Search-and-Matching Analysis of High Unemployment Caused by the Zero Lower Bound *

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Abstract

A basic principle of macroeconomics holds that an excessive real interest rate is the cause of high unemployment at the zero lower bound on the nominal interest rate. Absent the bound, the rate could be negative and the real rate could be low enough to restore full employment. Models backing up this principle make controversial assumptions about price-stickiness and the failure of market-clearing in the product market and sometimes in the labor market. This paper generates realistic effects of the zero lower bound without those assumptions, by substituting a search-and-matching setup in both the product and labor markets.

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> A landing on the non-Walrasian continent has been made. Whatever further exploration may reveal, it has been a mind-expanding trip: We need never go back to $\dot{p} = \alpha(D - S)$ and $q = \min(D, S)$. (Phelps and Winter (1970), p. 337)

Dale Mortensen participated in the famous conference in January 1969 that gave rise to the Phelps volume, and his paper for the conference delivered on Phelps and Winter's promise to banish demand gaps and *ad hoc* adjustment processes from macroeconomics. But demand gaps abound in macro today. Major economies have been stuck at the zero lower bound on the short-term interest rate for six years. The macro profession's analysis has relied uniformly on demand-gap models. This paper undertakes the task of building a model reasonably faithful to the basic facts about the zero lower bound without invoking a demand gap, but rather relying heavily on the Diamond-Mortensen-Pissarides search and matching model.

To frame the issue in this paper, consider a simple frictionless general-equilibrium macro model with a unique equilibrium. The model will describe an equilibrium value of the short-term safe real interest rate. Now implant a central bank in the model with a policy of setting that rate at a value above the equilibrium value. In particular, suppose that the bank's interest rate is elevated by the zero lower bound. What happens in the model? It cannot have an equilibrium—its only equilibrium is ruled out by assumption. One solution in macro theory to disable one equation. Then the model has one less endogenous variable, the interest rate (made exogenous by the zero lower bound), and one less equation. One example is to drop a clearing condition for the labor market and to interpret the gap between labor supply and labor demand as unemployment. When the central bank sets a rate above equilibrium, labor demand will fall short of labor supply and unemployment will be above its normal level. This approach has some practical appeal and often gives reasonable answers.

A closely related approach is to place the demand gap in the product market. Krugman (1998) and Korinek and Simsek (2014) are examples of that approach. Farhi and Werning (2013) present a general analysis of demand gaps, where any set of prices and wages can be jointly restricted and gaps can occur in any market.

The New Keynesian tradition takes a different and more subtle approach to this issue by adding the price level as another endogenous variable without any corresponding equation. The model has demand gaps in the product market associated with temporarily sticky prices that adjust over time to close the gaps. Thus it contains both of the equations that

Phelps and Winter hoped to supplant in macro theory. Eggertsson and Krugman (2012) and Christiano, Eichenbaum and Rebelo (2011) apply the NK model to the zero lower bound issue. One branch of the NK literature—notably Walsh (2003), Gertler, Sala and Trigari (2008), and, most recently, Christiano, Eichenbaum and Trabandt (2013)—uses the Diamond-Mortensen-Pissarides framework to describe the labor market, so the only role of demand gaps in in the product market. Skeptics question their success in matching actual movements of the price level in recent years. Cochrane (2014) finds that the NK model has multiple equilibria, and that the equilibrium chosen in papers studying the zero lower bound has quite different properties from other equilibria.

This paper uses a simple version of the standard DMP model in the labor market and a somewhat less standard search-and-matching model in the product market. The model tracks the intuition of most discussions of the zero lower bound. An elevated real interest rate encourages the deferral of spending by raising the incentive to save. The incentive to create jobs that is the driving force of labor-market tightness in the DMP model is depressed on account of the deferral incentive. Higher unemployment implies lower employment and lower production, which squares with the lower product demand. The economy is in a depressed equilibrium. Unlike other accounts of the adverse effect of the zero lower bound (or the elevation of the real interest rate by central-bank action apart from that bound), the model implies that the depressing effect of a given elevation of the real rate is greatest at the beginning of the episode and gradually declines, even though the rate remains at the same level. The model encounters none of the subtle issues of multiple equilibria that plague the NK model, most recently discussed in Cochrane (2014).

