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Innovation, Growth, and Unemployment

A Dynamic Model of Creative Destruction

by

Manfred Stadler

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Abstract

This paper presents a general-equilibrium model of innovation, endogenous growth, and unemployment in a disaggregated economy. The driving force decisive for both growth and unemployment is sustained technological change that arises from the innovation process in imperfect markets. In a first step, we consider the influence of innovative activity on growth and unemployment in a process of creative destruction. In a second step, we endogenize innovative activity and analyze the impact of market power on the endogenous rates of innovation, growth, and unemployment. Under certain circumstances, we derive an inverted U-shaped relationship between innovative activity and unemployment.

Zusammenfassung

Dieser Beitrag präsentiert ein gesamtwirtschaftliches Innovations-Gleichgewichtsmodell, mit dem sowohl Wachstum als auch Arbeitslosigkeit in einer sektoral disaggregierten Volkswirtschaft erklärt werden können. Ursächlich für beide Phänomene ist der technologische Wandel, der durch den Innovationsprozeß auf unvollkommenen Märkten ständig in Gang gehalten wird. Zunächst untersuchen wir, wie Innovationsaktivitäten Wachstum und Arbeitslosigkeit im Prozeß der schöpferischen Zerstörung beeinflussen können. Danach endogenisieren wir die Innovationsaktivitäten und fragen nach dem Einfluß der Marktmacht auf die endogenen Innovations-, Wachstums- und Arbeitslosenraten. Es wird gezeigt, daß unter bestimmten Bedingungen eine umgekehrt U-förmige Beziehung zwischen den Innovationsaktivitäten und der Arbeitslosenquote besteht.

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1. Introduction

Since Schumpeter's (1942) seminal conjectures about the process of creative destruction economists have modeled many forms of dynamic interactions between market structure and innovation. In Industrial Organization theory the process of creative destruction is modeled as a sequence of stochastic patent races where the winner takes all the rents until he is removed by the winner of the following race (Reinganum 1985). In recent work by Segerstrom et al. (1990), Grossman, Helpman (1991) and Aghion, Howitt (1992a) the patent race approach is integrated into a general-equilibrium model of innovation-based endogenous growth. Although growth in these models is generated by a process of creative destruction, no worker will ever get unemployed. Immediately after a firm has succeeded in developing a new technology it will take over the workers of the obsolete firm without friction and start production. However, as is well known from labor market theory, labor-turnover is an important factor determining a natural rate of unemployment (see Pissarides 1990). There may be a positive long-run trade-off between innovation and unemployment in the process of creative destruction. One of the few theoretical studies that deal with these issues in the context of innovation-based growth is the one of Aghion, Howitt (1992b). Analyzing various employment effects of growth, the authors derive an inverted U-shaped relationship between growth and unemployment that coincides with some empirical evidence they found for 19 OECD countries over the period from 1974 to 1989.

Although very illuminating, their model can be criticized in at least three ways. First, in one version of their model they account for plant obsolescence within a firm due to a new technology. However, they never permit for firm obsolescence, that is, every firm is assumed to have an infinite life-time even if new technologies continue to radically change the production structure. This assumption is crucial for their derived "capitalization effect" leading to new vacancies and thus reducing unemployment in the long-run equilibrium. It is worth noting that this capitalization effect is the only one indicating a positive influence of growth on employment. Therefore, if one allows for firm obsolescence, this single positive effect disappears, and only negative employment effects of growth remain valid. Secondly, Aghion, Howitt (1992b) do not realize that there may be a positive impact of innovative activity on employment simply by the fact that R&D requires labor resources. This effect might be able to reinforce some of the original results even if founded on an alternative reasoning. Thirdly, following Shleifer (1986), Aghion, Howitt (1992b) restrict their analysis to a deterministic environment which is certainly not adequate for modeling the process of creative destruction.

In the present paper, we propose an alternative approach that attempts to overcome these flaws. The approach draws on building blocks provided by the endogenous growth models of Romer (1990) and Grossman, Helpman (1991) on the one side and on the flow approach of unemployment with an endogenous job-separation rate as suggested by Aghion, Howitt (1992b) on the other side. This synthesis enables us to analyze some relationships between the endogenous rates of innovation, growth, and unemployment in the process of creative destruction.

