that was first introduced to macroeconomics in the 1970s, some indication that this was a period of major change. Carl Walsh's treatment in his third edition (2010) of "early models of inter-temporal nominal adjustment" starts with "Taylor's (1979) model of staggered nominal adjustment" and then goes on to examine a version due to Calvo (1983). David Romer's chapter in his fourth edition (2012) starts off with three modeling frameworks from this period: Fischer-Phelps-Taylor (1977), Taylor (1979) and Calvo (1983). Likewise Michael Woodford's (2003) chapter on nominal rigidities is mainly about staggered price or wage setting models that emanate from those days.

It is no coincidence that staggered contract models arose at about the same time as rational expectations was introduced to macroeconomics. Rational expectations meant that one had to be more rigorous and specific in modelling the adjustment of prices and wages and the impact of monetary policy. Slow adjustment of expectations—so-called adaptive expectations—would no longer work as a reason that prices and wages moved sluggishly over time.

The earliest work by Fischer (1977), Gray (1976) and Phelps and Taylor (1977) assumed that the price or wage was set in advance of the period it would apply and at a value such that markets would be expected to clear. In other words, prices would be set to bring expected demand into equality with expected supply. In the case of Phelps and Taylor (1977) the price was set one period in advance, and the price could change every period—no matter how short the period—much like in perfectly flexible price models. In the case of Fischer (1977) and Gray (1976) the wage could be set more than one period in advance but at a different level each period, so that expected supply could equal expected demand in every period, again not much different empirically from flexible price models.

In all these models the price or the wage would change continuously, period by period. If the model was quarterly, then the price or wage could change every quarter; if the model was monthly, the price or wage could change every month. As was apparent, and later confirmed in empirical work by Klenow and Kryvtsov (2007) or by Nakamura and Steinsson (2007), however, in the real world prices are set at the same level for more than one time period; they usually remain at the same level for several weeks, months or even quarters; and the same is true for wages with the representative period of constancy being about twelve months. In addition to being at variance with the micro data (and actually as a consequence of this variance), this type of model was completely inconsistent with the aggregate dynamics. Such models could not generate persistence mainly because the price setting assumption was only a minor change compared to the assumption that prices were market clearing. The staggered contract model arose as a reaction to these limitations. It was explicitly designed to reflect the micro data and thereby better match the aggregate dynamics.

3. A Canonical Staggered Price and Wage Setting Model

The simplest way to see how these limitations were overcome is to look at a canonical staggered contract model, as illustrated in Figure 1 using a degree of abstraction and simplification similar to expositions of the overlapping generation model. Later in this chapter I will discuss a range of variations and extensions of this simple form. The basic idea of staggered price setting is that firms do not change their prices instantaneously from period to period. Instead there is a period of time during which the firm's price is fixed, and the pricing decisions of other firms are made the same way but at different times. Price or wage setting would thus be staggered and unsynchronized.

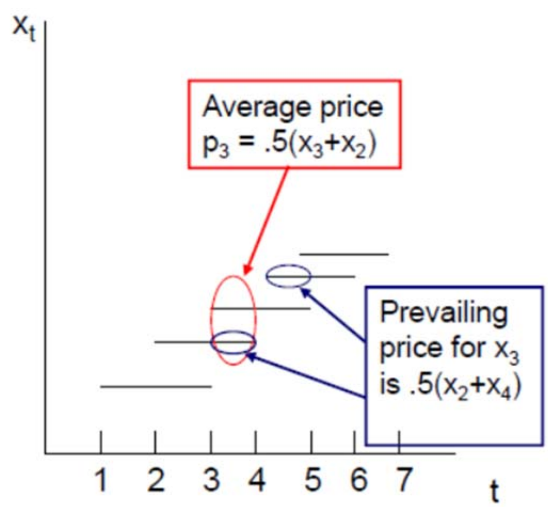

Figure 1. Illustration of a Canonical Staggered Contract Model

This "contract" or "set" price x_t is shown in the diagram. Note that it is set at the same level for two periods. Half the firms set their price each period in the canonical model. In the case where x is the contract wage rather than price, it would also be set for two periods and the wage would be determined for half of the workers each period. There is no reason for the either the price or the wage to be a formal contract or even an implicit contract; rather the price or wage set by the firm could apply to any particular good purchased or any worker of a certain type hired.

3.1 Canonical Assumptions

These two essential assumptions of staggered price setting are clear in the figure. First, the set price lasts for more than an instant, or in this discrete time set up for more than one period. Second, the price setting is unsynchronized or overlapping. When you think about how a market might work in these circumstances, you realize two more important things not in the classic supply and demand framework. First, you realize that some firms' prices will be outstanding when another firm is deciding on a price to set. So firms need to look back at the price decisions of other firms. Second, you realize that the firm's price will be around for a while, so the firm will have to think ahead and forecast the price decisions of other firms.

Figure 1 also illustrates two important concepts: the average price $p_t = (x_t+x_{t-1})$ and the prevailing price. For period t, the prevailing price is the average of the price in effect in period t-1 and the price expected to be in effect in period t+1, that is $.5(x_{t-1} + E_{t-1}x_{t+1})$. This is what is relevant for the price decision of the firm in period t.