I puzzled over the question of the link between the DMP labor market and the product market for some time before finding the setup described in this paper. I enlisted Mortensen in the quest for a coherent link when he was the discussant of a early ancestor of this paper in 2011. Mortensen (2011) was his answer—this written discussion appears in the appendix to this paper. He showed how to link a fixed-price product market to the DMP model. My objective here is different—it is to construct a DMP-style model of the product market and link it to the DMP labor market.

The basic idea of the model of the product market is that the opportunity to save at an elevated real interest rate alters the outside option of a consumer in the product market. In a standard Nash bargain, the product price is lower in the presence of cheaper consumption

from a source other than a current producer. The product price is the payoff to the producer from hiring an added worker, so by standard DMP logic, the labor market softens and unemployment rises when the interest rate is elevated.

The paper deals only with the issue of an elevated real interest rate and does not tackle the interesting question of translating the bound on the nominal rate into one on the real rate. That is, the paper has nothing to say about expected inflation. Because almost nothing actually happened to expected or actual inflation after the financial crisis of 2008, working with the real rate makes practical sense. but it remains an interesting question why there was such a pronounced failure of $\dot{p} = \alpha(D - S)$.

1 Model

The economy lasts for T periods and has four kinds of agents:

(1) *Endowed households* of measure one, with utility

$$\sum_t c_t, \tag{1}$$

where c_t is consumption in period t. These households have unit endowments of a primary input in each period .

(2) *Workers* of measure $\lambda > 1$, with the capacity in each period to turn one unit of the primary input into consumption, for which they receive a wage of w units of consumption goods. Their reservation wage is z.

(3) *Firms*, intermediaries who receive the input from endowed households, hire workers at the wage w, and return $1 - p$ units of consumption to endowed households for each unit of the input. Firms enter freely and earn zero profit, so the preferences of their owners are irrelevant.

(4) A *central bank* that accepts deposits (reserves) from endowed households that pay interest, in the form of the primary input, at a per-period rate of r, the *reserve rate*. The bank has a policy of keeping the total outstanding volume of reserves constant.

1.1 Frictionless equilibrium

The endowed household's demand for consumption is

$$c_t = 1 - p_t. \tag{2}$$

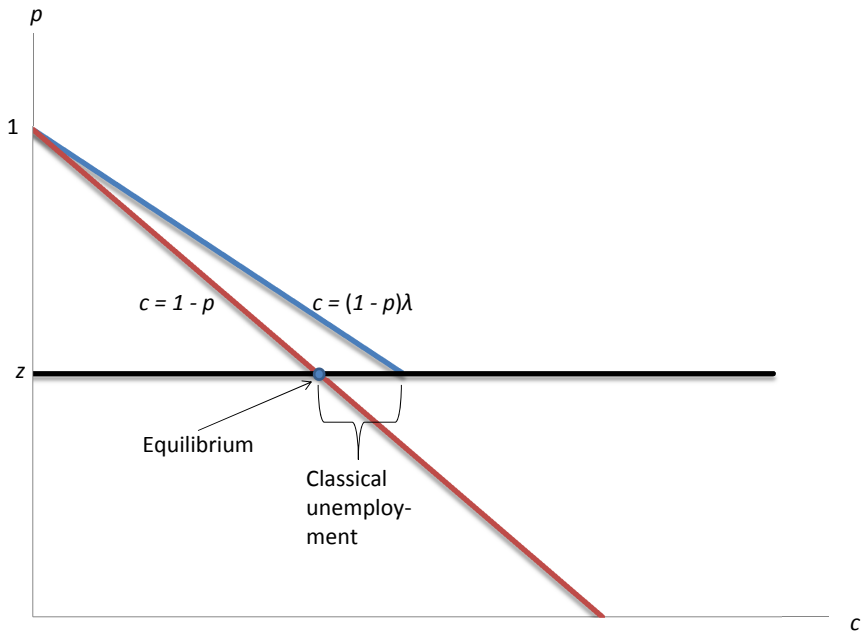

Figure 1: Equilibrium without Frictions

In the frictionless case, the wage is $w_t = p_t$ and the supply of consumption by firms, integrated with the market for workers, is

$$\begin{aligned} c_t &= 0 \text{ if } p_t < z \\ &\in [0, (1-z)\lambda] \text{ if } p_t = z \\ &= (1-p_t)\lambda \text{ if } p_t > z \end{aligned} \tag{3}$$