The paper is organized as follows. In Sect. 2, we present the basic growth model which combines special building blocks from the variety and quality growth models of Grossman, Helpman (1991). In Sect. 3 we study the impact of an exogenously given rate of innovation on the natural rate of unemployment. In Sect. 4, we endogenize the rate of innovation by analyzing intentional R&D decisions made by private firms. This enables us to ask for the influence of market power on innovation, growth, and unemployment. Section 5 finally contains some concluding remarks.

2. Monopolistic Competition, Quality Ladders, and Endogenous Growth

Let us start with a description of consumer behavior. We suppose that consumers share identical preferences. The utility that consumers derive from an infinite stream of consumption takes the additive separable form

$$(1) \qquad U(C) = \int_0^\infty e^{-\rho t}\, u(C)\, dt$$

where ρ is the subjective discount rate and u(C) represents the flow of utility at time t by consuming a level C of final output, Y. Assuming a unit elasticity of marginal utility of consumption leads to the instantaneous utility function

$$(2) \qquad u(C) = \ln C\,.$$

Every consumer maximizes utility over an infinite time horizon subject to an intertemporal budget constraint

$$(3) \qquad \int_0^\infty e^{-rt}\, p_Y C(t)\, dt \leq A(0)$$

where r denotes the nominal interest rate, p_y the price index of the output product, and A(0) the present value of the stream of factor incomes plus the value of initial asset holdings at t=0. Solving the intertemporal optimization problem yields the Euler equation

$$(4) \qquad \dot{C}/C = (r - \dot{p}_y/p_y) - \rho .$$

Thus, consumption of the final product grows at a rate given by the difference between the real interest rate and the subjective rate of time preference. It is well known in neoclassical growth theory that the accumulation of physical capital depresses the real interest rate, while technological progress raises the real interest rate. In the steady-state the rate of capital accumulation equals the rate of technological progress and the real interest rate remains constant. It follows that the economy sustains long-run growth. In innovation-based growth theories, however, investment consists primarily not of building new capital equipment, but of developing new knowledge. In these models people do not save a fraction of their income to finance their investment in the usual way, but reallocate (labor) resources from the production sector to the R&D sector, thereby increasing the future productivity of labor in the production process (Sala-i-Martin 1990).

We suppose that final output Y=C is assembled from differentiated intermediate inputs in the continuum interval $[0,n]$. All input factors are characterized by a common state of technological knowledge, q. Following Dixit, Stiglitz (1977) we adopt the CES form

$$(5) \qquad Y = \left\{ \int_0^n [\, q\, x(j)\,]^{\alpha}\, dj \right\}^{1/\alpha}, \qquad 0 < \alpha < 1 ,$$

where x(j) represents the input of intermediate good j into final production. In a competitive equilibrium the final product is priced at the minimum attainable unit manufacturing cost

$$(6) \qquad p_y = \left\{ \int_0^n [\, p(j)/q\,]^{-\alpha/(1-\alpha)}\, dj \right\}^{-(1-\alpha)/\alpha} .$$

Using Shepard's lemma we derive the demand for input j

$$(7) \qquad x(j) = \left\{ \int_0^n [\, p(j)/q\,]^{-\alpha/(1-\alpha)}\, dj \right\}^{-1/\alpha} p(j)^{-1/(1-\alpha)} q^{\alpha/(1-\alpha)}\, Y.$$

We assume that each intermediate input is produced by a single firm which is identical to an industrial sector. Rivals engage in monopolistic competition. If the number of intermediate inputs, n, is reasonably large, the own price elasticity of demand is given by $-\varepsilon = 1/(1-\alpha)$, which corresponds to the elasticity of substitution between any two input factors. Production of an intermediate good requires a certain amount of labor per unit of intermediate output. For simplicity we set the input-output coefficient to one, regardless of quality. Thus, each firm maximizes its operating profits

(8) $\pi(j) = p(j)\ x(j) - w\ x(j)$

with the wage rate w, common to all workers, and the demand function (7). The profit maximization condition for each firm is the equality of marginal revenue, $\alpha p(j)$, and marginal cost, w. Writing p for the common equilibrium price for each intermediate input, we get the price setting equation

(9) $p = w/\alpha$.

Since the technological level is the same in all sectors j, this pricing behavior implies a symmetry in factor demands, $x(j) = x$. In order to study the process by which innovations cause unemployment, we assume that each firm faces a capacity constraint that prevents it from employing more than one worker, i.e. $x=1$. Taking labor as the numeraire, i.e. $w=1$, symmetric operating profits are derived as

(10) $\pi = 1/\alpha - 1$

where the degree of market power of each firm in the intermediate sector is measured inversely by the parameter α or directly by π. Since each competitor realizes positive operating profits, the capacity constraints will be binding in all sectors. In this symmetric equilibrium the production and the dual price index are given by

(11) $Y = n^{1/\alpha}\ q$, $\quad p_y = n^{-(1-\alpha)/\alpha} / (\alpha\ q)$.