Given this set up, a decision rule for the firm setting the price x_t at time t can be written down as in equation (1) in terms of the prevailing price and a measure of demand pressure, say the output gap, the percentage deviation of real output from potential output (Taylor (1979). [1]

[1] Note that (ignoring the expectations operator) the first term on the right hand side of equation (1) can be written as $\frac{1}{2}(p_t + p_{t+1})$ because this equals $\frac{1}{2}[\frac{1}{2}(x_t + x_{t-1}) + \frac{1}{2}(x_{t+1} + x_t)]$ and thus $x_t = \frac{1}{2}(x_{t-1} + x_{t+1}) + \ldots$

The term E_{t-1} represents the conditional expectations operator and ε_t is a serially uncorrelated, zero mean random shock.

$$x_t = \frac{1}{2}(x_{t-1} + E_{t-1}x_{t+1}) + \frac{\gamma}{2}(E_{t-1}y_t + E_{t-1}y_{t+1}) + \varepsilon_t \qquad (1)$$

As described below, the forcing variable on the right hand side has been frequently interpreted as marginal cost in the case of a price decision (Woodford (2003)) or marginal revenue product in the case of a wage decision (Erceg, Henderson and Levin (2000)).

3.2 Enter Rational Expectations via a Three-Equation Macro Framework

To derive the implications of the staggered contracts assumption for aggregate dynamics and the persistence of shocks, we need to embed the staggered price setting equation into a model of the economy. For this purpose, consider two additional equations: An aggregate demand equation based on a money demand function (which could be derived from a money-in-the-utility or cash-in-advance framework) and an equation describing a monetary policy rule. The two equations are thus:

$$\mathrm{y}_{\mathrm{t}} = \alpha(m_t - p_t) + v_t \qquad (2)$$

$$m_t = gp_t \qquad (\mathrm{g} < 1) \qquad (3)$$

which can be combined to get

$$y_t = -\beta p_t + v_t \qquad (4)$$

where $\beta = \alpha(1-g)$ is the key policy parameter.

Here we define y to be the log of real output as in equation (1) and m to be the log of the money supply. Now if we insert the staggered contract equation (1) into the model we get the following difference equation with lags and leads

$$x_t = \frac{1}{2}(x_{t-1} + E_{t-1}x_{t+1}) + \frac{\gamma}{2}\left[-\beta\left(\frac{E_{t-1}x_t + x_{t-1}}{2}\right) - \beta\left(\frac{E_{t-1}x_{t+1} + E_{t-1}x_t}{2}\right)\right] + \varepsilon_t$$
$$= \frac{1}{2}(x_{t-1} + E_{t-1}x_{t+1}) - \frac{\gamma\beta}{4}[E_{t-1}x_{t+1} + 2E_{t-1}x_t + x_{t-1}] + \varepsilon_t$$

The solution is

$$x_t = ax_{t-1} + \varepsilon_t \qquad (5)$$

where $a = c \pm \sqrt{c^2 - 1}$ and where $c = (1 + \beta\gamma/2)/(1 - \beta\gamma/2)$.
Clearly $c > 1$, and we can chose stable root for uniqueness.
In terms of the aggregate price level, this implies that

$$p_t = ap_{t-1} + .5(\varepsilon_t + \varepsilon_{t-1}) \qquad (6)$$

an ARMA (1,1) from which steady state variances can easily be found

$$\sigma_p^2 = .5\sigma_\varepsilon^2/(1-a)$$
$$\sigma_y^2 = \beta^2\sigma_p^2$$

Note that the three equation macro model consists of a staggered price setting equation (1), a policy transmission equation (2), and a policy rule (3). The model is a combination of sticky prices and rational expectations which is the hallmark of *New Keynesian* models; this distinguishes them from Old Keynesian models in which expectations are not rational and prices are either fixed or determined in a purely backward looking manner, unlike equation (1). The term New Keynesian is used in many different ways and for this reason I tend not to use it. For example, in some usages the term refers only to models in which, along with a staggered price or wage setting equation, the monetary transmission equation is an IS curve—perhaps derived from an Euler equation—relating the policy interest rate to aggregate demand and the policy rule is an interest rate rule like the Taylor rule.

3.3 The Output and Price Stability Tradeoff Curve

The variances of y_t and p_t can be placed in an objective or loss function such as $\lambda var(p_t) + (1-\lambda)var(y_t)$. The monetary policy problem is then to choose a value of g (which feeds into β and thus *a)* to minimize the loss function. As the policy parameter is changed, the variances of p and y move in opposite directions tracing out a variance tradeoff curve. The lower panel of Figure 2 illustrates this variance trade off curve. Inefficient monetary policies would be outside the curve. Points inside the curve are not feasible. Performance could be improved by moving toward the curve.

