*ICT as Technical Change in the
Matching and Production
Functions of a Pissarides-Dixit-
Stiglitz model*

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Abstract

In this paper we integrate two workhorse models in economics: The monopolistic competition model of Dixit and Stiglitz and the search unemployment model of Pissarides. Information and communication technology (ICT) is interpreted as i) technical progress in the matching function of the Pissarides labour market search model where it is increasing the probability of filling a vacancy, and ii) as technical change in the production function of the Dixit-Stiglitz goods market model where it is increasing fixed costs and decreasing variable costs. All effects together, modelled as a permanent once-and-for-all ICT shock, increase the vacancy/ unemployment ratio, decrease the long-run equilibrium unemployment rate, and increase wages.

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1. Introduction

In the 1980s labour intermediaries started to use computers in the search process. Profiles of searching workers were entered into computer databases, as were employers' vacancies. A similar process takes place using the Internet. Public and private intermediaries have set up websites for job search. These measures improve the chances of employers and workers to find a job for given amounts of time or money invested into a search[1]. In labour market theory this can be captured by technical progress in the matching function of a search model, because here the success probabilities of finding a job or filling a vacancy are modelled. Therefore ICT, increasing these probabilities, should be modelled in the matching and search technology of the labour market, if we want to understand the macroeconomic effects of ICT.

   Moreover, firms have also invested into computer facilities, network connectivity and website development in order to ease ordering inputs and selling output[2], both of which are implicit parts of the output production functions used in economic theory. The time spent on websites and similar devices as well as the costs of training personnel is an increase in a firm's fixed costs, whereas the advantages of reduced administration costs are a reduction in variable costs. Some well-known examples[3] include cost reductions for transfers between bank accounts, processing costs of transaction of British Telecom, automobile producers' joint exchange to buy components, which are supposed to reduce the costs of making a car. Moreover, in the 1980s computer facilities were at the root of just-in-time production, which also increased fixed costs and decreased variable costs.[4] When fixed costs are essential, the assumption of perfect competition has to be dropped and an imperfectly competitive market structure has to be assumed.[5]

   In this paper we consider these aspects of ICT as once-and-for-all technical change. We investigate the macroeconomic effects of ICT within a framework using the Pissarides (1990) labour market search model and monopolistic competition according to the Dixit-Stiglitz (1977) goods market model. We choose the Dixit-Stiglitz model because it appears to be the most successful imperfect competition goods market model in general equilibrium theory as used in the fields of international trade, endogenous growth, regional economics and macroeconomics. The Pissarides model is one of the most successful in labour market theory and empirics. When examining ICT as a technology of search it is most straightforward to integrate ICT into that labour model, which has an explicit search technology. Among the major labour market models (see Pissarides 1998) the search model is the only one with an explicit search technology.

   We investigate in a comparative-static manner how ICT in the goods market and the labour market changes the endogenous variables.[6] This is done in two ways: The

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[1] See Autor (2001).

[2] See Meijers (2000) for a brief summary of business press information.

[3] See The Economist, A thinker's guide, Business Special, March 30, 2000.

[4] See Callen, Fader, and Krinsky (2000).

[5] Meijers (2000) relates the shift to higher fixed and lower variable costs to inflation using a Cournot model.

[6] It is not necessary to use an endogenous growth model here. Endogenous growth models are preferable when a continuous flow of innovations increasing total factor productivity is considered. This flow, however, is an aggregate from many sectors. When the emphasis is on just one technology

comparative-static effect of each change is considered separately and then the effects are considered jointly to see whether or not they work in the same direction. The most important results are that all effects together, modelled as *one*[7] permanent once-and-for-all ICT shock, increase the vacancy/ unemployment ratio, decrease the long-run equilibrium unemployment rate and increase wages[8] although rents available for bargaining are reduced by technical progress in the matching function.

   In the following section we merge the Pissarides and the Dixit-Stiglitz model. In section 3 we analyse the existence and uniqueness of the model and the effects of technical progress in the matching function. In section 4 we consider the effects of technical change, lowering variable but increasing fixed costs of production. In section 5 we summarize the results, as we have partly done in the abstract.

