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Rational Expectations, Discrete Price-Setting and the Role of Monetary Policy

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Abstract:

The role of monetary policy is examined in a class of *discrete price-setting* rational expectations models, which differ from current continuous clearing models in taking for granted that there is a minimum wage price setting interval and by assuming that full employment output is ant over time. It is found that anticipated money has no effect on real output in the models studied here. Surprisingly, however, this neutrality result does not necessarily imply that constant money growth is the optimal monetary policy: If private agents have no informational advantage over the monetary authority, the optimal policy is a feedback rule links the rate of growth of money supply in the current period to the output gap in the previous period.

Rational expectations are the most important recent development in macroeconomic analysis, and it stands now undoubtedly as the dominant hypothesis on expectations formation. As is well known, it was brought forward, together with continuous market clearing and the Lucas supply function, as one of the three key elements in the new equilibrium approach to business cycle analysis, developed by Lucas (1972a, 1972b, 1973), Sargent (1973) and others[2]. It is obvious, however, that these three ideas are logically independent, notwithstanding the fact that they have been frequently associated in the literature. As a matter of fact, the models in Phelps and Taylor (1977), Fischer (1977) and Taylor (1980) are good examples of how it is possible to put together rational expectations and some fora of wage or price stickiness which precludes continuous market clearing.

I think it is fair to acknowledge that continuous market clearing is the weak point in the equilibrium approach to business cycles. It implies that wages and prices will be instantaneously reset every time there is an anticipated change in money supply, which means that they must be continuously flexible over time. Casual observation of wage and price behaviour in the real economy seems to give no support to this assumption, as we notice that most prices are changed only at discrete and somewhat regular intervals. This, as Arthur Okun (1980) has forcefully suggested, may itself be a result of efficient transactional mechanisms that exhaust all perceived mutually advantageous possibilities for trading between economic agents.

In this paper I propose to discuss the role monetary policy in a class of rational expectations models that contrast with current continuous market clearing models in taking for granted that there is a minimum wage and price-setting interval – sort of hicksian "week" – that defines the period of analysis. They also differentiate themselves from those models by assuming that full employment output is constant over time[3]. The main axioms here are a) that wages and prices are set at the start of each period and remain unchanged until the start of next period, while money supply may change continuously over time, and b) that though expectations are rational, all economic agents – inclusive of the monetary authority – receive information on the values of aggregate variables in a given period only at the beginning of the following period[4]. It follows that an unanticipated change in money supply will throw the economy out of equilibrium in the period it occurs[5]. Disequilibrium may also result from velocity or supply shocks, and once established, it may either tend to disappear in the

[2] See Barro (1981) for a recent Survey of the literature on the equilibrium approach to business cycles.
[3] Thereby avoiding the issue of whether the Lucas supply function remains a meaningful concept when the continuous market clearing assumption is violated. This also restricts the discussion to a stationary economy, though it would be easy to account for economic growth by defining full employment output in terms of a time trend.
[4] This means that the monetary policy lag has the same length as the (minimum) wage and price-setting interval, with both equal to the period of analysis. Later in the paper, the wage setting interval will be made smaller than the monetary policy lag when we come to discuss optimal monetary policy.
[5] Since Money supply may change continuously within period, we face a complex time-aggregation problem as we try to associate a single Money supply index to each period. We disregard this problem by using the period's *average* money supply as the relevant economic variable.

following period or to persist over several periods. In the former case, we have a discrete time analogue of continuous market clearing, which we call discrete market clearing, which we call *discrete market clearing*. It occurs if wages and prices jump at the beginning of each period to the levels that may be expected to produce equilibrium if the economy is not disturbed by some unforeseen event: hence, all markets are expected to clear in each period, though they may fail to do so as a result of unpredictable shocks[6].

The paper will show that in a discrete market clearing economy, anticipated money has no effect on real output. This is the same neutrality proposition derived by Lucas (1972), Sargent (1973), Sargent and Wallace (1975) and Barro (1976) from continuous market clearing models, but it will be seen here that it can be established even in models that generate persistent disequilibria. The main point of the paper, however, is that a constant money growth rule does not necessarily follow from the neutrality proposition; indeed, it is possible that a feedback monetary policy rule may be required to minimize the variance of the rate of inflation.