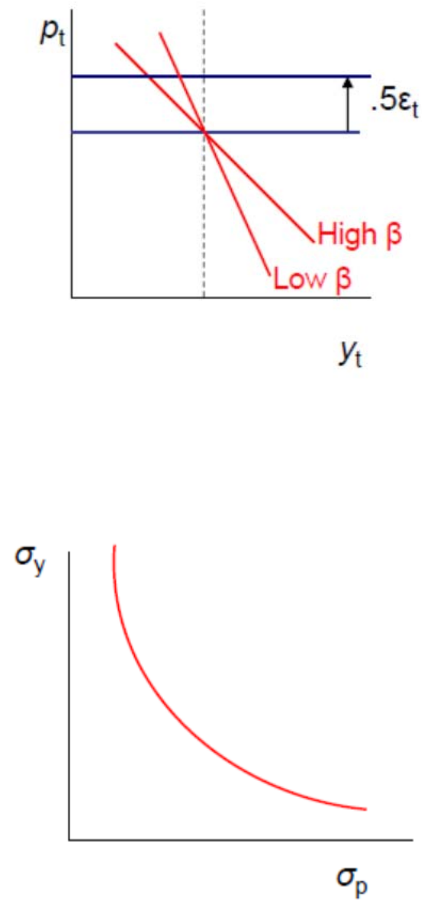

Figure 2. Output and Price Stability Tradeoff Curve with Graphical Explanation

The upper panel of Figure 2 is an aggregate demand–aggregate supply diagram which illustrates how the choice of g or β affects the variance of p and y. Suppose that there is a shock ε. Then, a steep aggregate demand curve (a monetary policy choice) makes for smaller fluctuations in y, but also means that a given shock to the price level takes a long time to diminish and thus a larger average fluctuation in p.

3.4 Key Implications

A number of important implications of staggered contracts can easily be illustrated with the canonical model. I list seven here.

First, the theory generates the simple equation (1) that can be used and tested. I list this result first because if the theory had not yielded such an equation, it would have been difficult to achieve the progress I report in this paper—including the derivation or reverse engineering of the equation in monopolistic competition frameworks. A key variable in this equation is the prevailing price (or wage) set by other firms. The prevailing price itself is an average of prices set in the past and prices to be set in the future. In this case the coefficients on past and the future are equal.

The second key implication is that expectations of future prices matter for pricing decisions today as also shown in equation (1). The reason is that with the current price decision expected to last into the future, some prices set in the future will be relevant for today's decision. This is an important result because expectations of *future* inflation now come into play in the theory of inflation. It gives a rationale for central bank credibility and for having an inflation target.

Third, there is inertia or persistence in the price setting process; past prices matter because they are relevant for present price decisions. The coefficients on past prices can be calculated from the staggered price setting assumptions. This implication can be most readily seen in equation (5). The contract price follows a serially correlated—that is persistent—autoregressive process.

Fourth, the inertia or persistence is longer than the length of the period during which prices are fixed. Price shocks take a long time to run through the market because last period's price decisions depend on price decisions in the period before that and so on into the distant past. I originally called this phenomenon is the "*contract multiplier*" because it was analogous to the Keynesian multiplier where a shock to consumption builds up and persists over time as it works its way through the economy from income to consumption to income back again, and so on. This is most easily seen in equation (5) or the ARMA model in equation (6). The first order auto-regression implies an infinite auto-correlation function or an infinite impulse response function. The larger is the autoregressive coefficient (that is, *a),* the larger will be the contract multiplier.

This is one of the most important properties of the staggered contract model because it means that very small rigidities at the micro level can generate large persistent effects for the aggregates. Klenow and Malin (2012) explain it well: "Real effects of nominal shocks…last three to five times longer than individual prices. Nominal stickiness appears insufficient to explain why aggregate prices respond so sluggishly to monetary policy shocks. For this reason, nominal price stickiness is usually combined with a 'contract multiplier' (in Taylor's 1980 phrase)."

Fifth, the degree of inertia or persistence depends on monetary policy. That is: the autoregressive coefficient a depends on the policy parameter g. The more accommodative the central bank is to price level movements (higher g), the more inertia there will be (higher a).

Sixth, the theory implies a tradeoff curve between price stability and output stability. This tradeoff curve has provided a framework for discussion and debate about the role of policy in economic performance for many years. Originally put forth in Taylor (1979a) it is referred to as the Taylor curve in various contexts (King (1999), Bernanke (2004), Friedman (2010)). Bernanke (2004) used such a tradeoff curve to explain the role of monetary policy during the Great Moderation. His explanation was that monetary policy improved and this brought performance from the upper right hand part of the diagram down and to the left closer or even on the curve. King (1999) made similar arguments. However, when the Great Recession and the slow recovery moved the performance in the direction of higher output instability—the end of the Great Moderation—King (2012) argued that the tradeoff curve itself shifted. As he put it, "A failure to take financial instability into account creates an unduly optimistic view of where the Taylor frontier lies…. Relative to a Taylor frontier that reflects only aggregate demand and cost shocks, the addition of financial instability shocks generates what I call the Minsky-Taylor frontier."

Note that the tradeoff implies that there is no "*divine coincidence*" as put forth by Blanchard and Gali (2007). Divine coincidence means that there is no such tradeoff between output stability and price stability, completely contrary to the existence of the tradeoff in Figure 2. Divine coincidence could occur if there were no shocks to the contract price or wage equation, but that is not the basic assumption of the staggered contract model. Broadbent (2014) suggested that the Great Moderation was due to the sudden appearance of divine coincidence, rather than to an improved monetary policy performance that brought the economy closer to the tradeoff curve as Bernanke (2004) and others argued.