Figure 1 shows the equilibrium of the model. At any price above z, there is an excess supply of consumption, in the sense that the measure of workers strictly desiring to work exceeds the demand of the endowed households. At any price below z, there is excess demand. At the equilibrium, $p_t = w_t = z$, all endowed households turn their inputs over to firms for conversion to output and receive $c_t = 1 - p_t = 1 - z$ consumption units in return, while a measure one of the workers are employed at the reservation wage z, and the remainder, $\lambda - 1$, do not work. The remainder is *classical unemployment* in the sense that they are indifferent between working and not working. Notice that this unemployment arises from the assumption of a fixed-coefficients technology and an excess of workers over endowed households. In the opposite case, the equilibrium price would be one and the households would be indifferent to participating in the consumption market.

Figure 1 shows a point with $p = 1$ that satisfies the conditions embodied in the figure. At that point, the endowed households turn their inputs over to firms for conversion to output and receive nothing in return. Workers receive a wage $w = 1$ and capture the entire surplus from trade. But this point is not an equilibrium in the labor market, because the entire labor force with measure $\lambda > 1$ unambiguously desires to work, but feasible employment is only one.

1.2 The central bank

The next step is to bring the central bank into the model. It sets a positive reserve rate r in all periods. An endowed household now faces an intertemporal choice, because it has the option of deferring consumption by depositing some of its endowment at the central bank. The period-1 Arrow-Debreu price for period-t consumption is

$$a_t = \frac{p_t}{(1+r)^{t-1}}. \tag{4}$$

Let $\underline{a} = \min_t a_t$. The household will choose $c_t = 0$ for all t with $a_t > \underline{a}$.

Although deferring consumption is an option open to individual endowed households, the central bank does not hold positive amounts of aggregate deposits. Rather, its policy is to keep them at zero. This policy mirrors that of many real-world central banks, which keep reserves at specified levels—they do not permit reserve holders (generally commercial banks) collectively to influence the volume of reserves. For convenience, I assume that reserves are always zero, but the analysis would be the same for any positive constant level of reserves.

All of the conditions for equilibrium shown in Figure 1 continue to hold in the model extended to include a central bank with a positive reserve rate. If the model has an equilibrium, it must be one shown in the figure. Consider first the low-price equilibrium, with price and wage equal to the reservation wage z, consumption of one, and classical unemployment of $\lambda - 1$. Then it remains to consider the new, intertemporal, condition for the timing of consumption based on the price in equation (4). For an economy with $p_t = z$ in every period, the equation becomes

$$a_t = \frac{z}{(1+r)^{t-1}}, \tag{5}$$

which reaches an unambiguous minimum in period T. In that economy, endowed households consume only in the last period, when consumption is cheapest. All individual household plan to build balances at the central bank in every period but the last, then consume the balance in the last period.

A simple conclusion follows: *The economy has no equilibrium with a positive reserve rate.* This conclusion applies quite generally to general-equilibrium macro models. It lies at the heart of the papers on the zero lower bound outside the New Keynesian paradigm, notably Krugman (1998) and Korinek and Simsek (2014). The quick and dirty explanation is that adding a central bank that sets an interest rate different from the equilibrium rate of a model, without removing an equation, results in an over-determined system of equations that has no solution.

1.3 Demand-gap unemployment

A simple description of an economy subject to an excessive real interest rate in the literature on the zero lower bound removes an equation, namely the market-clearing condition for the labor market, to obtain a model with a solution. Here, market clearing means that supply and demand must be equal unless the wage is equal to the reservation price of labor. The only kind of unemployment consistent with the model is benign classical unemployment, where workers are indifferent between work and unemployment. Without labor-market clearing, the wage and price could lie in the range between the reservation wage z and the maximum feasible level of one. In that range, demand-gap unemployment occurs, where workers would affirmatively benefit from more work, but demand constrains employment at the lower level. Unemployment is the gap between the supply of labor and the demand. Figure 2 shows such a price and the resulting demand gap.