2. The model

Trade in the labour market[9]

From the Pissarides (1990) model we use the matching function $mL = Tm(uL, vL)$, where L is the labour force, i.e. the total number of employed and unemployed workers, u is the unemployment rate, v is the rate of vacancies and mL is the number of matches produced by this function. T is an efficiency parameter or the level of productivity in the matching process. When computers enter the labour intermediation process or job-search websites appear on the Internet, T is assumed to go up. The function is assumed to be increasing in both arguments, concave and linearly homogenous.[10] Defining labour market tightness as $\theta \equiv v/u$, division of the matching function by vL yields $q(\theta)=T m(u/v,1)$ as the probability (Poisson arrival rate) of a firm to find a worker for a vacancy and $\theta q(\theta) = Tm/u = T m(1, v/u)$ as the probability of an unemployed worker to find a job. Both these probabilities are enhanced by a change in (IC)T. By implication, the expected duration of a vacancy, $1/q(\theta)$, is reduced by technical progress in the matching function and the same holds for the expected time an unemployed worker needs to find a job. We assume that the technical change is neutral. If it were augmenting $uL (vL)$, this would mean that it works like having relatively more (less) unemployed people from which the employers can choose than having a greater number of vacancies from which workers can choose. We rather assume that both these effects are equally strong because computer search is equally well accessible for both. Firms can afford computer equipment and workers can use those of public libraries or labour intermediaries, which may even provide some help in using the computer equipment.

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one can simplify by using the comparative static manner. In particular, ICT is assumed to have an impact on the matching function but other TFP growth probably does not.

[7] It is not a repeated shock as in Mortensen and Pissarides (1994).

[8] As we consider a macroeconomic model with just one skill, we do not analyse skill bias, wage inequality and related issues. See Acemoglu (2000), Jacobebbinghaus and Zwick (2001) and Kaiser (2000) and others on these aspects.

[9] Subsections are titled as in Pissarides 1990. The search part is explained in greater detail there.

[10] Pissarides (1998, p.167, footnote 15) refers to estimates of the matching function using a Cob-Douglas functional form, which justifies the assumptions made in the text. Anderson and Burgess (2000) provide similar estimation results but also convincingly argue that their findings - together with job search by the employed - suggest interpreting empirical matching functions as a combination of a structural matching function and a job competition model. We do not include job search by the employed for the mere sake of simplicity.

A shock is a percentage rate s at which *(1-u)L* employed workers loose their job by assumption in every period. Therefore *s(1-u)L* workers go from a job into unemployment every period. On the other hand $\theta q(\theta)uL$ unemployed workers are expected to find a job each period. A labour market steady state equilibrium is defined as a situation where the numbers of workers going into and out of unemployment are equal and expectations turn out to be true, i.e. *s(1-u)L= $\theta q(\theta)uL$*. All other variables constant, technical progress in the matching function increases the right-hand side of this equation, thus contributing to a quicker process of bringing workers out of unemployment. Solving this equation for *u* yields the Beveridge or UV curve (lower indices referring to variables indicate partial derivatives):

$$u = \frac{s}{s + \theta q(\theta)}, u_s > 0, u_\theta < 0 \qquad (1)$$

An increase in *T*, increasing *$\theta q(\theta)$*, therefore reduces *u* for a given tightness ratio. Multiplying equation (1) by *θ* yields an equation for the vacancy rate because *uθ=uv/u=v*:

$$v = \frac{s}{s/\theta + q(\theta)}, v_s > 0, v_\theta > 0 \qquad (1')$$

An increase in *T*, increasing *$q(\theta)$* for a given tightness ratio, therefore reduces *v*. Equation (1) and (1') and their shifts induced by a change in *T* are drawn in the lower right quadrant of Figure1. These two results are summarized in the following proposition:

Proposition 1: *For any given tightness ratio, ICT, interpreted as neutral technical progress in the matching function, decreases the unemployment rate and the rate of vacancies.*

Bleakley and Fuhrer (1997) find one shift of the Beveridge curve towards lower values of *u* and *v* taking place around 1987-89 in the USA and they suggest a second shift saying that 'Indeed the unemployment and vacancy rates from 1995 and 1996 suggest that the Beveridge curve is moving even further inward - to territory not explored since the 1950s.' They attribute part of this shift to efficiency improvements in the matching function as we do in this model. Clearly, in other countries the shift has been in the opposite direction. ICT is only one of the many forces that have an impact on the position of the Beveride curve and therefore other effects can easily outweigh those of ICT. Obviously, the shift is partly due to other effects.

Moreover, *observed* shifts of *single values* of *u* and *v* are the result not only of a shift in the curves (1) and (1') but also of i) the consequences of the shifts for the bargaining process; ii) the shift of marginal cost curves for profit maximization of firms; and iii) other changes such as the effects of ICT on fixed costs in the goods market. All of these changes are discussed in the remainder of this paper.