Seventh, the costs of reducing inflation are less than in the backward-looking expectations augmented Phillips curve. In the staggered contract model disinflation could be less costly if expectations of inflation were lower because of the forward-looking component of the model, as explained in Taylor (1982) though with reservations from others (see Gordon (1982)). The disinflation costs would not normally be zero as in the case of rational expectations models with perfectly flexible prices, but they would be surprisingly small. This prediction proved accurate when people later examined the disinflation of the early 1980s.

4. Generalizations and Extensions

Most of these results remain robust to variations in the model. An important variant is to allow for a greater variety of time intervals during which prices are fixed. Of course one could have longer contracts as in Taylor (1980) where contracts were of a general length N. However, a model with all price and wage setting being the same length is a simplifying assumption, not something that could be used in empirical work. Not all contracts are N periods in length; some could be shorter and some could be longer. Indeed there could be a whole distribution of contracts and this is what I assumed in early empirical work with these models. A generalized distribution of price-wage setting intervals was used by Taylor (1979c) in an estimated model of the United States.

Equation (1) was thus modified as follows.

$$x_t = \sum_{i=0}^{N-1} \theta_{it} E_t (p_{t+i} + \gamma y_{t+i} + \varepsilon_{t+i}) \qquad (7)$$

$$p_t = \sum_{i=0}^{N-1} \delta_{it} x_{t-i} \qquad (8)$$

The weights θ_{it} and δ_{it} were estimated using aggregate wage data in the United States. The distribution was only mildly restricted; allowed for a peak somewhere between 1 quarter and 8 quarters. The estimated distribution was reasonable with the distribution peaking at 3 quarters with 24 percent of workers; only 7 percent had one quarter contracts and only 2 percent had 8 quarter contracts. The interpretation was that the economy consisted of a whole variety of price and wage setting practices.

Figure 3: The Estimated Distribution of Workers by Contract Length

Observing the general distribution of wage setting intervals used in this empirical work, Calvo (1983) proposed a geometric distribution, which generated considerable algebraic simplicity. He also noticed that the distribution of contracts could be interpreted as occurring probabilistically as each contract expired randomly rather than deterministically. The resulting model is written as follows:

$$x_t = (1-\beta\omega)\sum_{i=0}^{\infty}(\beta\omega)^i E_t(p_{t+i} + \gamma y_{t+i} + \varepsilon_t) \qquad (9)$$

$$p_t = (1-\omega)\sum_{i=0}^{\infty}\omega^i x_{t-i} \qquad (10)$$

After some manipulation, these two equations can be rewritten as

$$x_t = \beta\omega E_t x_{t+1} + (1-\beta\omega)(p_t + \gamma y_t + \varepsilon_t)$$
$$p_t = \omega p_{t-i} + (1-\omega)x_t$$

Once a model for y and the impact of monetary policy is added, you have a well - defined rational expectations model as before.

The two equations can also be re - written in an interesting form :

$$\pi_t = \beta E_t \pi_{t+1} + \delta\gamma y_t + \delta\varepsilon_t \qquad (11)$$

where

$$\delta = \left[\frac{(1-\omega)(1-\beta\omega)}{\omega}\right]$$

which is very simple and reminiscent of an old expectations augmented Phillips curve except that the expected inflation rate next period rather than this period is on the right hand side. Calvo's modifiations helped the staggered contract model grow in use and popularity.

5. Derivation of Staggered Price Setting When Firms Have Market Power

Another important development regarding the staggered contract model is its derivation from an optimization problem in which firms face a downward sloping demand curve and decide on an optimal price subject to the staggered contract restriction that they cannot change prices every period. The idea of using market power to derive a price setting equation goes back to Svensson (1986), Blanchard and Kiyotaki (1987), Akerlof and Yellen (1991) as I reviewed in Taylor (1999). As described below, Chari, Kehoe and McGrattan (2000) used the approach as part of a critique of staggered price setting. For expository purposes here, I focus on a simple derivation used in Taylor (2000) in which firms maximize profits taking the downward sloping demand curve for their products as given.

Consider a firm selling a product that is differentiated from the other goods. The demand curve facing each firm is linear in the difference between the firm's own price for its product and the average price for the other differentiated products. Such a linear demand curve can be derived from models of consumer utility maximization. Suppose that this linear demand curve is written as

$$y_t = \varepsilon_t - \beta(x_t - p_t) \qquad (12)$$

where y_t is production, x_t is the price of the good, and p_t is the average price of other (differentiated) goods. The term ε_t is a random shift to demand.

Suppose that the firm sets its price to last for two periods, and that it sets its price every second period. Other firms set their price for two periods, but at different points in time. These timing assumptions correspond to the canonical model in Figure 1, and the average price is just as in the canonical model $p_t = (x_t + x_{t-1})$.