The paper is organized as follows. Section I sets down a basic model that provides a simple framework for the ensuing discussion. The model can be fixed to generate either discrete market clearing or persistent disequilibria. Section II derives its discrete market clearing solution and establishes the neutrality proposition for this case. Section III deals with persistent disequilibria, and finally, Section IV shows that in spite of the neutrality proposition, monetary policy activism may be desirable from the point of view of price stability.

I. The Basic Model

There are four equations in our basic model. First, there is a simple quantity theory of aggregate demand:

(1) $$dm_t + \delta_t = dy_t + dp_t$$

where y_t, p_t and m_t indicate the logarithms of real output, price level and average money supply in period t, and the letter "d" stands for the difference operator: $dm_t = m_t - m_{t-1}$. Velocity changes are assumed representable by a random white noise disturbance term δ_t.

A second equation decomposes the rate of growth of money supply into a systematic fully anticipated term x_t and a white-noise monetary policy shock μ_t:

(2) $$dm_t = x_t + \mu_t$$

This is just a restatement of the rational expectations assumption: the expected rate of growth

[6] If there is continuous market clearing, wages and prices are continuously flexible over time and the economy will be permanently in equilibrium. With discrete market clearing, however, since wages and prices are fixes within each period, the best the market system can do is to try to make the economy return immediately to equilibrium whenever it is thrown out of it by some unpredictable disturbance.

of money supply in period t, as computed using (2) at the end of period $t-1$, is $x_t = E_{t-1}(dm_t)$, and the forecast error $dm_t - E_{t-1}(dm_t)$ is a white-noise process. The operator $E_{t-1}(.)$ used in this paper to denote a conditional expectation based on the true model of the economy and on the values of all variables realized up to the end of period $t-1$.

Our third equation relates the price level to the nominal wage by a mark-up factor that does not depend on the level of activity[7], but can be affected by supply shocks:

(3) $dp_t = dw_t + \Phi_t$

where Φ_t is a white noise disturbance term representing supply shocks. It is worthwhile to notice that because information on aggregate variables is avail- able to economic agents only with a one period lag, the monetary policy shock must necessarily be uncorrelated with both velocity and supply shocks[8].

The model has to be closed with a wage-setting equation, but we cannot use the traditional Phillips Curve specification:

(4a) $dw_t = -a(\bar{y} - y_{t-1}) + dp_t^e = -ah_{t-1} + dp_t^e$

where $\bar{y}$ is full employment output, dp_t^e is the rate of inflation for period t as expected at the end of period $t-1$, $h_t = \bar{y} - y_t$ is the output gap measured by the logarithmic deviation of real output from its full employment level, and the slope coefficient (a) is a positive constant[9]. Bennett McCallum (1980) was the first to point out that this equation is incompatible with rational expectations. To see this put (3) and (4a) together into

$$dp_t = -ah_{t-1} + dp_t^e + \Phi_t$$

and apply the expectations operator $E_{t-1}(.)$ to both sides of the equation. Since $E_{t-1}(\Phi_t) = 0$, $E_{t-1}(dp_t^e) = dp_t^e$, and under rational expectations, $E_{t-1}(dp_t) = dp_t^e$ and $E_{t-1}(ah_{t-1}) = ah_{t-1}$, it follows that h_{t-1} is identical to zero (i.e., equal to zero for all values of t). Thus, real output must be permanently at its full employment level, which obviously cannot be true in a discrete price-setting economy exposed to unpredictable random shocks: this identity would only make sense in a continuous market clearing economy.

Phelps (1978) has used the following Phillips Curve specification in a rational expectations model:

(4b) $dw_t = -h_t^e + dp_t^e$

[7] This assumption is used here to keep the argument as simple as possible, but the Appendix shows that a flexible mark-up would not invalidate any of the conclusions of this paper.

[8] Hence, we cannot follow Taylor (1980) in assuming that the monetary policy rule is $dm_t = gdp_t$, where g is a positive constant smaller than one. This amount to $dm_t = gdw_t + g\Phi_t$, which implies, from (2) – assuming that dw_t is a fully anticipated variable – that $\mu_t = g\Phi_t$. In this case, the stochastic disturbances are not independent, and government may try to compensate supply shocks by means of monetary policy shocks. Such possibility is ruled out in our model because, if we give an informational advantage to the monetary authority, the case for policy activism becomes a trivial one.