Government and unemployment benefits

The government is assumed to pay unemployment benefits *z* to each unemployed worker. The financing of this is not explicitly treated in Pissarides (1990). We show

how this can be modelled to keep Pissarides' results intact. Total expenditures of the government or unemployment benefits are zuL. It will turn out that the incentives are ultimately unchanged if both the employed and the unemployed pay a tax or premium t to finance the unemployment benefits. Revenue then is tL. From the balanced budget assumption we make, it follows that $tL = zuL$ and therefore $t = zu$. Workers therefore receive $w\text{-}t = w - zu$ and unemployed *net* benefits are $z - t = z - zu$. As z is considered to be a policy variable, the budget equation determines the value of t, whereas u is determined in the general equilibrium part of the model below. Given the gross benefit z, a lower value of the rate of unemployment, u, implies a lower unemployment premium t.

Households and workers

The present value, with discount rate r, of the expected income stream of an unemployed and an employed worker, U and E respectively, are: $U = [z - zu + \theta q(\theta)(E\text{-}U)]/r$ and $E=[w\text{-} zu+ s(U\text{-}E)]/r$. $E\text{-}U$ is the income difference an unemployed worker can gain by finding a job with probability $\theta q(\theta)$. $U\text{-}E$ is the corresponding loss by a worker from losing his job with probability s. These two equations can be solved for E and U explicitly:

$$U = \frac{(r+s)z + \theta q(\theta)w}{r+s+\theta q(\theta)}/r - zu/r \ , \ E = \frac{sz + [r+\theta q(\theta)]w}{r+s+\theta q(\theta)}/r - zu/r$$

Households are assumed to have love-of-variety preferences $y=\left[\int_{i=0}^{n} c_i^\alpha di\right]^{\frac{1}{\alpha}}$, with $0 <$ $\alpha < 1$, on a continuum of goods ranging from zero to n, the (integral measure of) the number of firms.[11] It is well known that this specification of preferences leads to a constant elasticity of the inverse demand function, $\alpha\text{-}1$, and to relative demand of goods independent of the income earned by employed or unemployed persons.

Firms

The present-discounted value of a vacancy is $V = [-\gamma+q(\theta)(J\text{-}V)]/r$. It consists of the hiring costs γ and the net return of transferring the vacancy V into a job with value J, which is expected with probability $q(\theta)$. We assume that hiring costs are identical for all firms.[12] As the value of the vacancy is zero in equilibrium, we get $J = \gamma/q(\theta)$: the value of a job is equal to the vacant job costs γ multiplied by the expected duration of the vacancy, i.e. expected hiring costs. When considering the firms' hiring costs we must consider that the occupied job may be separated from the worker again with probability s. The current value of the expected value of a job therefore is $(r + s)J = (r + s)\gamma/q(\theta)$. These are labour costs in addition to the real wage received by the worker. Labour costs per worker then equal $w + (r + s)\gamma/q(\theta)$. Technical progress in the matching function then implies the following:

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[11] By implication we only consider the case of a large number of firms in which no strategic behaviour takes place.
[12] Acemoglu (2001) considers two sectors in which firms have different hiring costs. Rents are different therefore and the firms with higher hiring costs have higher rents and therefore higher wages, i.e. better jobs.

Proposition 2: *For a given tightness ratio,* e*xpected hiring costs and the value of a job are both decreased by technical progress in the matching function because the probability of filling a vacancy, q(θ), is increased.*

Pissarides (1990) links the above to the neo-classical production function.[13] Here we link it to the model by Dixit and Stiglitz (1977). If the temporary utility function is discounted and integrated we may get the inter-temporal utility function $\int_{t=0}^{\infty} e^{-rt} y(t)dt$.

It is well known from endogenous growth theory or the theory of optimal growth that, in the absence of a rate of permanent productivity growth, the steady-state value of consumption will be stationary and the interest rate will equal the discount rate *r*. This seems to be the shortest way to determine the interest rate.[14]

Technologies are defined by $l_i = f + a x_i$, with $a, f > 0$. The left side represents demand for labour to produce good *i*, *f* is the fixed part and ax_i is the variable part of labour demand. As all goods are assumed to be identical in the utility function and in the production technology, their prices and quantities will be the same.