In the process of creative destruction new innovative products appear that display earlier vintage products from the market. The blue prints for these higher quality products are developed in the research sector. Following the quality ladder model of Grossman, Helpman (1991) we assume that every intermediate input can be improved an unlimited number of times, and that each improvement engenders a discrete jump in the technology level q. Grossman, Helpman (1991), who are not interested in analyzing unemployment, assume a simple market structure characterized by Bertrand competition. Together with a Cobb-Douglas technology, this assumption is sufficient for modeling separate R&D races in all sectors which are not restricted to be synchronized. Our analysis of a monopolistic competition market structure requires symmetry between the rivals in the intermediate sector. Therefore, we have to assume that each R&D race takes place at an economy-wide level and that each successful innovation improves all intermediate products at the same time (see also Aghion, Howitt 1992a).

Each new generation of products provides a λ times higher quality as the quality of the last product generation. If we normalize the lowest quality available at time t=0 to unity, $q_0=1$, we can write $q_m=\lambda^m$ for all m=0,1,2,... and $\lambda>1$. As usual the probability that the current technology will take m steps up the quality ladder in a time interval of length dt is assumed to follow a Poisson distribution. Thus, the expected number of innovations until time t is ht where h is the arrival rate of a single innovation. To keep things tractable, we assume that all innovations are drastic in the sense that an intermediate monopolist using the best technology is not constrained by potential competition from the users of an obsolete technology even if the latter would supply at a price equal to unit cost, w=1. It is easy to show that innovations are drastic if and only if $\lambda>1/\alpha$.

For now we assume that innovations are the result of public research. Once a new blue print has been developed, the government sells a continuum of patents, one for each intermediate sector, randomly to different firms which become local monopolists in their sectors until the next innovation occurs. The buyers have to pay an administrative price k for the patent as a lump sum in exchange for an unconstrained use of the infinite life time patent. No potential entrant is excluded from the option of buying the patent. Given the above assumption of drastic innovations and a price k that allows for non-negative profits, at each point of time only the highest quality products are used in production. Thus, we can calculate the innovation-based growth rates for final production and the dual price index in (11) as

(12) $\quad g_y = h \ln \lambda \, , \qquad g_{py} = - h \ln \lambda \, ,$

implying $r=\rho$ in (4). In accordance with the models of Grossman, Helpman (1991) and Aghion, Howitt (1992a,b) the average output growth rate depends positively on the arrival parameter, h, and on the size of innovations, λ. In addition, changes in these two parameters have the same qualitative effects on the variance of the growth rate, $h(\ln\lambda)^2$. In the following sections we will assume that the arrival rate of innovations depends on (labor) resources devoted to R&D. This will accordingly imply that the number of scientists raises macroeconomic growth and the fluctuations around it.

3. Innovative Activity and Natural Rate of Unemployment

We assume that the labor force of the economy, L, does not change over time. A number of n workers is employed in production, Z workers in R&D, and U workers are unemployed.

(13) $L = n + Z + U$.

The source of unemployment are labor-turnovers between obsolete and new firms. Every new firm creates a vacancy and searches for a worker that matches its technological requirements. Workers have different preferences and abilities, and information about job searchers and vacancies is imperfect. Therefore, it usually takes time for a searching worker to find a new job. Under these conditions, frictional unemployment will occur through creative destruction. We assume, however, that workers in R&D are flexible enough to change research firms without friction.

Following Aghion, Howitt (1992b) we interpret the arrival parameter h of innovations as the job separation rate. Further we assume a deterministic matching process between firms and workers. Since each firm has a finite life time, the whole labor force with the exception of scientists is searching for new jobs. As suggested by Pissarides (1990) and Blanchard, Diamond (1989, 1990), the flow of hiring is assumed to be a matching function of the number of searching workers, here (L-Z), and the mass of job vacancies, V. If the matching function is homogeneous of degree 1, the rate of matching is given by $\mu(1-z,v)L$ where z denotes the number of scientists as a fraction of the labor force and v denotes the vacancy rate. Aghion, Howitt (1992b) analyze the special case of z=0, neglecting the need of labor resources in the R&D sector.