Let c_t be the marginal cost of producing the good. Under these assumptions, the firm's expected profit for the two periods to which the price set in period t applies is given by

$$\sum_{i=0}^{1} E_t(x_t y_{t+i} - c_{t+i} y_{t+i}) \qquad (13)$$

where x_t applies in period t and period t + 1. (I have assumed for simplicity that the discount factor is 1). Firms maximize profits taking marginal cost and average price at other firms as given.

Differentiating with respect to x_t results in the solution for the optimal price

$$x_t = .25\sum_{i=0}^{1}(E_t c_{t+i} + E_t p_{t+i} + E_t \varepsilon_{t+i} / \beta) \qquad (14)$$

which is analogous to the canonical staggered contracting equation in equation (1) (see also Footnote 1).

5.1 Pass-Through Implications

Though the functional form of the optimization-based price setting equation is the same as in the canonical model, it reveals another important implication of the theory—an "eighth" implication: a more price-stability focused monetary policy—say due to inflation targeting—implies a smaller pass-through of price shocks (commodities or exchange rates) to inflation. That this implication might be borne out by reality was noted in Taylor (2000), but has now been documented in many countries. The reason originally given for the empirically observed decline in pass-through was that there was a reduction in the "pricing power" of firms. But another view is that the decline in pass-through is due to the low inflation rate achieved by a change in monetary policy.

To see this note that, according to equation (14), the amount by which a firm matches an increase in marginal cost with an increase in its own price depends on how permanent that marginal cost increase is. Similarly, the extent to which an increase in the price at other firms will lead to an increase in the firm's own price will depend on how permanent that increase in other firms' prices is expected to be. However, in neither case does the extent of this pass-through depend on the slope of the demand curve.

To see how the pass-through of an increase in marginal costs depends on the persistence of the increase suppose that marginal cost follows a simple first order autoregression:

$$c_t = \rho c_{t-1} + u_t$$

In this case the pass-through coefficient will be proportional to $(1 + \rho)$. Thus, less persistent marginal costs (lower ρ) reduce the pass-through coefficient, even though it might seem like a reduction in pricing power. The general point is that if an increase in costs is expected to last, then the increase will be passed-through to a greater extent. A more stable price level will reduce the persistence.

For firms that import inputs to production, marginal cost will depend on the exchange rate. Currency depreciation will raise the cost of the imports in domestic currency units. According to this model, if the depreciation is viewed as temporary, the firm will pass through less of the depreciation in the form of a higher price. Hence, less persistent exchange rate fluctuations will lead to smaller exchange rate pass-through coefficients. A more stable price level will lead to less persistent changes in exchange rates.

5.2 **Marginal Cost versus the Output Gap**

Note that equation (14) has marginal cost driving price movements rather than output as assumed in equation (1). To make the connection between equation (14) and equation (1) (again keeping footnote 1 in mind) we need to think of marginal cost as moving proportionately to the movements in the output gap. Gali and Gertler (1999) or Gali, Gertler and Lopez-Salido (2006) argue that there are plenty of reasons that marginal cost and the output gap might diverge from time to time. So they look at a version of equation (11) in which marginal costs appear rather than the gap (they use the geometric distribution assumption of Calvo rather than the canonical form used here). Though the empirical accuracy of this equation was questioned by Mankiw (2001), the paper by Gali, Gertler and Lopez-Salido (2006) finds that marginal cost is significant and quantitatively important. However, they introduce a modification in that model. They assume that a fraction of firms adjust prices with a backward looking “rule of thumb” which simply depends on past inflation. They thereby create a hybrid model with the lagged inflation rate on the right hand side. The modification is ad hoc—especially compared with the theory that goes into deriving the staggered price setting equation.

Another issue noted by Nekarda and Ramey (2013) is that the markup of price over marginal cost needs to move in a countercyclical way if the equation is to explain empirically the effects of a change in demand on prices. They report, however, that markups are either “procyclical or acyclical conditional on demand shocks” and thereby conclude that the “New Keynesian explanation for the effects of government spending or monetary policy is not supported by the behavior of the markup.”

5.3 **Debate Over the Contract Multiplier**

Yet another issue is whether the contract multiplier is capable of explaining the persistence of prices or output. The contract multiplier is the same conceptually but not necessary the same in magnitude in the micro-derived model and in the canonical model. Chari Kehoe and McGrattan (2000) argued that it is not capable of explaining persistence, at least for contract lengths of one quarter in length and a particular measure of aggregate persistence. Woodford (2003, pp. 193-194) argues that their conclusion “depends on an exaggeration of the size of the contract multiplier that would be needed and an underestimate of the empirically plausible degree of strategic complementarities.” He also argues that Chari, Kehoe and McGrattan (2000) set up too high a persistence hurdle for the contract multiplier, in effect asking it to explain persistence more reasonably due to other serially correlated variables.

Christiano Eichenbaum and Evans (2003) argue that assuming that the representative length of contacts is only one quarter is too small. If you use somewhat longer contracts, say close to the survey summarized by Klenow and Malin (2011), the contract multiplier seems to work fine. Christiano Eichenbaum and Evans (2003) also question the persistence measure used by Chari, Kehoe and McGrattan (2000).