Total labour demand is $nl_i = n(f + a x_i)$. Equating this to employment *(1-u)L* yields *(1-u)L= n(f + a x_i)*. Solving this equation we find the number of firms linked to the rate of unemployment as:

$$n = (1-u)L/(f + ax_i) \qquad (2)$$

There is a partial negative relation between the rate of unemployment and the number of firms: The larger the number of firms, the lower the unemployment rate (ceteris paribus), or the lower the unemployment rate the more firms can be in the market.

Profits of a firm, which are zero in equilibrium, are defined (dropping index i) in nominal terms as:

$$p(x)x\text{-}[W + p(r + s)\gamma/q(\theta)](f + a x)(=0) \qquad (3)$$

W is the nominal wage rate and real hiring costs are made nominal by multiplying their real value with the price. The assumption is that *nominal* hiring costs are given from the labour market; monopoly pricing then has no impact on the value of hiring costs. The first-order condition of profit maximisation with respect to output x (and implicitly employment f + ax) given wages, is:

$$p\alpha = a[W + p(r + s)\gamma / q(\theta)] \qquad (4)$$

Technical progress in the matching function implies the following:

Proposition 3: For constant wages, *technical progress in the matching function decreases marginal costs on the right-hand side of equation (4) because the expected*

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[13] In Pissarides (1990) this leads to the zero-profit condition *f(k) - (r+δ)k - w – (r + s)γ/ q(θ) = 0.* Here f(k) is the output per unit of labour and δ is the rate of depreciation.
[14] Shapiro and Stiglitz (1984, p.435, fn. 5) also follow this procedure.

duration of filling a vacancy and therefore expected hiring costs are reduced. The first-order condition then requires decreasing prices.

Wages

There are two sorts of rents in Pissarides' model: there are occupied jobs, indexed *j*, where i) employed workers do not have to search and therefore have an income rent of $E_j - U$ and ii) firms do not have to incur hiring costs and therefore have a rent J_j-V. Bargaining these rents is assumed to determine real wages. This is done by choosing the real wage by maximising the Nash product $(E_j-U)^\beta (J_j-V)^{1-\beta}$ with β as the bargaining power of workers and $1-\beta$ that of firms, *V=0*, $E_j=[w_j - zu + sU]/(r+s)$, *U* according to the explicit solution given above, and $J_j= \{[p(x)x]/(f + a x)\} -W_j\}/[(r + s)p]$ which equals $\gamma/q(\theta)$ when setting profits in (3) equal to zero.[15] *E, U* and *V* are as in Pissarides (1990). The value for *J* differs from Pissarides' model because we have replaced the neoclassical production function by elements of the Dixit-Stiglitz model. The result of the maximisation of the Nash product with respect to the real wage in its general form is identical to that of Pissarides in that workers get a share β of the sum of the rents to be distributed: $E_j-U = \beta(E_j-U + J_j-V)$. Insertion of the values for E_j, *U*, J_j and *V* yields the solution for real wages:[16]

$$w_j = (1-\beta)(rU + zu) + \beta \frac{x}{f + ax}$$

Insertion of $E_j-U = \beta(J_j-V)/(1-\beta)$ from the general form of the bargaining result and $J=\gamma/q(\theta)$ into $rU = [z - zu + \theta q(\theta)(E-U)]$ yields $rU = z - zu + \theta\beta\gamma/(1-\beta)$. Insertion of *rU* into the above wage result yields[17]:

$$w_j = (1-\beta)z + \beta \left(\frac{x}{f + ax} + \theta\gamma \right) \qquad (5)$$

The last term indicates that workers participate in the hiring costs saved on occupied jobs compared to vacancies. The second but last term is net revenue or output per worker as in Pissarides (1990) - where the output-per-worker term is $f(k) - (r+\delta)k$ -, but here without capital cost as in the Dixit-Stiglitz model. The unemployment premium or tax, *zu,* has dropped out only in the very last step of the calculation yielding (5). The Pissarides approach is consistent with an explicit financing scheme for the unemployment benefit if both unemployed and employed workers have the same reduction of their gross payments *w* and *z* respectively. Then the difference of going from a status of unemployed to employed workers is unchanged and all incentives are exactly as in Pissarides' model.[18]

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[15] As in Pissarides (1990, equation 1.14) this is profit per labour unit gross of expected hiring costs. Units of labour are defined on the real line.

[16] This result corresponds to equation 1.18 in Pissarides 1990. Note that with $\beta=1$, the negotiation result would require $V=J=\gamma/q=\gamma/(m/v)=0$, which could only hold for *v=0* without additional assumptions on the matching function. However, with *v=0* we also have $\theta=0$ and therefore no vacancies and hiring costs. Equation (5) would imply that wages equal revenue per worker.

