Aggregate Supply, Investment in Capacity, and Potential Output

The New-Keynesian aggregate supply derives from micro-foundations, an inflation-dynamics model very much like the tradition in the monetary literature. Inflation is primarily affected by: (1) economic slack, (2) expectations, (3) supply shocks, and (4) the persistence of inflation. This paper extends the New-Keynesian aggregate supply relationship to include also investment in capacity. Potential output, defined as the flexible-price equilibrium output depends endogenously on investment in capacity, on the pricing policy of firms. New-Keynesian theory stresses the notion that the pricing decisions are based on expected movements in marginal costs. In the absence of investment in capacity, inflation is related to movements in real marginal costs, and the latter is uniquely associated with movements in the output gap. In the presence of investment in capacity, the unique link between fluctuations in marginal costs and fluctuations in output gaps breaks down. Implications for central bank targeting of potential output and for the estimation of the Phillips curve are pointed out.

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The New-Keynesian aggregate supply relationship typically links inflation surprises with fluctuations in the output gap, while potential output, defined as the flexible-price equilibrium output, is exogenous. Based on such construct, micro-based interest rules respond exclusively to fluctuations in the inflation rates and the output gaps.

Another branch in the inflation literature is concerned with the long-term level of potential output. The literature points out to the long run costs of inflation, based on some cross-country evidence. Findings point to some threshold effects in the

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relationship between inflation and growth. Consequently, above certain country-specific inflation thresholds, growth is negatively affected by mean inflation (e.g., see Barro, 1995 and Khan and Senhadji, 2001). However, this long run channel through which monetary policy affects potential output is not considered in this paper. Rather, the paper demonstrates how to bring the potential output into the aggregate supply relationship, by incorporating the effects of investment in capacity on aggregate supply.

The analysis in the paper is conducted in an optimization-based “New Keynesian” framework, a la Blanchard and Kiyotaki (1987), employing the analytical tools in the lucid exposition of Woodford (2003). Specifically, the model features imperfect competition in the product market, in which the producers mark-up output prices over marginal costs, and also mark-down wages below the marginal productivity of labor. We thus derive a version of the mark-ups of prices over wages in our model. Mark-ups turn out to be counter-cyclical—a very pronounced phenomenon in the European markets, as noted by Cohen and Farhi (2001). They note that “European firms in bad times manage to keep the prices high, while their U.S. counterparts are pressed into cuts and discounts of various forms.” This is why the product market version of the Phillips curve (i.e., the relation between inflation and the output gap), in Europe, seems to be relatively more stable empirically than the labor market version (i.e., the relation between wage growth and unemployment).

Evidently, the equilibrium relation between inflation and excess capacity is significantly influenced by the degree of competition in the product market. A key feature of such equilibrium is the degree of strategic interactions between firms that set their prices ex ante and other domestic and foreign firms that set their prices so as to clear the markets ex post. This market-organization feature determines in turn the degree of price stickiness.

Understanding why nominal changes have real consequences (why a short run aggregate supply relationship exists) has long been a central concern of macroeconomic research. Lucas (1973) proposes a model in which the effect arises because agents in the economy are unable to distinguish perfectly between aggregate and idiosyncratic shocks. He tests this model at the aggregate level by showing that the Phillips curve is steeper in countries with more variable aggregate maximal demand. Following Lucas (1973), Ball, Mankiw, and Romer (1988) show that sticky-price Keynesian models predict that the Phillips curve should be steeper in countries with higher average rates of inflation and that this prediction too receives empirical support. Loungani, Razin, and Yuen (2001) and Razin and Yuen (2002) show that both Lucas’s and Ball–Mankiw–Romer’s estimates of the Phillips curve slope depend on the degree of capital account restrictions.