Let the variables f and s denote the job finding rate and the recruiting-success rate, respectively. Then, 1/f is the waiting time for a searching worker to find a new job and 1/s is the waiting time for a new firm to find a suitable worker. The rates are determined by the matching technology as $f(1-z,v) \equiv \mu(1-z,v)/(1-z)$ and $s(1-z,v) \equiv \mu(1-z,v)/v$. Thus, the job finding rate is assumed to be an increasing function of vacancies and scientists, while the recruiting-success rate is assumed to be a decreasing function of both variables. The former assumption reflects a "thin market externality" whereby more vacancies and more workers bounded in R&D make it easier for a searching worker to find a job, and the latter assumption reflects a "congestion externality" whereby it is harder for a new firm to fill its vacancy when there are more vacancies competing for a smaller number of searching workers (see Pissarides 1990).

During the time interval between receiving a patent for a better technology and recruiting the resulting vacancy, the incumbent firm can continue production using its current worker and its old technology. At the same time, it is in the current worker's interest to stay working in the obsolete firm until he will find a new job or the firm will be replaced by a new firm and he will be fired. In the latter case, the current worker will become involuntaryly unemployed and will continue to search.

As is well known the rates of job separation, h, and job finding, f, determine the natural rate of unemployment. The flow of workers into unemployment is given by (1-z-u)hL, and the flow of matchings is given by (1-z)fL. A necessary condition for the long-run labor market equilibrium is therefore

(14) $u = [\, h - f(1\text{-}z, v) \,] \; [\, 1 - z \,] \, / \, h \, .$

Like Aghion, Howitt (1992b) we have to assume that the (expected) duration of each job, 1/h, is less than the time 1/f it takes for a searching worker to find a job, i.e. h > f. Equation (14) can be interpreted as the famous Beveridge curve relating unemployment to the number of vacancies. All employment effects can be decomposed into direct effects, holding v constant, and indirect effects that work through changing the equilibrium value of v. Thus, direct effects induce shifts of the Beveridge curve while indirect effects induce movements along it. We identify three different effects, two of which corresponding to the effects analyzed by Aghion and Howitt (1992b). First, an increase in the frequency of innovations, h, raises unemployment ($\partial u/\partial h>0$). Since h is the job destruction rate, Aghion and Howitt call this the "direct creative destruction effect". Secondly, if one endogenizes the vacancy rate by a free-entry condition there will be an "indirect creative destruction effect" of innovations that works through a decreasing number of vacancies and a declining job finding rate ($\partial u/\partial f<0$). We will discuss this effect in detail below. Thirdly, Aghion and Howitt identify a "capitalization effect", whereby an increase in growth raises the rate at which the returns from creating an ever living firm will grow, and hence increases the capitalized value of these returns. This raises the number of job openings thereby reducing the equilibrium rate of unemployment by increasing the job finding rate. However, in our model of firm obsolescence this effect does not appear. Instead we identify an alternative effect which is completely neglected by Aghion, Howitt. We call it "research staff effect" because it recognizes a direct positive employment effect of the number of scientists in the R&D labs ($\partial u/\partial z<0$). For example, Flaig and Stadler (1988) give some supporting empirical evidence for this effect.

To identify the overall impact of innovative activity on the equilibrium rate of unemployment, we have to further specify our model. First, we assume a linear research technology

$$(15) \quad h = \theta L z$$

relating the arrival rate of innovations to a productivity index for R&D, θ, and to the number of workers employed in R&D labs. Inserting in (14) yields

$$(16) \quad u = [\, z - f(1-z,v)/\theta L \,] \; [\, 1 - z \,] \, / \, z \, .$$

Under plausible specifications of the matching function, (16) is able to produce an inverted U-shaped relationship between innovative activity and unemployment. Since growth depends positively on innovative activity, our model is, like the model of Aghion, Howitt, able to generate an inverted U-shaped relationship between growth and unemployment even with an alternative explanation: The positive employment effect of large growth rates is not caused by a capitalization effect, but by the need of a larger research staff.