A feasible path of the economy exists with prices satisfying the intertemporal equality condition (the consumption Euler equation) of the endowed households and with demand-gap unemployment in every period. The price trajectory is

$$p_t = \frac{p_T}{(1+r)^{T-t}}, \tag{6}$$

with p_T less than one but close enough that $p_1 \geq z$. Then

$$a_t = \frac{p_T}{(1+r)^{T-1}} \text{ for all } t. \tag{7}$$

Demand-gap unemployment is

$$u_t = \lambda - 1, \tag{8}$$

the excess of the labor force over maximum feasible employment.

The demand-gap level of unemployment along this path has no connection to the level from the DMP model of unemployment. The demand-gap model and the DMP model clash.

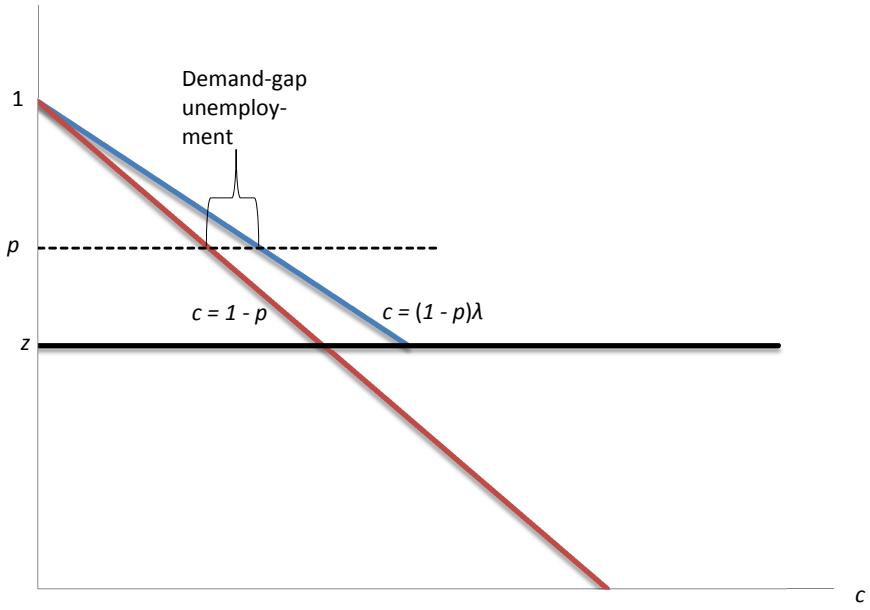

Figure 2: Demand Gap Resulting from a Price and Wage above the Equilibrium Level

2 Search and Matching

As in the standard DMP model, jobseekers search for employment opportunities at firms. The searchers meet firms at random. The firm posts employment opportunities to attract jobseekers. The flow cost of posting is k and the flow probability of matching is q. The probability that a jobseeker will encounter a posting is $\phi(q)$, a decreasing function. The number of postings is $V = \frac{\phi(q)}{q}U$, where U is the number of searchers. A reasonable specification for $\phi(q)$, based on the matching function $\alpha\sqrt{UV}$, is

$$\phi(q) = \frac{\alpha^2}{q}. \tag{9}$$

2.1 Nash-bargained wage

The worker and the firm make a Nash bargain, with a fraction β of the surplus going to the worker. To simplify the bargaining problem relative to the standard model of Mortensen and Pissarides (1994), I assume that jobs last only one period and the worker's outside option is to receive the non-work value z during that period. The payoff to the firm from a match is the price p that the firm will earn in the consumption market. The surplus from a match is $p - z$; the worker receives a fraction β of the surplus and the firm retains the rest.

2.2 Unemployment

Firms expand their efforts to find workers to the point of zero profit:

$$q(1-\beta)(p-z) = k. \tag{10}$$

The unemployment rate is

$$u = 1 - \frac{\alpha^2}{q} \tag{11}$$

and the wage is

$$w = z + \beta(p-z) = \beta p + (1-\beta)z. \tag{12}$$

The labor market imposes a functional relation between unemployment and the price:

$$u(p) = 1 - \frac{(1-\beta)\alpha^2(p-z)}{k}. \tag{13}$$

2.3 Product market

With unemployment, employment may fall short of the level needed to convert all of the primary factor supplied by endowed households into consumption goods. For simplicity, I assume that this always happens, by setting $\lambda = 0$. The matching function for transactions between endowment households and firms is the minimum of the amount offered for conversion by households and the conversion capacity of firms, $1-u$.