The paper is organized as follows. Section 1 lays out the New-Keynesian analytical framework. Section 2 derives the aggregate supply relationship. Section 3 concludes with implications of the aggregate supply relationship to optimising monetary rules, and to the empirical literature.
1. THE ANALYTICAL FRAMEWORK

Consider a closed economy with a representative household that is endowed with a continuum of goods-specific skills—uniformly distributed on the unit interval $[0, 1]$—to be supplied to a differentiated product industry. Consumption goods are distributed on $[0, 1]$. The household seeks to maximize a discounted sum of expected utilities:

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[ u(C_s; \xi_s) - \int_0^1 (\nu(h_s(j); \xi_s))dj + \phi(M_s/P) \right],$$

where $\beta$ is the subjective discount factor, $C$ is the Dixit–Stiglitz (1977) index of household consumption, $P$ the Dixit–Stiglitz price index, $M/P$ the demand for real balances, $\xi$ a preference shock, and $h(j)$ the supply of type- $j$ labor to the production of good of variety $j$. As usual, we define the consumption index and its corresponding price index, respectively, as

$$C_t = \left\{ \int_0^1 c(j) \frac{1}{\theta} dj \right\}^{1/\theta},$$

and

$$P_t = \left\{ \int_0^1 p(j)^{1-\theta} dj \right\}^{1/\theta}, \quad (1)$$

where $c(j)$ represents consumption of the $j$th good and $p(j)$ the price of $c(j)$. The elasticity of substitution among the different goods is $\theta > 1$, and the number of goods that are produced is equal to 1.

For our purpose, the relevant utility-maximizing conditions include an intra-temporal condition for the choice of labor supply of type $j$:

$$\frac{\nu(h_t(j); \xi_t)}{u_t(C_t; \xi_t)} = \frac{w_t(j)}{P_t}, \quad (2)$$

and an inter-temporal condition for the consumption-saving choice:

$$\frac{u_t(C_t; \xi_t)}{u_t(C_{t+1}; \xi_{t+1})} = \beta(1 + r_t), \quad (3)$$

where $r_t$ is the real rate of interest in period. As in the Dixit–Stiglitz (1977) model, demand for good $j$ satisfies

$$y(j) = Y_t \left( \frac{p_t(j)}{P_t} \right)^{-\theta}. \quad (4)$$
The production function assumes the form

\[ y_t(j) = k_t(j) f[A_t h_t(j)/k_t(j)] , \]

where \( A_t \) is a random labor-augmenting productivity shock. We follow Woodford (2003, chapter 5) and assume (for tractability) that there is a firm-specific capital stock, \( k_t(j) \), for each good, rather than a single-rental market for capital services that each producer has access to.

Investment spending is in the amount

\[ I_t(j) = I[k_{t+1}(j)/k_t(j)] k_t(j) . \]

The function \( I[\cdot] \) is a convex function, as in the standard investment cost-of-adjustment textbooks. \( I_t(j) \) represents purchases by producer \( j \) of a Dixit–Stiglitz composite good:

\[ I_t(j) = \left[ \int_0^1 \frac{1}{\theta} \theta^\theta (\theta^\theta - 1) dt \right] ^{\theta-1}, \theta > 1 . \]

For simplicity, the elasticity of substitution \( \theta \) is the same as in the case of consumption purchases. The variable cost of supplying \( y_t(j) \) is \( w f^{-1}[y_t(j)/k_t(j)] \). This implies that real marginal cost is:

\[ s_t(j) = \frac{w_t(j)}{P_t A_t f^4[f^{-1}(y_t(j)/k_t(j))]} . \]

By using Equation (2), we can replace the real wage above by the marginal rate of substitution. Imposing symmetry across firms (so that we can drop the index \( j \)), the above equation can be rewritten as

\[ s(k,y,C;\xi,A) = \frac{v_h[f^{-1}(y_t/k_t)] k_t \xi}{u(C;\xi,A_t f^4[f^{-1}(y_t/k_t)] } . \] (5)