6. Price and Wage Staggering Together

Much of this review has focused thus far on staggered price setting, but the original work on staggered contracts actually was on wages, where the time between changes in contracts is quite a bit longer. In Taylor (1980) the staggering of wages was the key part of the model, and this created a persistence of prices through a simple fixed markup of prices over wages. In the empirical multi-country model in Taylor (1993), the staggered wage contracting equations were estimated for seven countries and markups of prices over wages were influenced by the price of imports.

Erceg, Levin and Henderson (2000) brought the focus back to wages, but with an important innovation. Rather than simply marking up prices over wages, they built a model which combined staggered price and wage setting, and, moreover, they derived both equations from profit or utility maximization considerations as in Section 5 above. Their work in turn helped enable the development of more empirically accurate policy models, such as those due to Christiano, Eichenbaum and Evans (2005), Smets and Wouters (2003), and many others that have become part of Volker Wieland's (2012) model data base.

The model of Christiano, Eichenbaum and Evans (2005) assumes staggered contracts for prices and wages with Calvo weights. It was the first medium-sized, estimated example of a

New-Keynesian model explicitly derived from optimizing behavior of representative households and firms. It stimulated the development of similar optimization-based models for many other countries. Smets and Wouters (2003, 2007) also showed how to use Bayesian techniques (Geweke (1999) and Schorfheide (2000)) in estimating such models.

6.1 Debates about the Persistence of Inflation and Indexing

Prior to the work of Chari, Kehoe and McGrattan (2000), Fuhrer and Moore (1995) raised questions about the ability of the staggered contract model to explain the persistence of inflation rather than the persistence of the price level. They proposed a modification of the model to deal with this problem. As I reviewed in Taylor (1999), they transformed the model from price levels into the inflation rate, noting that it was *relative* wages rather than absolute wages that would go into the staggering equations. But questions about this issue continued into the 2000s.

Guerrieri (2006) argued, for example, that viewed within the context of fully-specified macro models inflation persistence and its changes over time could be explained with the regular staggered contract setup. Guerrieri (2006) used a vector autoregression to represent the facts that a staggered contract model should explain. He found that the staggered contract model did as well as the Fuhrer-Moore (1995) relative contract model in generating the actual inflation persistence in the United States through the 1990s. His charts shown in Figure 4 below illustrate the degree to which both specifications can explain the inflation process. The staggered contract models are well within the 95% confidence bands with the exception of the cross impulse response functions for output and inflation.