[9] We cannot have h_t instead of h_{t-1} in this equation, because in a discrete price-setting economy, the value of h_t cannot be known at the beginning of period t when $dw_t = w_t - w_{t-1}$ is determined.

where $h_t^e = E_{t-1}(h_t)$. This equation, in conjunction with (3), implies – by the same argument used above – that h_t^e is identical to zero, or that real output is expected to be permanently at its full employment level, though this expectation may turn out to be wrong ex-post if the economy is hit by some unpredictable disturbance. Note that this is exactly our definition of discrete market clearing, which can exist only if wages and prices are free to jump at the beginning of each period to whatever levels may be required to ensure the expectation of equilibrium in the period. Hence, (4b) may be used to model an economy in which there is discrete market clearing, but not to model an economy in which disequilibria persists over time as a result of wage and price stickiness.

What we have to learn from (4a) and (4b) is that, if we want a Phillips Curve equation that does not impose any priori market clearing restriction on our model, we should not place the expected rate of inflation on its right-hand side. Obviously, to be consistent with long run money neutrality, the equation must decompose wage inflation into a cyclical component and an autonomous, "pure inflation", component; otherwise, steady state inflation would be incompatible with general equilibrium. But there is no reason, traditional usage notwithstanding, why the autonomous inflation component should be the same as the expected rate of inflation.

We write then our wage-setting equation as:

(4) $$dw_t = -a_t h_{t-1} + b_t$$

where both the slope coefficient, a_t, and the autonomous inflation term, b_t. must be determined as part of the solution of the model, after we specify the market behaviour hypothesis we want to consider. In the spirit of Lucas' 1976 critique, this Phillips Curve equation allows for the possibility of systematic parametric drift (or shift) in response to policy innovations (which are restricted here to changes in x_t).

Before proceeding to solve the model under different market behaviour assumptions, let us point out a few interesting relationships that may already be established here. First we clear up the connection between the expected rate of inflation and the autonomous inflation term in (4), which henceforth we call the "autonomous rate of inflation". By eliminating dw_t from (3) and (4), one finds:

(5) $$dp_t = -a_t h_{t-1} + b_t + \Phi_t$$

and by applying the (rational) expectations operator $E_{t-1}(.)$ on both sides of the equation[10],

(6) $$dp_t^e = -a_t h_{t-1} + b_t$$

This last equation shows that a) if the economy is in equilibrium in period $t-1$ (hence $h_{t-1} = 0$), expected inflation and autonomous inflation will be the same in period t; but, b) if the economy is out of equilibrium in period $t-1$, actual inflation will be expected to differ from autonomous inflation, because – as will be seen later in detail – in this case part of the inflation has to be "used"

[10] Note that $E_{t-1}(a_t) = a_t$ and $E_{t-1}(b_t) = b_t$ result from the assumption that economic agents have full knowledge on the true model of the economy.

to produce the adjustment process (basically, a change in the real quantity of money) by which the economy moves toward equilibrium. In other words, when the economy is in equilibrium, it is rational to expect that all of next period's inflation will be "pure", autonomous, inflation; when the economy is out of equilibrium, it is rational to expect that a cyclical component will be added to next period's inflation (relatively to what it would have been if the economy were in equilibrium), as a result of the automatic (though, perhaps, partial) response of the price system to disequilibrium.

Consider now the relationship between actual and expected rates of inflation. By subtracting (6) from (5), you may obtain:

(7) $dp_t = dp_t^e + \Phi_t$

which confirms the rationality of expectations in our model: actual and expected prices differ by a random, serially independent, forecast error. Is it puzzling that only the supply shock disturbance appears in this equation? Note, however, that we are dealing here with the expectation of the price level for period t, as calculated at the end of period $t-1$ when the output gap for that period is already known. Therefore, since economic agents have full knowledge of the true model of the economy, a supply shock is the only possible source of forecasting errors in (5). lf we look instead at the expected rate of inflation as computed before the end of period $t-1$, without knowledge of real output in this period, which we write as dp_t^{e-}, (6) has to be replaced by:

(8) $dp_t^{e-} = -a_t h_{t-1}^e + b_t$

where $h_{t-1}^e = E_{t-2}(h_{t-1})$. Subtracting (8) from (5), we now derive:

(9) $dp_t = dp_t^{e-} + \Phi_t + a_t(h_{t-1}^e - h_{t-1})$

showing that actual and expected prices may differ in this case as a result of both supply shocks and lagged demand (i.e., monetary policy or velocity) shocks.