Let us now turn to the indirect creative destruction effect which works through a change in the equilibrium vacancy rate. Since the cumulative density function of an innovation is by assumption $\tilde{P}(t) = 1-e^{-ht}$, the present value of the profits attributable to each created vacancy discounted back to the innovation date t=0 is

$$(17) \quad \Gamma = \int_0^\infty \left\{ \pi \, e^{-\rho(t+1/s(1-z,v))-ht} \right\} dt \; = \; e^{-\rho/s(1-z,v)} \, \pi \, / \, (\rho + \theta L z) \, .$$

Thus, intertemporal profits depend positively on market power, π, but negatively on research activity, the subjective discount rate, and the vacancy rate. In order to analyze the indirect effects of any parameter change on unemployment, we have to endogenize the vacancy rate. To this end, we assume that the patent's price, k, is identical to the fixed cost of entry. Then, the free entry condition for the intermediate sector can be written as

$$(18) \quad e^{-\rho/s(1-z,v)} \, \pi \, / \, (\rho + \theta L z) - k = 0 \, .$$

The assumed market structure of monopolistic competition is suitable to deal with a changing number of rivals. While Romer (1990) and Grossman, Helpman (1991) analyze the growth effect of a sustained increase in the number of competitors, we follow Aghion, Howitt (1992b) in assuming that the number of firms and, hence, the vacancies are endogenously determined by the free entry condition.

We can conclude from the free entry condition (18) that the vacancy rate depends positively on market power, but negatively on innovative activity, the subjective discount rate, and fixed entry cost. Due to the positive correlation of vacancies and job finding rates, the same effects hold for the job finding rate while the opposite effects hold for the natural rate of unemployment. In particular, the indirect creative destruction effect works as follows: An increase in innovative activity will discourage entry with the result of decreasing the number of vacancies. This in turn will reduce the job finding rate due to the thin market externality with the result of a higher unemployment rate. Thus, innovative activity has not only a direct creative destruction effect, but also an indirect creative destruction effect, similar to the one derived by Aghion and Howitt (1992b).

4. Market Power, Endogenous Innovative Activity, and Unemployment

In this section, we turn to the optimization problem of a private research firm. Following the patent race approach suggested by Lee, Wilde (1980), we assume that firms engage in costly innovative activity to search for higher quality technologies. Any research firm i that invests R&D resources at intensity h_i for a time interval of length dt will succeed in producing a new blue print with probability $h_i dt$. This implies a cumulative density function

$$(19) \quad P(t) = 1-e^{-h_i t}$$

for the success of a single research firm and a cumulative density function

$$(20) \quad \tilde{P}(t) = 1-e^{-ht} \quad \text{with} \quad h = \sum_i h_i$$

for overall innovative success as it was already used in the section before. The successful innovator obtains a continuum of patents, one for each intermediate sector. Instead of the government it is now the monopolistic innovator which sells each patent to a demanding firm that becomes the local monopolist in that sector until the next innovation occurs. As before, each local monopolist has an exclusive right to produce the higher quality product in its sector. Because the market for blue prints is competitive, the price for the patent will be bid up until it is equal to the expected present value of the monopoly rents accruing to the patent. The buyer pays that price as a lump sum in exchange for an unconstrained use of the patent (sunk cost). In the symmetric equilibrium each of the n entrants will pay its expected intertemporal profits, Γ, to the winner of the patent race.

Let J_m be the value of a research firm i after the m th innovation. Assuming that each research firm takes wages, w=1, and the overall innovation arrival rate, h, as given, the optimization problem can be written as the Bellman equation

$$(21) \quad J_m = \max_{h_i} \int_0^\infty e^{-(r+h)t} \left[J_{m+1} h + n \Gamma h_i - h_i / \theta \right] dt$$

which can be transformed to

$$(22) \quad r J_m = \max_{h_i} \left[(J_{m+1} - J_m) h + n \Gamma h_i - h_i / \theta \right] .$$

Assuming free entry into the research sector, i.e. J_m=0 for all m, (22) reduces to

$$(23) \quad 0 = \max_{h_i} \left[n \Gamma h_i - h_i / \theta \right] .$$

Since $h_i \geq 0$, the Kuhn-Tucker conditions for the solution of (23) are

$$(24) \quad n \Gamma - 1/\theta \leq 0, \quad h_i \geq 0, \quad h_i (n\Gamma - 1/\theta) = 0.$$

As usual, we restrict our analysis to the steady-state growth path where $h_i > 0$. Hence, inserting Γ from (17) yields

$$(25) \quad h = e^{-\rho/s} \pi n \theta - \rho .$$

Similar to the no-arbitrage condition (line LL) in the quality ladder model of Helpman (1992), innovative activity and hence the rate of growth depend positively on the labor resources devoted to production of the intermediate input, the market power of firms in the intermediate sector, and the productivity index of R&D, but negatively on the subjective rate of time preference. In addition, our model suggests a positive influence of the recruiting-success rate which in turn depends negatively on the number of scientists and the vacancy rate. Of course, the number of intermediate firms is not an exogenous variable. Due to the employment restriction (13), which corresponds to the resource restriction (line NN) in the Helpman (1992) model, we can substitute for n and resolve (25) in terms of