I assume that a matched household and firm make a Nash bargain for the price of consumption goods, p. The firm's outside option is to sell to another household at the prevailing price, $\bar{p}$, but the firm faces a cost γ of breaking off bargaining with one household and starting up with another, so the outside option is worth $\bar{p}-\gamma$. In period T, the household has no outside option because there are more households offering to trade their endowments for consumption goods than there are firms able to convert endowment goods to consumption goods, and no opportunity to invest the endowment at the central bank. The surplus from the potential trade is $1-(\bar{p}_T-\gamma)$. The bargaining weight for the household is b. The bargained price solves

$$1 - p_T = b[1-(\bar{p}_T-\gamma)]. \tag{14}$$

In the symmetric equilibrium, where $\bar{p} = p$, the price is

$$p_T = 1 - \frac{b}{1-b}\gamma. \tag{15}$$

In earlier periods, the endowed household has the option to invest its endowment at the central bank at rate r for τ periods, and pay

$$\frac{p_{t+\tau}}{1-u_{t+\tau}} \tag{16}$$

for conversion in period $t+\tau$. The effective price is boosted by division by $1-u_{t+\tau}$ to account for the possibility that the household will not be matched to a firm. The present value in period $t-1$ of output purchased by saving in period $t-1$ and purchasing in period $t+\tau$ is

$$X_{t,\tau} = \frac{p_{t+\tau}}{(1+r)^{\tau}(1-u(p_{t+\tau}))}. \tag{17}$$

The most advantageous outside option is

$$x_t = \min_{\tau} X_{t,\tau}. \tag{18}$$

This outside option for the household in period t is worth $1-x_t$. If $x_t > 1$, it has no influence and the bargain becomes the same as in period T, in which case I redefine $x_t = 1$. The firm has the same option as in period T. The surplus is

$$S_{t-1} = 1 - (1-x_t) - (\bar{p}_{t-1} - \gamma). \tag{19}$$

The household's payoff is

$$\begin{aligned} 1 - p_{t-1} &= bS + 1 - x_t \\ &= b[1 - (1-x_t) - (\bar{p}_{t-1} - \gamma)] + 1 - x_t. \end{aligned} \tag{20}$$

The symmetric equilibrium is

$$p_{t-1} = x_t - \frac{b}{1-b}\gamma, \tag{21}$$

provided that $p_t \geq \lambda$ for all t. Given p_T from equation equation (15), one can compute the equilibrium price path by backward recursion.

2.4 Equilibrium with frictional labor and product markets

With a central bank, equation (21) gives the equilibrium path of the price that endowment households pay for consumption goods, Equation (13) gives the corresponding unemployment rate, equation (10) the vacancy-filling rate q, and equation (9) the job-finding rate $\phi(q)$.

In the absence of a central bank, the determination of the price in every period follows the logic of the determination of the terminal price p_T expressed in equation (15). The price of consumption goods is

$$p = 1 - \frac{b}{1-b}\gamma \tag{22}$$

and the unemployment rate is

$$u = 1 - \frac{(1-\beta)\alpha^2(p-z)}{k}. \tag{23}$$

3 Properties of the Model

I describe the operation of the model using the following illustrative parameter values:

Efficiency of matching: $\alpha = 0.28$

Bargaining weight of jobseekers: $\beta = 0.5$

Bargaining weight of endowment households: $b = 0.5$

Firm's cost of maintaining a posting of a vacancy: $k = 0.02$

Flow value of not working: $z = 0.5$

Number of years: $T = 10$

Central bank's real interest rate: $r = 0.01$.