II. Discrete Market Clearing

This section gives the solution of the basic model in the discrete market clearing case, and shows that it leads to the neutrality proposition. Equations (1) to (4) are not enough to determine our six unknowns dm_t, dp_t, dw_t, y_t (or h_t), a_t and b_t. Note however that, with discrete market clearing, wages and prices will be set, at the end of each period, at the levels that may be expected to clear all markets in the following period; therefore, real output must be expected to be permanently at its full employment level. This condition imposes two additional restrictions on the values of a_t and b_t which render the model determinate.

You may see this by substituting (2) and (5) into (1) to find:

$$dy_t = a_t h_{t-1} + x_t - b_t + \varepsilon_t$$

where $\varepsilon_t = \mu_t + \delta_t - \Phi_t$ is the net (expansionary) effect of random shocks on real output, or since

$dy_t = y_t - y_{t-1} = -h_t + h_{t-1}$,

(10) $h_t = (1 - a_t)h_{t-1} + b_t - x_t - \varepsilon_t$

Real output will be expected to be permanently at its full employment level if $h_t^e = E_{t-1}(h_t)$ is equal to zero for all values of h_{t-1} and x_t. Suppose first that $h_{t-1} = 0$; then $h_t^e = 0$ only if $b_t = x_t$, that is, if the autonomous rate of inflation is the same as the expected rate of growth of money supply. This reduces (10) to:

$$h_t = (1 - a_t)h_{t-1} - \varepsilon_t$$

which shows that, with h_{t-1} different from zero, $h_t^e = 0$ only if $a_t = 1$. Thus, discrete market clearing will occur only if $a_t = 1$ and $b_t = x_t$.

From these restrictions on the Phillips Curve parameters, that (5) may be rewritten as:

(11) $dp_t = -h_{t-1} + x_t + \Phi_t$

and that (10) is reduced to:

(12) $h_t = -\varepsilon_t$

or, equivalently:

(13) $y_t = \bar{y} + \varepsilon_t$

The last equation indicates that, under discrete market clearing, real output will depart from its full employment value only in response to unanticipated disturbances. Thus, the neutrality proposition holds: real output reacts to monetary policy shocks (μ_t), but the systematic anticipated component of money supply growth (x_t) has no effect whatsoever on its behaviour.

III. Persistent Disequilibria

Equation (13) leads to the neutrality proposition, but it also implies that real output is serially uncorrelated, which is, of course, inconsistent with the well-established evidence on real output persistence. One way to circumvent this problem[11] is to make the model generate persistent disequilibria as a result of the assumption that the nominal wage is sluggish when reacting to disequilibrium, but fully flexible when adjusting to changes in anticipated money. This "cyclical stickiness" of wages and prices has been rationalized by McCallum (1980) in terms of the real resource cost of rapid changes in employment and output. When expectations turn out to be wrong and the economy departs from equilibrium, allocation errors (such as the sub-optimal accumulation of inventories) may occur, and if these are costly to correct rapidly, an immediate return to the full employment output level may not be optimal from the point of view of rational economic agents.

[11] Another way is to assume that full employment output is determined by a Lucas supply function that has the lagged dependent variable on its right-hand side on account of, for example, capital stock inertia, as stressed by Lucas (1975), or inventory inertia, as stressed by Blinder and Fischer (1981). In this case, the model may generate output persistence from its supply side, even though discrete market clearing forces the output gap to be a white-noise process, as shown by (12).

This is not, however, a restriction on wage and price flexibility in response to fully anticipated changes in money supply.

To make the nominal wage "cyclically sticky" in our basic model, we have to assume that the Phillips Curve slope coefficient is smaller than its discrete market clearing value, say $a_t = a < 1$, while the autonomous rate of inflation remains equal to the expected rate of money growth (i.e., $b_t = x_t$) as in the discrete market clearing case. It follows, from (5), that the rate of inflation is given by:

(14) $$dp_t = -ah_{t-1} + x_t + \Phi_t$$

and, from (10), that the output gap is determined by the following first-order stochastic difference equation:

(15) $$h_t = (1 - a)h_{t-1} - \varepsilon_t$$

This last expression shows that disequilibria will persist over time, but it also shows that this is not sufficient to invalidate the neutrality proposition. As in the discrete market clearing case, in the present case only unanticipated money (μ_t) has any effect on real output.