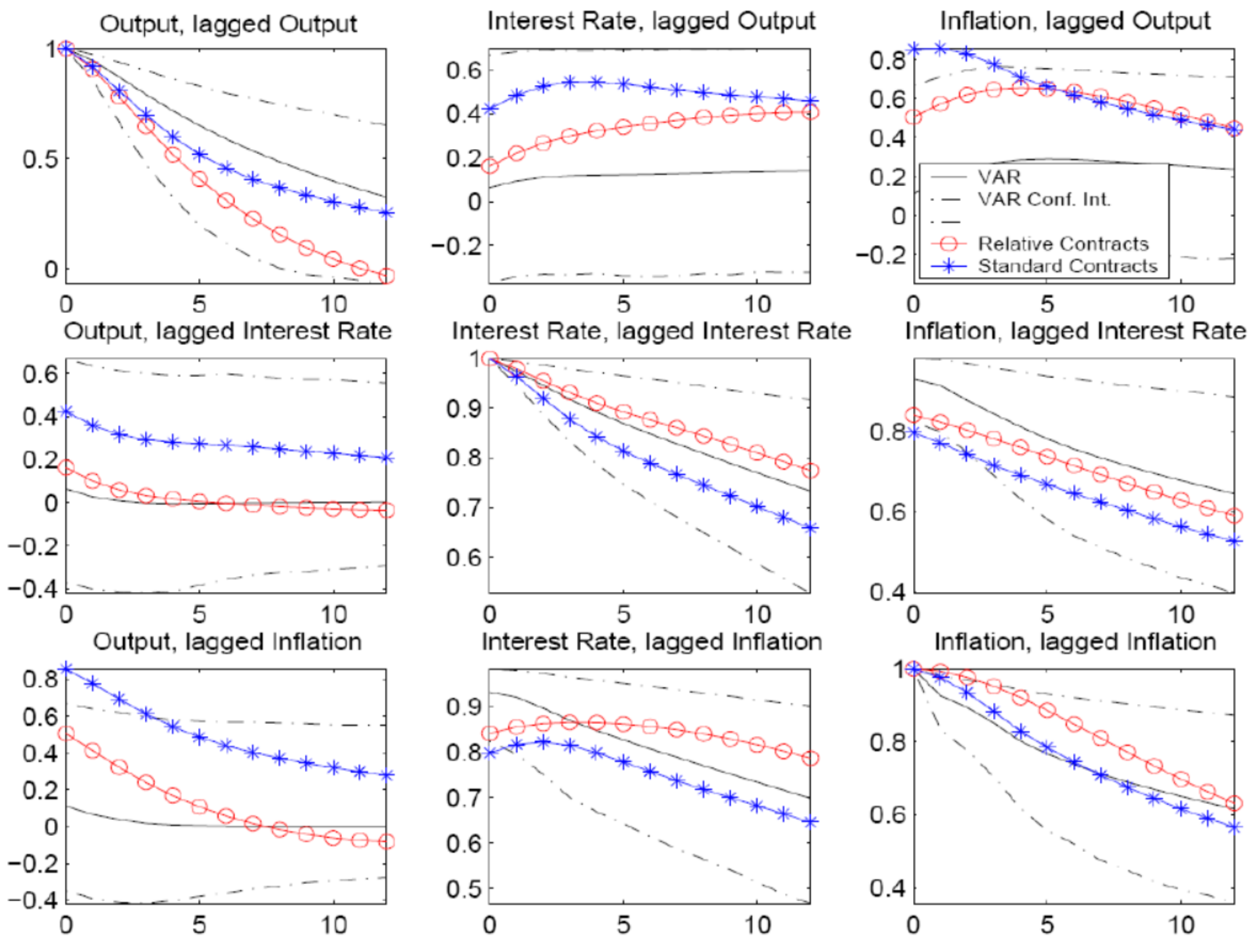

Figure 4. Staggered Contract Model explaining output, inflation and interest rate dynamics (Source: Guerrieri (2006)

Nevertheless both Christiano, Eichenbaun and Evans (2005) and Smets and Wouters (2003) felt the need to modify the staggered price and wage setting equations in order to get the proper persistence and better match the other cross correlations. They assumed backward-looking indexation in those periods when prices and wages were not allowed to adjust. The Christiano, Eichenbaum, Evans (2005) model assumes wages and prices are indexed to last period's inflation rate during periods between changes, while the Smets-Wouters model assumes firms index to a weighted average of lagged and steady-state inflation.

None of these modifications are part of the optimization process; they are akin, in my view, to simply assuming that wage and price inflation is autoregressive in an ad hoc way rather than deriving the equations.

6 Surprising properties

An important question for research is how the overall properties of the models changed as a result of the innovations. The eight implications mentioned above still hold in my view but the quantitative sizes of the impacts are important to pin down. Taylor and Wieland (2012) investigated this question using a new database of models designed for this purpose. They considered the Christiano, Eichenbaum, Evans (2005) model, the Smets and Wouters (2007) model, and the Taylor (1993) multicountry model mentioned in the previous section. Although the models differ in structure and sample period for estimation, the impacts of unanticipated changes in the federal funds rate are surprisingly similar.

There is a difference between the models in the evaluation of monetary policy rules, however. Model-specific policy rules that include the lagged interest rate, inflation and current and lagged output gaps are not robust. Policy rules without interest-rate smoothing or with GDP-growth replacing the GDP gap are more robust, but performance in each model is worse with the more robust rule.

6.3 Calvo contracts versus Taylor contracts

Walsh (2010, p.243) discusses some of the differences between the “Calvo contracts” described in Section 4 and “Taylor contracts” which are based on the canonical model in Section 3, though in way there are many other types of distributional assumptions other than the one assumed by Calvo (1982, 1983). Walsh (2010) notes a similarity between the two equations (his equation (6.17) and equation (6.36)) derived from the two models, but notes that Kiley (2002) uncovers some differences, including that the persistence is greater in the Calvo contracts for the same average frequency of price change.

There is no question that there is a much longer tail in the Calvo model than for any fixed length contract, but Dixon and Kara (2006) argue that Kiley's comparison is wrong because it compares "the average age of Calvo contracts with the completed length of Taylor contracts." When Dixon and Kara (2006) compare average age Taylor contracts with the same average age Calvo contracts, the differences become much smaller. They also show that output can be more auto-correlated with Taylor contracts with "age-equivalent" Calvo contracts.

In a series of papers Dixon and Kara (2005, 2001) and Kara (2011) develop what they call a Generalized Taylor Economy (GTE) where many sectors have staggered contracts with different lengths. When two such economies have the same average length contracts, monetary shocks are more persistent with longer contracts. They also show that when two GTE's have the same distribution of completed contract lengths, the economies behave in a similar manner.

Knell (2010) also considered the differences in more detail than Kiley. He examined survey data on wage-setting in 15 European countries from the Wage Dynamics Network (WDN) of the ECB. It is informative to quote from his paper: "There are at least four dimensions along which the data contradict the basic model with Calvo contracts. First, the majority of wage agreements seems to follow a predetermined pattern with given contract lengths. Second, while for most contracts this predetermined length is one year (on average 60% in the WDN survey) there exists also some heterogeneity in this context and a nonnegligible share of contracts has longer (26%) or shorter (12%) durations. Third, 54% of the firms asked in the WDN survey have indicated that they carry out wage changes in a particular month (most of them—30%—in January). Fourth, 15% of all firms report to use automatic indexation of wages to the rate of inflation. In order to be able to take these real-world characteristics of wage-setting into account one has to move beyond the convenient but restrictive framework of Calvo wage contracts." Knell then presents a model along the lines of Taylor (1980) that allows one to incorporate all of these institutional details.