1.1 Price Setting

Firms are monopolistically competitive in the goods markets, and each one of them behaves like a monopsony in the labor market (with producer \( j \) as the sole demander for labor of type \( j \)). A fraction \( \gamma \) of the monopolistically competitive firms sets their prices flexibly at \( p_{1t} \), supplying \( y_{1t} \); whereas the remaining fraction \( 1 - \gamma \) sets their prices one period in advance (in period \( t-1 \)) at \( p_{2t} \), supplying \( y_{2t} \). In the former case, the price is marked up above the marginal cost by a factor of \( \mu = ((\theta/(\theta - 1)) > 1) \), so that

\[ \frac{p_{1t}}{P_t} - \mu s(k_t y_{1t},Y - I_t \xi_t A_t) = 0 . \] (6a)
In the latter case, $p_{2t}$ will be chosen to maximize expected discounted profit

$$E_{t-1}\left\{\frac{1}{1 + i_{t-1}}\left[(p_{2t})^2 - w_t h_t\right]\right\}$$

$$= E_{t-1}\left\{\frac{1}{1 + i_{t-1}}\left[Y_t p_1^\theta p_{2t}^{1-\theta} - w f^{-1}(Y_t p_1^\theta p_{2t}^{1-\theta}/k)\right]\right\},$$

where we have used the inverse demand function from Equation (4) for $y_{2t}$ and the inverse production function for $h_t$. One can show that $p_{2t}$ satisfies

$$E_{t-1}\left\{\frac{1}{1 + i_{t-1}}\left[Y_t P_t^\theta - \mu s(k, y_{2t}, Y_t - I_t, \xi_t, A_t)\right]\right\} = 0.$$  \hspace{1cm} (6b)

This condition has an intuitive interpretation. In the special case of perfect certainty, this is nothing but a standard equation describing price as a mark-up over marginal cost like Equation (6a). With uncertainty, it can be interpreted as a weighted average of price mark-ups over marginal cost. This expected value is equal to zero. With price-pre-setting, the firm is committed to supply according to the realized demand. Hence, the realization of shocks will affect actual output, with negative shocks leading to excess capacity and positive shocks to over-capacity.\(^1\)

Our model predicts that the mark-ups of the producers who pre-set their prices will be counter-cyclical. Negative demand shocks will induce the flex-price firms to adjust their prices downward, attracting demand away from, and thus lowering the marginal costs and jacking up the price mark-ups, of fix-price firms.

Given $p_{1t}$ and $p_{2t}$, the aggregate price index in Equation (1) can be rewritten as:

$$P_t = \left[\gamma p_{1t}^{1-\theta} + (1 - \gamma)p_{2t}^{1-\theta}\right]^{1-\theta}.$$  \hspace{1cm} (1')

1. Woodford (2003) assumes the Calvo price-setting framework. He derives an aggregate supply block, consisting of multiple dynamic equations. Our assumed price-setting framework yields a single-equation aggregate supply relationship. This simple form focuses attention on the coefficient of the potential output variable in the aggregate supply relationship.
Equilibrium wage is given by B, with the worker’s real wage marked down below her marginal product by a distance AB.\footnote{Fig. 1. Labor Market Equilibrium}

Full employment obtains because workers are offered a wage according to their supply schedule. This is why our Phillips curve will be stated in terms of excess capacity (product market version) rather than unemployment (labor market version).

In fact, the model can also accommodate unemployment by introducing a labor union, which has monopoly power to bargain on behalf of the workers with the monopsonistic firms over the equilibrium wage. In such case, the equilibrium wage will lie somewhere between \( S_h \) and \( M P_h \), and unemployment can arise—so that the labor market version of the Phillips curve can be derived as well. To simplify the analysis, we assume in this paper that the workers are wage-takers.

1.3 Investment

Profit maximization by producer \( j \) yields a first-order condition for investment

\[
I'[k_{t+1}(j)/k_t(j)] = E_t \left( \frac{1}{1 + \theta} \right) P_{t+1} (q_{t+1}(j) + (k_{t+2}(j)/k_{t+1}(j))I'[k_{t+2}(j)/k_{t+1}(j)] - I[k_{t+2}(j)/k_{t+1}(j)]) ,
\]

where \( q \) is the shadow value (because there is not any rental market) of an additional unit of capital.\footnote{See Woodford (2003, chapter 5).} It is written in a Bellman-like equation as follows.