IV. Optimal Monetary Policy

The neutrality proposition is usually assumed to provide strong intellectual support to Milton Friedman's (1959) proposal that monetary policy should follow a constant money growth rule. If anticipated money has no effect on real output and employment, monetary policy should be concerned only with price stability, and the optimal policy would be one that minimizes the variance of the rate of inflation around a desired target. This, so the argument goes, results from a constant rate of growth in money supply. We know that the argument is correct in the case of continuous market clearing models, but this section shows that, in the case of discrete price-setting models, monetary policy activism may be desirable from the point of view of price stability, in spite of the neutrality proposition. The discussion here will be initially concentrated on the simpler discrete market clearing model of Section II, but it will be shown later that it trivially generalizes to the persistent disequilibria model of Section III.

Suppose the monetary policy rule is given by:

(16) $$x_t = \bar{x} + gh_{t-1}$$

where x is the target rate of inflation; if $g = 0$ we have a constant money growth rule; if g is positive we have a feedback rule. We have seen that, in the discrete market clearing model, the rate of inflation is given, from (11), by:

(17) $$dp_t = -h_{t-1} + x_t + \Phi_t = \varepsilon_{t-1} + x_t + \Phi_t$$

since $h_{t-1} = -\varepsilon_{t-1}$, from (12).

From (16) and (17) it follows that:

(18) $dp_t = \bar{x} + (1-g)\varepsilon_{t-1} + \Phi_t$

and, by computing variances in this equation:

(19) $var(dp_t) = (1-g)^2 . var(\varepsilon_{t-1}) + var(\Phi_t)$

Thus, the variance of the rate of inflation is minimized when $g = 1$, and the optimal monetary policy rule is the feedback rule $x_t = \bar{x} + h_{t-1}$, in which the rate of growth of the money supply must deviate from trend in period t by exactly the output gap in period $t-1$.

A simple example may enhance our understanding of the above result. Suppose the economy is in equilibrium until period t when, ceteris paribus, it is hit by an expansionary velocity shock $\delta_t = \bar{\delta}$. The consequence is a negative output gap $h_t = -\bar{\delta}$, from (12), while the rate of inflation remains constant, $dp_t = \bar{x}$, as shown by (18). Assume there are no random shocks in period $t+1$. In that case, discrete market clearing will make the economy return to equilibrium in this same period; hence, $h_{t+1} = 0$ and $dy_{t+1} = -h_{t+1} + h_t = -\bar{\delta}$. From (1), follows that $dm_{t+1} - dp_{t+1} = -\bar{\delta}$, showing that the return to equilibrium will be accomplished through a reduction in the real quantity of money. This, however, can be done in many different ways. Consider first the case of a constant money growth rule, where $g = 0$; from (18) we see that $dp_{t+1} = \bar{x} + \bar{\delta}$, therefore, $dm_{t+1} = \bar{x}$. In this case, the reduction in real money results from a rise in the rate of inflation while money supply grows at a constant rate. Consider now the optimal feedback monetary policy rule, in which $g = 1$; from (18) we have $dp_{t+1} = \bar{x}$, and consequently, $dm_{t+1} = \bar{x} - \bar{\delta}$. In this case, the real quantity of money falls because the rate of growth of money supply is reduced while the rate of inflation remains constant. Obviously, the second policy is the best one from the point of view of minimizing the variance of the rate of inflation.

An interesting corollary from this discussion is that if monetary policy is optimal, with $g = 1$, the model will not generate a statistical Phillips Curve, in the sense of a negative covariance between h_{t-1} and dp_t. Note that, from (12) and (18):

(20) $cov(dp_t, h_{t-1}) = E\{[(1-g)\varepsilon_{t-1} + \Phi_t](-\varepsilon_{t-1})\} = -(1-b)var(\varepsilon_{t-1})$ which will be zero if $g = 1$. Hence, if we believe that our discrete market clearing model is an adequate representation of the real world, and we do observe a statistical Phillips Curve in it, we have to infer that monetary policy has been typically sub-optimal in the past[12].