[17] This result corresponds to equation 1.19 in Pissarides 1990.

[18] In particular, bargaining determines wages according to (5) conditional on the tightness ratio and output. The firm chooses output, x, or employment, f +ax, by profit-maximization for given wages. The

This model is kept as simple as the basic workhorse models were. We resist the temptation to endogenize the bargaining power parameter or the mark-up, or to distinguish between different skills, or between the parameters for love-of-variety, scale economies and the price elasticity. These extensions can be taken on board when applications require doing so.

3. The Equilibrium Solution: Existence and uniqueness of the model and the effects of technical progress in the matching function

Equations (1)-(5) determine the five variables of the model when goods produced serve as numéraire *(p=1): u, n, x, θ and w.* Insertion of wage plus hiring cost per worker from (4) into (3) allows to solve for the equilibrium quantity:

$$x = \frac{f\alpha}{a(1-\alpha)} \qquad (6)$$

The equilibrium quantity of the model is independent of the labour market variables stemming from Pissarides' part of the model (unemployment benefit z, hiring costs γ, unemployment rate u, vacancies v, separation rate s, power parameter β).

Clearly, this result is due to the fact that the firm part of the Dixit-Stiglitz model is merely changed by adding hiring costs to the wage rate: this term drops out when solving (3) and (4) for the quantity. Next, we replace real revenue or output per worker in (5) by the labour cost term from (3) and solve for w:

$$w = z + \frac{\beta}{1-\beta} \frac{r+s+\theta q(\theta)}{q(\theta)} \gamma \qquad (5')$$

This equation essentially has the real wage as a function of the $v/u=\theta$ ratio. This equation is drawn as the BB curve in the upper right quadrant of Figure 1.[19] Technical progress in the matching function then implies the following:

Proposition 4: *An increase in the matching probability because of technical change, dT, will shift the bargaining curve down, because expected hiring costs and therefore rents are going down thus having a negative impact on wages.*

ICT therefore is not necessarily the friend of the employed worker unless other effects outweigh this one.[20]

To solve the system the next steps serve to get a second equation of this type. Using (6) to replace x in (2), we get:

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intersection of (4') and (5') then determines wages and the tightness ratio. In a model by Stole and Zwiebel (1996) there is individual bargaining *in the firm* over employment and wages *simultaneously*. Consequently wages are valid only for the employees hired, and not for the whole market as in the Pissarides approach.

[19] The equation follows from this model but can also be derived from equations 1.20b and c in Pissarides (1990).

[20] Borghans and ter Weel (2001) find that computers are given more frequently to employees with higher positions in the hierarchy. This is another indication that ICT is not necessarily the friend of the employed worker.

$$n = \left[L - \frac{sL}{s + \theta q(\theta)} \right] \frac{1 - \alpha}{f} = L(1 - u)\frac{1 - \alpha}{f} \qquad (2')$$

This is a function $n(\theta)$ or $n(u)$. The $n(u)$ function is drawn in the lower left quadrant of Figure 1. *If* technical progress in the matching function decreases the unemployment rate it increases the number of firms. Dividing (4) by the price and solving for the real wage yields:

$$w = \frac{\alpha}{a} - \frac{r + s}{q(\theta)}\gamma \qquad (4')$$

Larger hiring costs *(r+s)J* imply lower wages according to (4') as in Pissarides' model when interest is given. Here the model resembles Pissarides' because the zero-profit condition in his model – rewritten in an endnote - implies constant labour costs as long as $r = f'(k)-\delta$ and therefore k are constant. By implication wages w always move in the opposite direction of hiring costs, *(r+s)γ/q(θ)*, in Pissarides' model and in ours. Equation (4') is drawn as a function $w(\theta)$ in the upper right quadrant of Figure 1, indicated as the MM curve. It is also drawn in the upper left quadrant of Figure 1 with wages as a function of hiring costs. The intersection of lines BB and MM determines the wage and the tightness rate in the upper right quadrant, and hiring costs in the upper left quadrant. Given the rate of tightness thus determined, the solution for the rates of unemployment and vacancies can be found in the lower right quadrant. The rate of unemployment then determines the number of firms in the lower left quadrant.