With these parameters, the unemployment rate in all years is $u = 0.055$, a normal level for the U.S. It is helpful to note that the DMP-style labor-market specification in the model has properties resembling those of sticky-wage specifications in the post-Shimer DMP literature. The elasticity of the unemployment rate with respect to the product price is around 25, a value known to equip the model to turn small observed fluctuations in productivity into meaningful fluctuations in unemployment. The model's reliance on Nash bargaining with equal bargaining weights—shown in Shimer (2005) to generate pathetically small fluctuations in unemployment—is offset by the model's different specification of the matching process.

Figure 3 shows the paths of the consumption price and unemployment. In years 7, 8, and 9, both p and u have the same values as in year 10 and are unaffected by the presence of the central bank. In year 6, the option to sock away wealth at the central bank is influential. The option delivers a more favorable price to the endowed households. The lower value of output depresses the labor market according to standard DMP principles—a lower p has the same effect as a decline of the same proportion in productivity in the DMP model. The effect on unemployment is substantial for the reason just noted. The effect is bigger in years

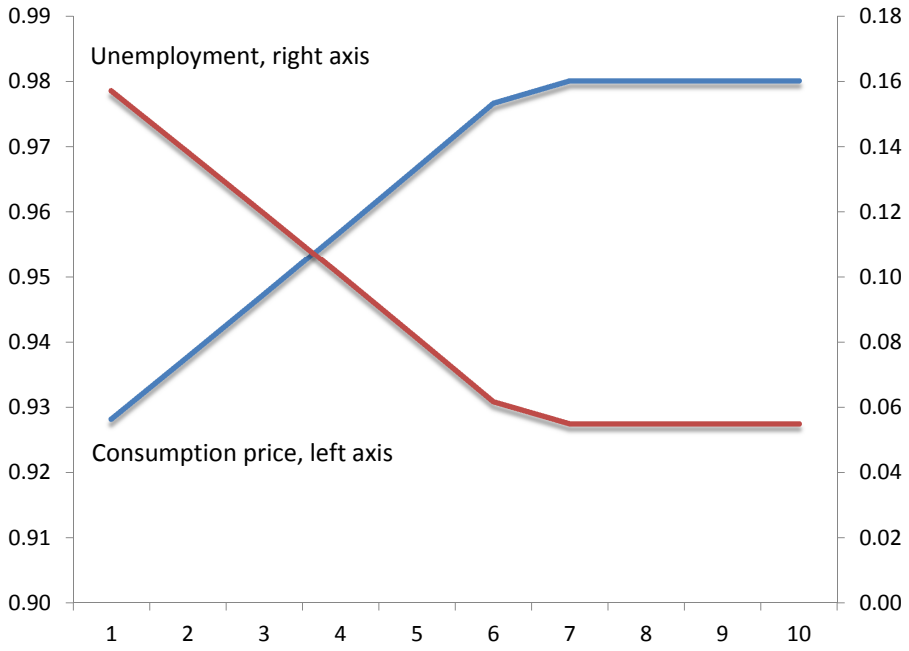

Figure 3: Paths of Unemployment and Consumption Price Induced by a Central-Bank Interest Rate of 0.01

1 through 5 because the discounting at rate $r = 0.01$ compounds to improve the endowed households' outside option to defer consumption through the central bank. The effect of the elevated interest rate in the first year is to raise unemployment to the near-depression level of 0.157.

4 Concluding Remarks

The zero lower bound on the nominal interest rate has cost the U.S., Britain, Europe, and Japan many trillions of dollars of lost output, according to the received principles of modern macroeconomics. The bound prevents the correction that otherwise would have occurred in the form of a real interest rate sufficiently low to maintain full employment. The intuition about the mechanism behind this effect is straightforward—a real interest rate that is above the full-employment level induces people to postpone spending.

Macroeconomists have used established models to study the postponement effect and to show how the decline in current product demand translates into lower output and employment. With the real interest rate out of the picture, no other equilibrating force takes over to limit the decline in output and employment. All models have questionable assumptions. The weak point in the New Keynesian models that completely dominate ZLB analysis today

is their assumption that businesses respond passively to declining demand until the random future moment when they can cut prices.

The NK model resonates with practical macroeconomists, but nonetheless it seems useful to see what happens if other assumptions—those of DMP's search-and-matching model—replace the demand-gap part of the NK model. This paper shows that the answer is that the DMP-based model is capable of generating realistic behavior.