2. In the limiting case where the producers behave perfectly competitive in the labor market, the real wage becomes equal to the marginal productivity of labor and the marginal cost of labor curve is not sensitive to output changes. Thus, with a constant mark-up \( \theta/\theta - 1 \), the Phillips curve becomes flat, i.e., no relation exists between inflation and excess capacity.
\[ q(j) = w_i(j) \left( f(A_i h_i(j)/k_i(j)) \right) \left( f(A_i h_i(j)/k_i(j)) \right) \frac{f''(A_i h_i(j)/k_i(j))}{A_i f'(A_i h_i(j)/k_i(j))}. \] (7)

Note that if a rental market were to exist, \( q(j) \) in Equation (7) will be equal to the marginal productivity of capital, as expected from standard theory.

Potential output is defined as the price-flexible level of output. In the case where all prices are fully flexible (i.e., \( \gamma = 1 \), output will attain its natural level, \( Y^*_t \), implicitly defined by

\[ 1 = \mu s(K_t, Y^*_t, Y^*_t; I_t, \xi_t, A_t). \]

Note that, \( Y^*_t \) depends on the capital stock, \( K_t \), and on current investment, \( I_t \).

2. AGGREGATE SUPPLY AND INVESTMENT

This section derives the aggregate supply relationship. It has its roots in the expectations-augmented Phillips curve of the kind hypothesized by Friedman (1968) and Phelps (1970) for both closed and open economies (see also Ball, Mankiw, and Romer, 1988 and Roberts, 1995).

In order to obtain a tractable solution, we log-linearize the equilibrium conditions around the steady state. In the steady state, \( \hat{\xi} = 0 \) and \( \hat{A} = \bar{A} \). We assume that \( \beta(1 + r) = 1 \) and \( i = r \) (i.e., inflation is set equal to zero in the shock-free steady state). Define \( \hat{x}_t = \log(x_t/x) \) as the proportional deviation of any variable \( x_t \) from its deterministic steady state value \( \bar{x} \). We can then utilize the equilibrium condition \( C_t = Y_t - I_t \), and log-linearize the model equations around the deterministic steady state equilibrium.

\[ \omega = \omega_w + \omega_p, \]

\[ \omega_w = \frac{v_{hh}}{v_h}, \quad \omega_p = -\frac{f''}{f^{'2}}. \]

and

\[ \sigma = -\frac{cu_{cc}}{u_c}. \]

Log-linearizing the firm demands:

\[ \dot{y}_{1t} = \hat{Y}_t - \theta(\log(p_{1t}) - \log(P_t)). \] (4a)

\[ \dot{y}_{2t} = \hat{Y}_t - \theta(\log(p_{2t}) - \log(P_t)). \] (4b)
Log-linearizing the two price-setting Equations (6a) and (6b), the investment rule, Equation (7), and using Equation (8), yields:

\[
\log(p_{1t}) = \log(P_t) + (\omega + \sigma^{-1})(\hat{Y}_{1t} - \hat{Y}_{1t}^n) - \sigma^{-1}(\hat{I}_t - \hat{I}_t^n) - \omega_p(\hat{k}_{1t} - \hat{k}_{1t}^n). \\
\log(p_{2t}) = E_{t-1}[\log(P_t) + (\omega + \sigma^{-1})(\hat{Y}_{2t} - \hat{Y}_{2t}^n) - \sigma^{-1}(\hat{I}_t - \hat{I}_t^n) \\
- \omega_p(\hat{k}_{2t} - \hat{k}_{2t}^n)].
\]

Substituting Equations (4a) and (4b) and rearranging terms, we have

\[
\log(p_{1t}) = \frac{1}{1 + \theta(\omega + \sigma^{-1})}\{\log(P_t) + (\omega + \sigma^{-1})(\hat{Y}_t - \hat{Y}_t^n) \\
- \sigma^{-1}(\hat{I}_t - \hat{I}_t^n) - \omega_p(\hat{k}_{1t} - \hat{k}_{1t}^n)\}
\]

\[
\log(p_{2t}) = \frac{1}{1 + \theta(\omega + \sigma^{-1})}E_{t-1}\{\log(P_t) + (\omega + \sigma^{-1})(\hat{Y}_t - \hat{Y}_t^n) \\
- \sigma^{-1}(\hat{I}_t - \hat{I}_t^n) - \omega_p(\hat{k}_{2t} - \hat{k}_{2t}^n)\},
\]

where \(\hat{k}_{1t} = \hat{k}_{2t} = \hat{k}_n\) and \(\hat{k}_{1t}^n = \hat{k}_n^n\). Together, these equations imply that

\[
\log(p_{1t}) = E_{t-1}\log(p_{2t}).
\]