7. State Dependent Models and Staggered Contracts

A more recent development has been to relax the simplifying assumption that prices are set for an exogenous interval and allow the firm's price decision to depend on the state of the market, which gave rise to name "state dependent" pricing models and created the need to give the original canonical model a new name, "time dependent." (See Dotsey, King, and Wolman (1999), Golosov and Lucas (2006), and Gertler and Leahy (2008)). There are some benefits from these improvements as Klenow and Kryvtsov (2007) have shown using new microeconomic data. Many of the key policy implication mentioned above hold but the impact of monetary shocks can be smaller.

Alvarez and Lippi (2014) consider a state-dependent model with multiproduct firms, which is otherwise similar to the state dependent model of Golosov and Lucas (2007). They find that as they alter the model from one product firm to a multiproduct firm, the impact of monetary shocks becomes larger and more persistent. For a large number of products they show that the economy works as in the staggered contract model: it has the same aggregation and impulse response to a monetary shock. In this sense, the menu cost models with multi-product firms gives another basis to the staggered contract model.

Woodford (2003, p. 142) questions whether the state dependent models are really any better than the staggered contract models. Not only are they more complex, he argues, but they may be less realistic and have inferior micro-foundations. The idea that firms are constantly evaluating the price misses the point that firms set their prices for a while to reduce "the costs associated with information collection and decision making. Kehoe and Midrigan (2010) have developed a model in which formal considerations of such management costs do indeed increase the impact and persistence of shocks.

8. Wage-Employment Bargaining and Staggered Contracts

In recent years there has been an increased interest in explaining fluctuations in unemployment as well as output. As explained by Hall (2005), the standard wage-employment bargaining model needs to assume some form of sticky wages if it is to be consistent with the data, and for this reason the idea of nominal rigidities is common to this research. It is not surprising therefore that many of the models built to examine this question have combined staggered contracts with a formal treatment of the wage-employment bargaining. Ravenna and Walsh (2008), Gertler, Sala and Trigari (2008), and Christiano, Eichenbaum and Trabandt (2013) focus on this question.

There are some byproducts too. The Christiano, Eichenbaum and Trabandt (2013) model is able to drop the arbitrary indexing assumption in Christiano, Eichenbaum and Evans and still get the requisite persistence. This works because when a monetary shock increases the demand for output and sticky price firms produce, the firms also purchase more wholesale goods. With this model, the authors argue that "alternating offer bargaining mutes the increase in real wages, thus allowing for a large rise in employment, a substantial decline in unemployment, and a small rise in inflation."

9. Staggered Contracts versus Inattention Models

Mankiw and Ries (2001) have argued that the whole apparatus of staggered wage and price setting should be replaced by a model with inattention. They argue in favor of sticky information rather than sticky prices, mainly because such a model would solve the persistence problem alluded to above. Recall that the concern is that there may be too little persistence of inflation to monetary shocks in staggered price setting models. Though some would argue that the persistence is fine, it is important to consider alternatives.

The main question is why there should be more persistence with inattention than with staggered contracts. Upon examination it appears that in the sticky information model, the price could be set to increase during the so-called set period where it is fixed in the regular model. For example in a staggered contract model of four periods the price would be 1.015, 1.015, 1.015, 1.015 while in the sticky information it could be set as 1.0, 1.01, 1.02, 1.03 and could not change from that path. In effect, some inflation is built in. Figure 5 illustrates this and can be compared with Figure 1.

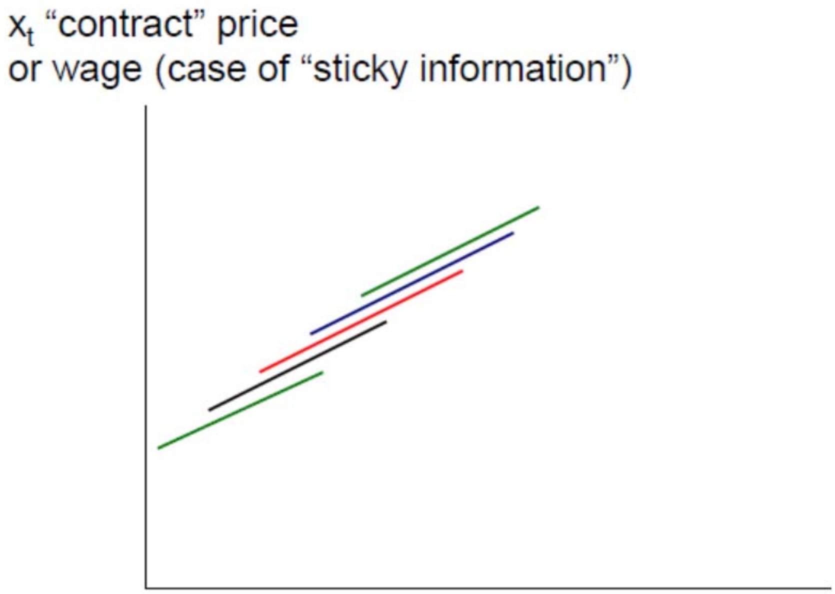

Figure 5. Price setting with sticky information to be compared with Figure 1

If prices or wages are set in this way it is clear that there will be more persistence of inflation. It is very rare, however, for prices or wages to be set in this manner except in multiyear union contracts as explained in Taylor (1983).

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