<center>INSERT FIGURE 1 OVER HERE</center>

Technical progress in the matching function shifts the MM curve up and implies the following:

Proposition 5: *Technical progress in the matching function, dT>0, increasing the probability of filling a vacancy and decreasing expected hiring costs and marginal costs, exerts upward pressure on wages.*

Equations (5') and (4') are two functions $w(\theta)$. Replacing labour costs in (4) using (5') or equating (4') and (5') we get:

$$\alpha = a\left[z + \frac{1}{1 - \beta}\frac{r + s}{q(\theta)}\gamma + \frac{\beta\gamma\theta}{1 - \beta} \right] \qquad (7)$$

The left side is marginal revenue and the right side is marginal cost. In Figure 2 both functions are drawn. The left side is denoted as MR and the right side as MC in Figure 2. MC is increasing in θ and may have a negative second derivative in θ.[21]

<center>INSERT FIGURE 2 OVER HERE</center>

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[21] To get a negative second derivative of the MC curve it is sufficient to assume that the matching function is of the Cobb-Douglas type.

The MC curve starts at az if $\theta=0$ and $lim_{\theta\to0} q = lim\, m(1/\theta, 1) = lim\, m(\infty,1)=\infty$; otherwise it starts above az. As θ goes to infinity the MC curve also goes to infinity. Thus, the MC curve either intersects once or not at all. Therefore we have a unique or no equilibrium.

The existence of a unique equilibrium is guaranteed if $az < \alpha$. This implies a positive equilibrium value for the tightness ratio $v/u=\theta$. The fixed cost parameter f and the size of the economy, L, have no impact on the value of $v/u=\theta$.

If, however, $az \geq \alpha$, the tightness ratio is zero, there are no vacancies and unemployment is 100% according to equation (2). With no output, z cannot be paid. Therefore this cannot be an equilibrium situation.

Technical progress in the matching function, $dT>0$, shifts down the upward sloping curve of Figure 2 and generates a higher tightness ratio. Wages, on the one hand, are decreased by technical progress in the matching function, because the expected duration of filling a vacancy, expected hiring costs, the value of a job and therefore rents about which a bargain can take place, are reduced. This was captured by a downward shift in the BB curve. On the other hand, the MM curve shifted up because reduced hiring costs imply lower marginal costs. One can see from equation (5) that an increase in the tightness ratio caused by both of these shifts, increases wages because output x is unaffected by technical progress in the matching function. Therefore the shift in the BB curve is weaker than the one in the MM curve. This leads us to the following interpretation:

Proposition 6: *The net effect of technical progress in the matching function, inducing a reduction in marginal costs and in rents, will lead to an increase in wages, because the effect of reducing costs is stronger than the effect of reducing rents.*

As technical progress in the production function, technical progress in the matching function increases wages as usual.

4. Comparative static analysis of technical change in the production function

Changes in technologies towards computers, Internet connectivity and website technology cause increases in fixed costs - in particular labour costs. Changes in fixed costs, $df >0$, do not change the tightness ratio and therefore the unemployment and vacancy rates and labour costs are unchanged.[22] Firm size x is increased[23] and the number of firms is decreased as in Dixit-Stiglitz. This latter effect is captured by a rightward shift of the curve in the lower left quadrant. Aggregate output, nx, is unaffected. This can be seen from equations (2') and (6).

As a consequence of these ICT changes, variable costs of ordering inputs and selling output are reduced. A decrease in marginal costs via $da<0$, decreases the slope and intercept of the MC curve in Figure 2 and shifts up the MM curve in Figure 1 as indicated by the arrows drawn. The result is a larger value for the tightness ratio, $v/u=\theta$. This reduces the unemployment rate and increases the rate of vacancies according to equation (1) and (1'). The size and number of firms are both increased according to equation (6) and (2'). Wages are increased according to equation (5').

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[22] Effects of changes in fixed costs may be quite different in endogenous growth models. See de Groot (2000).
[23] Of course, there may be other real world events, such as the shift from industry to services that work towards a decrease of firm size. Here we consider only the effects of ICT in isolation.

Proposition 7: *Technical change in production technology in the form of higher fixed and lower variable costs, df>0 and da<0, increases the size of the firm, wages, the tightness ratio and aggregate output and decrease the unemployment rate.*

Both changes, *da* and *df*, lead to an increase in the size of firms.[24] Note that technical progress in the matching function and in the production function always shift the MM and the BB curves to the right and the UV curve towards lower unemployment rates. This leads us to the following result:

Proposition 8: *ICT as technical progress in the matching function and in the production function increases the tightness ratio, decreases the unemployment rate of the general equilibrium solution of the model and increases wages. The fall in the unemployment rate implies that the unemployment premium, t=zu, can be reduced if the gross benefit z is kept constant.*

5. Summary and conclusion

Linking Pissarides' (1990) search theory of unemployment to the Dixit-Stiglitz (1977) model rather than to the neo-classical production function yields a framework in which effects of ICT can easily be identified, which together increase the vacancy/ unemployment ratio and decrease the unemployment rate.