From the aggregate price equation, we know that

\[
\log(P_t) = \gamma\log(p_{1t}) + (1 - \gamma)\log(p_{2t}).
\]

Define, as standard, the inflation rate by, \(\pi_t = \ln(P_t/P_{t-1})\), so that \(\pi_t - E_{t-1}(\pi_t) = \log(P_t) - E_{t-1}\log(P_t)\). From these relationships, the unanticipated rate of inflation is given by

\[
\pi_t - E_{t-1}(\pi_t) = ((\log(p_{1t}) - E_{t-1}\log(p_{1t})) = \gamma(\log(p_{1t}) - \log(p_{2t})).
\]

Also, \(\log(P_t) = \gamma\log(p_{1t}) + (1 - \gamma)\log(p_{2t})\) implies that

\[
\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{1 - \gamma}(\log(p_{1t}) - \log(P_t)).
\]

These equations can now be combined to obtain the link between inflation surprise, and fluctuations in output gap, investment, and the stock of capital, as follows:

\[
\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{(1 - \gamma)}\left[\left(\frac{\omega + \sigma^{-1}}{1 + \theta\omega}\right)(\hat{Y}_t - \hat{Y}_t^n) - \frac{\sigma^{-1}}{1 + \theta\omega} (\hat{I}_t - \hat{I}_t^n) \\
- \frac{\omega_p}{1 + \theta\omega} (\hat{k}_t - \hat{k}_t^n)\right].
\]

Thus, inflation depends on inflation expectations, the output gap, the (log) difference between the actual and flexible-price investment, and the (log) difference between the actual and flexible-price stock of capital. Evidently, in the presence of
investment in capacity and rigid prices, monetary policy has long-lasting effects. By targeting inflation, the path of capital accumulation is affected.

\[
\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{(1 - \gamma)} \left[ \frac{(\omega + \sigma^{-1})}{1 + \theta \omega} \left( \hat{Y}_t - \hat{Y}_t^e \right) \right]
\]

In the absence of investment, however, the aggregate supply relationship reduces to the conventional relationship between surprise inflation and the output gap:

\[
\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{(1 - \gamma)} \left[ \frac{(\omega + \sigma^{-1})}{1 + \theta \omega} \left( \hat{Y}_t - \hat{Y}_t^e \right) \right].
\]

Therefore, the inflation-output trade-off becomes two-dimensional: between inflation rates and output gaps.

Note that potential output (the flexible-price output), which used in the output gap definition is linked to flexible-price investment, as follows.

\[
\hat{Y}_{t+1}^e = \frac{1}{\omega + \sigma^{-1}} \{ \omega_p \hat{K}_{t+1}^n + \sigma^{-1} I_{t+1}^e + u_t \}, \quad (10)
\]

where,

\[
u_t = \frac{\zeta}{\varsigma} d\bar{\xi}_t + \frac{\varsigma}{\zeta} d\bar{A}_t,
\]

is a synthetic shock term to preferences and technology.

Importantly, potential output is endogenously determined in the aggregate supply relationship, Equation (9). That is, the flexible-price output depends on the capital stock and investment. If a lagged level of the capital stock were to be used in the definition of the flexible-price output so as to make potential output exogenous, the flexible-price output would have appeared as a separate argument, side by side with the output gap, in the aggregate supply relationship.

Rearranging terms in Equation (10) and substituting the resulting relationship into Equation (9), yields an alternative form of the aggregate supply relationship:

\[
\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{(1 - \gamma)} \left[ \frac{(\omega + \sigma^{-1})}{1 + \theta \omega} \right] \left( \hat{Y}_t \right) - \frac{\sigma^{-1}}{1 + \theta \omega} \hat{I}_t - \frac{\omega_p}{1 + \theta \omega} \hat{K}_t - u_t \].
\]

Equation (11) demonstrates that the output gap, per se, need be linked to inflation surprise if actual investment and the preference shock are taken into proper account in the aggregate supply relationship.