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Appendix: Mortensen's discussion of my predecessor paper

The subject of Mortensen's discussion was an earlier version of a paper available on my website: http://www.stanford.edu/∼rehall/QuantifyingForces.pdf

Comments on Hall's "Clashing Theories of Unemployment"

Dale T. Mortensen, July 18, 2011

0.1 Introduction

In his paper, Bob Hall poses the following question: Is the DMP model of unemployment consistent with the neo-Keynesian theory under conditions of excess supply of final goods and services? In the later model, unemployment arises a consequence of insufficient demand for final goods and services, he contends, while in the former it appears to be determined by matching friction independent of product market conditions. The purpose of this note is to sketch a simple resolution of the apparent inconsistency.

0.2 The Model

Suppose that a single final good is produced with a continuum of intermediate inputs. For concreteness, assume a linearly homogenous Dixit-Stigliz production function of the form

$$Y = \left[\int_0^1 x(j)^{\frac{\rho-1}{\rho}} dj\right]^{\frac{\rho}{\rho-1}}.$$

In this case, the demand for each input is

$$x(j) = \left(\frac{P}{p(j)}\right)^{\rho} Y, j \in [0,1].$$

Perfectly competitive producers are willing to supply the final good so long as its price is no less than the marginal cost, which requires

$$P \geq \left[\int_0^1 p(j)^{\rho-1} dj\right]^{\frac{1}{\rho-1}}. \tag{1}$$

Of course, given demand, there is excess supply if the inequality is strict.

Suppose that intermediate products are produced using labor as the only input. Given constant returns, $x(j) = n(j)$ is the number of workers employed to produce product j. Suppose that there is a search market for labor

in each industry and that suppliers are perfect competitors in their product market. Given symmetry, all will receive the same price and hire the same number of workers, $p(j) = p$ and $x(j) = n(j) = n$ for all j where

$$n = \frac{m(\theta)}{m(\theta) + \delta}.$$

and $m(\theta)$ is the job finding rate expressed as function of the ratio of vacancies to unemployed workers and δ is the job destruction rate. Labor market tightness solves the free entry condition

$$\frac{Pc\theta}{m(\theta)} = \frac{(1-\beta)(p - zP)}{r + \delta}$$

where c is the cost of posting a vacancy in terms of final output, β is the workers share of match surplus, z is the real output opportunity cost of employment, r is the real interest rate and δ is the job separation rate. Hence, the market clearing condition in the intermediate goods market requires that

$$\left(\frac{P}{p}\right)^{\rho} Y = \frac{m(\theta(p/P))}{m(\theta(p/P)) + \delta} \tag{2}$$

where $\theta(p/P)$ is the increasing function implicitly defined by the free entry condition.

0.3 Implications of the Model

Equation (2) together with the inequality (1) define aggregate supply of final goods. As $p = p(j)$ for all j by symmetry so that (1) implies $P \geq p$, and the solution to (2) for the relative price of p/P in increasing in Y, there is a unique value of Y for which $P = p$. As the final output price is equal to the marginal cost of production only at that value, it is aggregate supply,

$$Y^s = n(1) = \frac{m(\theta(1))}{m(\theta(1)) + \delta} \text{ where } \frac{c\theta(1)}{m(\theta(1))} = \frac{(1-\beta)(1-z)}{r + \delta} \tag{3}$$

In sum, the DMP model *is a theory of aggregate supply.*

However, if the real interest rate is too high to clear the goods market so that $Y = Y^d < Y^s$, then employment falls below its final goods market clearing level. Formally,

$$n = \frac{m(\theta)}{m(\theta) + \delta} < \frac{m(\theta(1))}{m(\theta(1)) + \delta} \tag{4}$$

where P/p and θ solve

$$\begin{aligned} \left(\frac{P}{p}\right)^{\rho} Y^{d} &= \frac{m(\theta)}{m(\theta)+\delta} \\ \frac{c\theta}{m(\theta)} &= \frac{(1-\beta)p}{(r+\delta)\,P} \end{aligned} \tag{5}$$

Hence, under conditions of excess supply, employment is determined by the level of demand for final goods and the real interest rate as in the neo-Keynesian model.