R&D activity. Unfortunately, we have three endogenous variables (u,z,v) left, but only two solution equations for the equilibrium. The reason for this degree of freedom is that we have no patent pricing rule like that in the last section where the government determined the price k per patent. Let us assume a rise in market power to illustrate this problem. The adjustment to the new equilibrium will either be an increasing number of vacancies, or an increasing research staff. In both cases all intertemporal profits of the intermediate sector firms are exhausted by the winner of the last patent race. Thus, both kinds of reaction are consistent within our approach.

One way to resolve the model is to assume that the recruiting-success rate and the job finding rate are not much affected by new vacancies and scientists, i.e. both rates are "almost constant" (Agion, Howitt 1992b). Inserting (13) and (15) in (25) then yields

$$(26) \quad u = 1 - (1 + \beta\pi)\, z \,/\, \beta\pi - \rho/(\theta L \beta\pi)$$

where $\beta \equiv e^{-\rho/s}$. Equation (26) shows that an increasing number of workers in the intermediate sector induces an increasing number of workers in the research sector. These employment effects work together to reduce unemployment. The equilibrium values of innovative activity and unemployment are jointly determined by the equations (16) and (26).

We are now able to determine the influence of market power, π, on the endogenous rates of innovation, growth, and unemployment. The impact of a change in market power can be appraised by using the total differential of equations (16) and (26), holding the other exogenous variables constant.

$$(27) \quad \begin{bmatrix} -(1-2z-u+f/\theta L) & z \\ 1+\beta\pi & \beta\pi \end{bmatrix} \begin{bmatrix} dz \\ du \end{bmatrix} = \begin{bmatrix} 0 \\ (1-z-u)\beta \end{bmatrix} d\pi$$

The determinant of the (2x2) matrix of partial derivations is given by

$$(28) \quad \Lambda = -(1-z-u+f/\theta L)\beta\pi - z < 0 .$$

Using Cramer's rule, we derive a strictly positive impact of market power on innovative activity and hence on the equilibrium growth rate,

$$(29) \quad dz/d\pi = -(1-z-u)\, z\, \beta \,/\, \Lambda > 0 ,$$

but an ambiguous influence of market power on unemployment,

$$(30) \quad du/d\pi = -(1\text{-}2z\text{-}u+f/\theta L)\,(1\text{-}z\text{-}u)\,\beta\,/\,\Lambda \gtrless 0 .$$

As can be seen from (30), unemployment will increase with market power, if innovative activity is small, but it will decrease with market power, if innovative activity is large. Therefore, the modified model is also able to generate an inverted U-shaped relationship between innovation and unemployment which is now endogenously determined by market power in the intermediate sector. It is again the research staff effect that produces similar evidence compared to the capitalization effect derived by Aghion, Howitt (1992b).

5. Concluding Remarks

The theoretical analysis of the relationships between innovation, growth, and unemployment is still in its infancy. While earlier investigations centered interest either to endogenous growth, neglecting frictions on the labor market, or to unemployment, neglecting the effects of R&D activity, the intention of this paper was to join these streams of inquiry to develop a more comprehensive model of innovation, growth, and unemployment. We identified three different channels through which innovative activity affects unemployment. First, there is a direct creative destruction effect, because workers cannot immediately adopt the new technologies and are separated from production. Secondly, there is an indirect creative destruction effect since a high frequency of innovations reduces the value of incumbent firms. The number of vacancies and thus the job finding rate will decline while unemployment will rise. Finally, we identified a research staff effect taking into account that the rate of unemployment decreases with the number of workers in the research labs. Under certain circumstances, these effects work together to generate an inverted U-shaped relationship between innovative activity and unemployment.

Because the model relies on a large number of simplifying assumptions, the derived results should be viewed as suggestive. Of course, the technological development of a growing economy is much more complicated as can be studied in formal models which are of necessity highly abstract and stylized. Nevertheless, the presented model explains the empirical evidence of the relationship between growth and unemployment fairly well. Due to the fundamental importance of the topic, it seems to be worthwhile to integrate some further aspects like capital accumulation, imperfect credit markets, and international trade into the approach to achieve an even more comprehensive model of innovation, growth, and unemployment.

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