First, ICT serves as technical progress in the matching function of job search. For any given tightness ratio this decreases the rate of unemployment and vacancies. When technical progress reduces expected hiring costs there is more room for wages paid to households because marginal costs are lowered. On the other hand, this is a decrease in expected rents and therefore the wage bargaining yields lower wages. The result of technical progress in the matching function is a higher tightness ratio and a lower rate of equilibrium unemployment. A higher tightness ratio yields higher wages.

Second, fixed costs increases as maintaining computers, making Internet connectivity and keeping websites working require trained personnel. This increases the size of firms and, ceteris paribus, decreases the number of firms. Other variables are not affected by a change of the fixed cost parameter.

Third, the shift to higher fixed costs causes lower variable costs for ordering inputs and selling outputs, modelled here as production costs including the process of ordering and selling. This effect increases wages and the tightness ratio and decreases the equilibrium unemployment rate and the unemployment premium as the first effect does.

All of these results do not contradict the empirical literature on shifts in the Beveridge curve and the NAIRU.[25]

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[24] See also Barras (1990) on this aspect.

[25] The theoretical result of a decrease in the rate of unemployment is in accordance with the empirical finding that the NAIRU (Non-accelerating inflation rate of unemployment) has decreased during the 1990s (see Meijers 2000 and Autor 2001 for brief summaries of the literature). We do not claim, however, that the entire change in the NAIRU is due to arguments modelled here.

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List of symbols

α *marginal revenue, CES parameter*
a *marginal costs*
β *bargaining power*
γ *hiring costs*
f *fixed costs*
L *country size*
n *number of firms*
nx *aggregate output*
r *interest rate*
s *separation rate*
t *unemployment premium or tax*
θ *tightness ratio v/u*
u *unemployment rate*
v *vacancy rate*
w *wage*
x *firm size*
y *utility*
z *unemployment benefit*

MR, MC
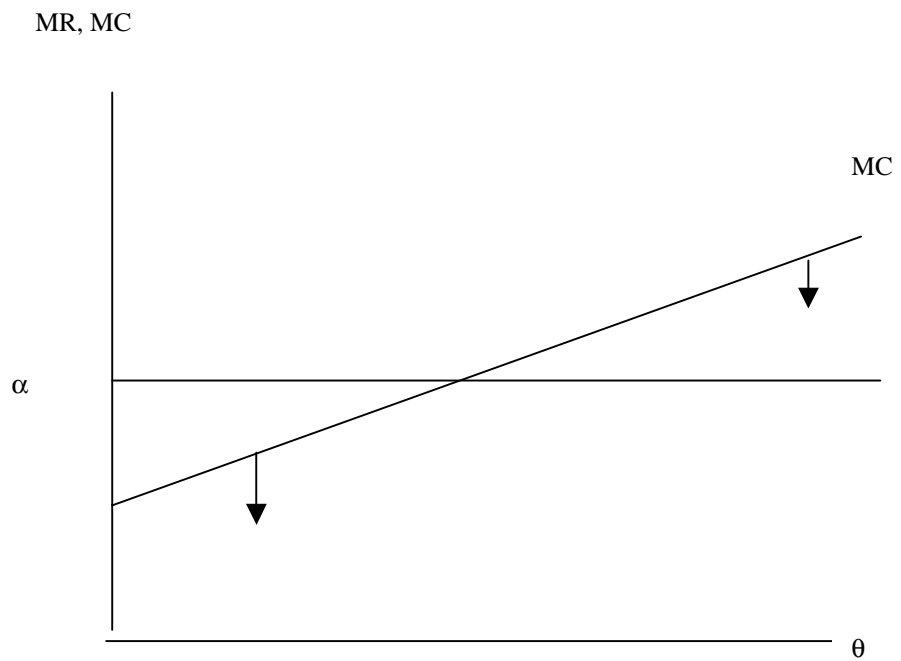
Figure 2. Marginal revenue, MR at value α, is equal to
marginal cost, MC. The intersection of both lines determines
the tightness ratio θ. Technical progress in production and
matching shifts the MC curve down and increases the
tightness ratio.

w

M

B

B

M

(r+s)γ/q(θ)