Around the no-shock steady state \( I = \delta K \). Therefore, \( \hat{I} = \hat{K} \), and \( (\sigma^{-1}/(1 + \theta \omega)) \hat{I}_t - (\omega_p/(1 + \theta \omega)) \hat{K}_t = (\sigma^{-1} + \omega_p)/(1 + \theta \omega) \hat{E} \hat{Y}_{t+1}^n \). Substituting into
Equation (11) yields an approximate aggregate supply relationship, in which the future potential output enters as an independent argument, as follows.

$$\pi_t - E_{t-1}(\pi_t) = \frac{\gamma}{(1 - \gamma)} \left[ \left( \frac{\omega + \sigma^{-1}}{1 + \theta \omega} \right) (\hat{Y}_t) - \left( \frac{\sigma^{-1} + \omega}{1 + \theta \omega} \right) (E\hat{Y}_{t+1}^n) - u_t \right].$$

3. CONCLUSION

The New-Keynesian aggregate supply derives from micro-foundations an inflation-dynamics model very much like the tradition in the monetary literature. Inflation is primarily affected by: (1) economic slack, (2) expectations, (3) supply shocks, and (4) the inflation persistence. Thus, inflation depends on inflation expectations, the output gap, the (log) difference between the actual and flexible-price investment, and the (log) difference between the actual and flexible-price stock of capital. Evidently, in the presence of investment in capacity and rigid prices, monetary policy has long-lasting effects. By targeting inflation, the path of capital accumulation is affected, and thereby the level of expected future potential output.

Should potential output become a target variable for central banks in addition to inflation and output gaps? First, one has to be clear what “target variable” and “responding” means. The most useful definition of “targeting” a variable is that the variable is a “target variable” in the sense of it is an argument in the loss function to be minimized by the central bank (the loss function is increasing in the distance between the target variable and the “target level” for that variable). There is another use of “targeting a variable” as meaning “responding to a variable.” The latter means that the variable in question is an argument in the reaction function that represents the equilibrium instrument setting as a function of the state of the economy. The problem is that relation between the loss function and the corresponding optimal reaction function (the reaction function, which minimizes the loss function) is complex and typically not one-to-one. What enters into the reaction function are the determinants of (the forecasts of) the target variables. That is, the predetermined variables that describe the state of the economy. Typically, a target variable enters the reaction function only if the variable is also a predetermined state variable. If potential output is the full-fledged price-flexible output, a clearly endogenous concept, it does not qualify to be a target variable. But, if the potential output is the flexible-price output based on some predetermined stock of capital, it does qualify top be a target.

Should potential output be a target variable, in the sense of independently entering into the loss function? This is an open question, awaiting for the derivation of a loss function, which is consistent with the representative individual utility function, in the presence of investment in capacity.

In the open-economy literature, terms other than the output gap have already appeared in the aggregate supply function, once one substitutes the marginal costs by its determinants. Gali and Monacelli (2003) demonstrate that in the open-economy case, while the marginal rate of substitution relates the real exchange rate with
a consumption basket containing domestically produced and imported goods, the marginal product depends on domestic production. This drives a wedge among the CPI and the GDP deflators, leading to an additional term in the aggregate supply, the real exchange rate. Razin and Yuen (2002) demonstrate how to incorporate the real exchange rate in the New-Keynesian aggregate supply function.

The broader-scope aggregate supply that is derived in this paper has also implications for the empirical literature. The New-Keynesian Phillips curve has attracted renewed interest also in much of the empirical research. Gali and Gertler (1999) and Gali, Gertler, and Lopez-Salido (2001) present evidence that U.S. and Europe inflation dynamics are consistent with a variant of the New-Keynesian Phillips Curve. Potential output plays a role in the analysis only to the extent that it is needed to measure the output gap. New-Keynesian theory stresses the notion that the pricing decisions are based on expected movements in marginal costs. In the absence of investment in capacity, inflation is related to movements in real marginal costs. The latter is uniquely associated with movements in the output gap. In the presence of investment in capacity, the unique link between marginal costs and output gaps breaks down. The recent empirical literature’s econometric strategy is to link inflation surprise to marginal costs, rather than to output gaps, potential output, etc.

LITERATURE CITED