It is worthwhile to point out that constant money growth will indeed be the optimal policy if the monetary authority has access to information on aggregate variables only with a two period lag – in which case (16) will not be a feasible policy rule – while the one-period information lag remains in effect for the private sector. It is easy to see that, if monetary policy sets $x_t = x + gh_{t-2}$, we have

(21) $dp_t = \bar{x} + \varepsilon_{t-1} - g\varepsilon_{t-2} + \Phi_t$

[12] Unless, of course, we have a Lucas supply function generating a statistical Phillips Curve from the supply side.

instead of (18), and the variance of the rate of inflation is minimized with $g = 0$. Thus, a constant money growth rule will be desirable, from the point of view of price stability, only if private agents have an informational advantage over the monetary authority. This is consistent with Lucas' (1980) recent reaffirmation of Friedman's proposal, but it also makes clear that the policy activism issue can only be settled on empirical grounds.

We now show that all of the discussion above trivially generalizes to the persistent disequilibrium model of Section III. From (16) and (14) it is seen that:

(22) $$dp_t = (g - a)h_{t-1} + \bar{x} + \Phi_t$$

which shows that the optimal monetary policy is given by $g = a$, or

(23) $$x_t = \bar{x} + ah_{t-1}$$

Here, the rate of growth of money supply deviates from trend in period t by a fraction of the output gap in period $t - 1$, the fraction being given by the slope coefficient of the Phillips Curve. We leave to the reader the simple tasks of checking that again no statistical Phillips Curve will be generated if monetary policy is optimal and that a constant money growth rule will be desirable from the point of view of minimizing the variance of inflation when private agents have an informational advantage over the monetary authority.

V. Conclusion

This paper has discussed the role of monetary policy in rational expectations discrete price-setting models. In these models, it is assumed that there is a minimum wage and price-setting time interval, which defines the period of analysis. Within each period, wages and prices are frozen but money supply and velocity are free to change continuously. Hence, notwithstanding the rationality of expectations, the economy will be thrown out of equilibrium by unanticipated disturbances in money supply or velocity. Disequilibrium may also result from supply shocks, which have been modelled here as unpredictable changes in an otherwise fixed mark-up factor linking prices to wages. If there is discrete market clearing, wages and prices are set at the beginning of each period at those levels that can be expected to clear all markets in that same period. In this case, disequilibrium will tend to vanish as soon as it appears, but models in which disequilibria may persist over time have also been studied.

It was shown that the Lucas-Sargent-Wallace neutrality proposition, which claims that anticipated money has no effect on real output, is rather robust in the class of models analysed here. It holds in a discrete market clearing model, but also in a model that may produce persistent disequilibria on account of cyclical stickiness of the nominal wage.

Unexpectedly, however, we have found that the neutrality proposition does not necessarily imply that the optimal monetary policy is constant money growth. In a discrete price-setting model in which anticipated money is neutral, but private agents have no informational advantage over the monetary authority, the optimal monetary policy is given by a feedback rule that links the rate of growth of money supply in the current period to the output gap in the previous period.

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Appendix

Here we consider a flexible mark-up version of our model, in which the price equation is

(A1) $dp_t = dw_t + jdy_t^e + \Phi_t$

where j is a positive constant and $dy_t^e = y_t^e - y_{t-1} = -h_t^e + h_{t-1}$ is the expected logarithmic rate of change of real output. Note that we cannot have dy_t instead of dy_t^e in this equation, because y_t is not known at the beginning of period t when $dp_t = p_t - p_{t-1}$ is determined.

Using (4) to eliminate dw_t in (A1), we get

(A2) $dp_t = (j - a_t)h_{t-1} - jh_t^e + b_t + \Phi_t$

From (1), (2), and (A2), it follows

(A3) $h_t = (1 - a_t + j)h_{t-1} - jh_t^e + b_t - x_t - \varepsilon_t$

and, under rational expectations, we may compute h by applying the expectations operator to both sides of this equation. The result is

(A4) $h_t^e = \frac{1-a_t+j}{1+j} h_{t-1} + \frac{b_t-x_t}{1+j}$

which reduces (A2) to the equivalent of (5):

(A5) $dp_t = -\frac{a_t}{1+j} h_{t-1} + \frac{b_t+jx_t}{1+j} + \Phi_t$

and (A3) to the equivalent of (10):

(A6) $h_t = (1 - a_t + j)h_{t-1} + b_t - x_t - \varepsilon_t$

From these two equations we may derive all results of the paper. For example, under discrete market clearing we have $a_t = 1 - j$ and $b_t = x_t$ and, therefore, from (A5),

(A7) $dp_t = -h_{t-1} + x_t + \Phi_t$

which is the same as (11); and from (A6):

(A8) $h_t = -\varepsilon_t$

which is the same as (12), and implies the neutrality proposition.