θ

n

u(θ)

1

v(θ)

u , v
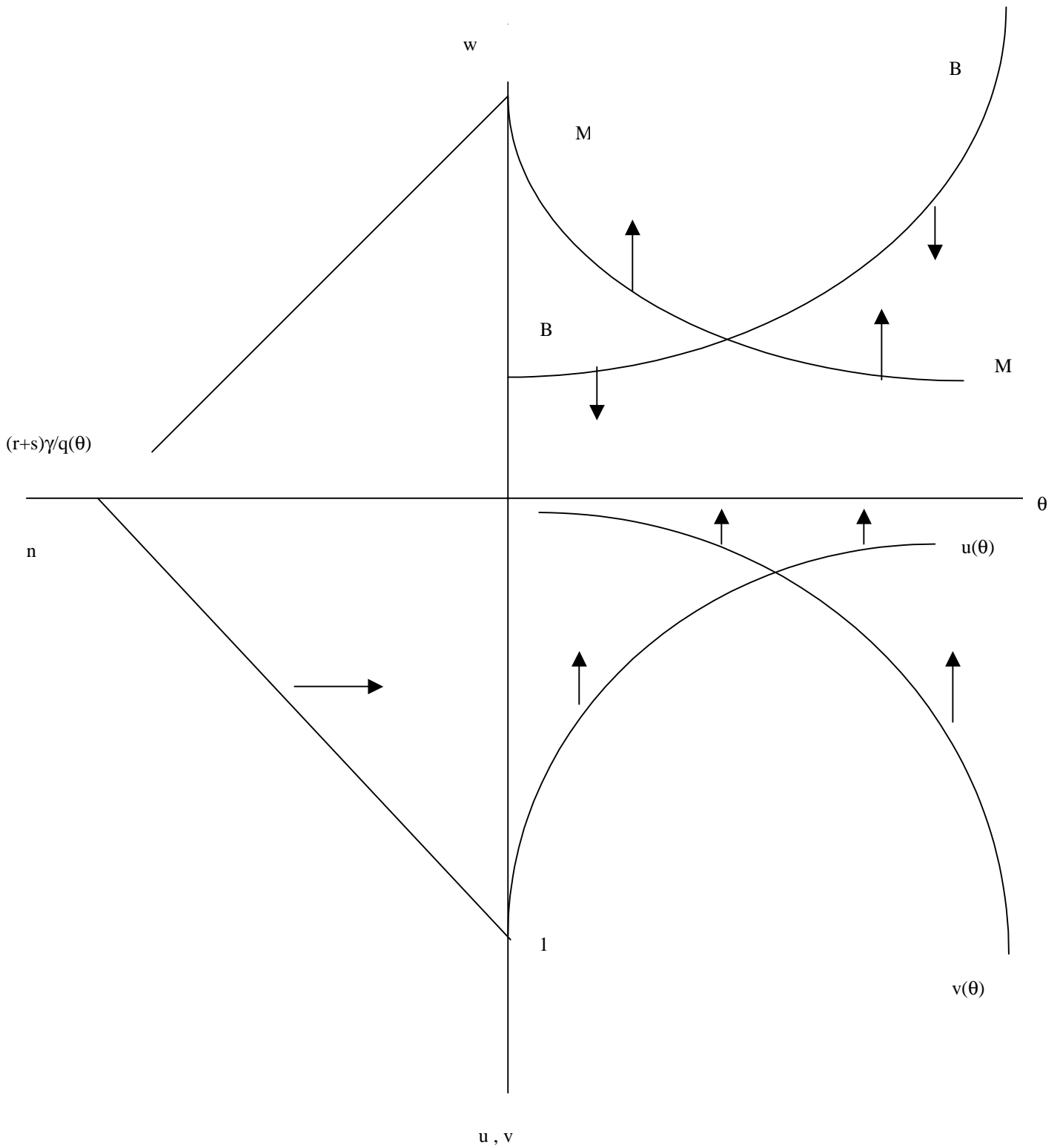
Figure 1. The wage bargaining result, BB, and the profit maximising real wage, MM, determine the real wage and the tightness ratio in the upper right quadrant. This implies a solution for the unemployment rate u and vacancies v in the lower right quadrant. The unemployment rate u determines how many firms can be in the market, in the lower left quadrant. Each result for wages implies a result for hiring costs in the upper left quadrant. Technical progress in the matching function shifts BB and the Beveridge curve towards the axes and MM up. The latter effect is supported by a decrease in variable costs.

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