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Schumpeterian Adaptation and Labour Shortage

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Abstract

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1 Introduction

Evolutionary models confront Schumpeter's (1934, 2010 [1942]) concepts of innovation and creative destruction in the study of growth and technical change. They usually assume that the supply of labour adapts perfectly to the demand of firms, who therefore always realize the employment levels they desire (see Nelson and Winter, 1982).

In a recent paper, Metcalfe and Steedman (2013) argue that the assumption of surplus labour is not as innocuous as it may seem. They exemplify this in a simple one-commodity model, where labour supply is fixed and two types of firms, say innovators and established firms, differ in their methods of production. They show: If surplus labour exists, adaptation in terms of economic weights is brought about by differential growth. This mechanism relies on the idea that differences in methods translate into differences in growth rates. But if labour is in short supply, the innovator will pay a wage premium in order to compete workers away from established firms. Through the predation of economic resources, new methods conquer the system at the expense of old ones by depriving them of the basis of their very existence. Hence, rivalry for a common resource in short supply changes the way in which adaptation is effectuated; it does not only involve the relative decline of inferior firms but also their absolute decline due to what is termed 'growth predation' here. Overall their study gives a clear meaning to the notion of the *process of creative destruction* in a world in which economic resources are finite but (partly) mobile.

The paper explores the idea of 'growth predation' in a simple growth model. In line with Metcalfe and Steedman (2013), the growth rate of labour supply is assumed to be given and constant. Further, the adaptation is brought about through the change in economic weights of firms; hence the problem of imitation is set aside. The model proposed differs in the following from the one by Metcalfe and Steedman: 'Capital' is not circulating but assumed to be perennial; it further is not malleable, it cannot be dismantled and hence it is not possible to transform installed capacity to serve another purpose. This implies that in case of a shortage of labour, some firms are unable to obtain the manpower required to fully utilize their equipment. To the author's best knowledge, the role of capital utilization has not been explored in the literature on Schumpeterian adaptation. However, note that *unintended idleness of capital* results from a lack of essential inputs and not from a lack of effective demand; the latter problem is set aside in the paper.

The aim of the paper is to explore the relation between the process of adaptation and aggregate growth given the assumption that labour supply is inflexible. Emphasis is put on the idea that different types of innovations lead to different adaptation paths and results. To this end, a 'causal analysis' is performed, in which the adapting economy is compared to the reference economy, which has not been shaken by the innovative impulse.

Main findings include: (i) Certain types of innovations lead to instant effects such as technological unemployment if born into a situation of full employment. (ii) The labour inflexibility assumption imposes constraints on firm expansion which, if binding, shift the adaptation regime. Three phases are identified, namely the 're-absorption phase', where technological unemployment prevails and differential growth effectuates adaptation; the 'predation phase' during which the new firm lures away workers from the old one; the 'restoration phase' in which the innovator adapts to given conditions. It is shown that as long as unemployment prevails, adaptation involves a logistic replacement pattern, whereas 'growth predation' implies an exponential pattern. (iii) The consequences of adaptation for aggregate growth depend both on the phase the system is in and the innovation bias; and it is not necessarily the case that innovations boost growth.

The paper is organized as follows: Section 2 presents a simple growth model with two rival firms. In Section 3 the relation between adaptation and growth for different types of innovations is explored by means of a causal analysis. Section 4 concludes.

2 Heterogeneous firms and labour shortage

This section presents a simple model of growth, where labour supply growth is exogenously given and firms differ with in their methods of production. Before the model is explained in detail, a note on one main assumption concerning the treatment of firms will clarify what we can expect from what follows.

Basically, a firm is understood not as a profit-maximizing device but as a bundle of behavioural routines, such as its method of production or its investment policy, and complementary resources, such as its skills or technological competencies or its organisational structure. Because past resources determine what firms can do today, their ability to adapt to changed conditions is at best limited. And because of the path-dependent and cumulative nature of learning, there is no reason to expect that firms are identical. Overall, imperfect adaptability leads to inertia of firms, whose routines differ but tend to persist. For this reason, Nelson and Winter (1982) stress that firms are "much better at changing in the direction of 'more of the same' than they are at any other kind of change" (pp. 9–10). If for some substantial reason it is the case that a firm can change its capital stock faster than the method it uses, we may push it to the limit and take the conventional route of treating 'slow' (firm) variables as *given data* in the analysis of how comparatively 'fast' variables change and the economic effects this entails.[1]

[1]This temporal isolation, which rests on the idea that adjustment is not instantaneous and that variables differ in their adjustment speed, serves as a conventional crutch to the problem

This argument may motivate one main assumption of the model, namely that firms are unable to transform their resources in order to serve another purpose, that is, firms neither innovate nor imitate. Hence firms' technical conditions of production belong to the set of given data.[2] However, we will account for the process of innovation in terms of its economic effects (see section 3.1).

The set of assumptions adopted in the following are similar to that of evolutionary diffusion or selection models.[3] What we get from it is an idea how economic movements result from changes in the economic weight of different firms and hence of different ways of doing things. The rise and fall of firms, it seems, is central to Schumpeter's concept of *creative destruction*. Through this process of selection the economy as a whole is able to adapt even though there is stasis at the level of firms.

2.1 Production

Firms produce a single and homogeneous good which serves both as an investment and as a consumption good. For analytical convenience, there are just two rivals (or two types of rivals), namely the established or 'old' firm 1 and the innovating or 'new' firm 2. Output of firm i is determined by the limitational production function

$$x_{i,t} = \min\left\{\frac{L_{i,t}}{l_i}; \frac{K_{i,t}}{b_i}\right\} \qquad \text{for} \quad i \in \{1, 2\}\,, \tag{1}$$

where $x_{i,t}$ is firm i's output, $K_{i,t}$ its stock of perennial capital (machines) and $L_{i,t}$ is the amount of labour firm i employs. These firm variables change over time, whereas the labour coefficient l_i and the *full-utilization* capital coefficient b_i are fixed parameters. The two firms differ in their technical conditions of production.

Before production starts, firms hire workers. Every firm wants to employ that amount of labour which it needs to fully utilize its machines. Firm i's labour demand hence is

$$L^d_{i,t} = \frac{K_{i,t} l_i}{b_i}.$$

that essentially all economic data are in constant flux.

[2]Evidence suggests that the case of strong 'incumbent inertia' is not purely hypothetical; see for example Gilbert (2005) and the references he gives.

[3]The first evolutionary diffusion model dates back to Nelson (1968). Nelson and Winter (1982, chap. 6) and Metcalfe (1998) explore competitive selection for a single industry facing an exogenously given downward-sloping industry demand curve. Nelson and Winter (1982, chap. 10), Soete and Turner (1984), Silverberg (1984), Englmann (1992), Metcalfe (1997), Nelson and Pack (1999) and Metcalfe and Steedman (2013) explore the restructuring process within a one-commodity growth framework; see also Haas (2015). For an overview of the evolutionary perspective on growth and technical change see Santangelo (2003) and Silverberg and Verspagen (2005).

Supply of labour N_t grows at a given and constant rate n,[4] i.e.

$$N_t = (1+n)\, N_{t-1}. \tag{2}$$

Given the assumption that labour is inflexibly supplied, total employment $L_t = \sum_i L_{i,t}$ never exceeds total supply:

$$L_t \leq N_t.$$

It follows that if total labour demand exceeds labour supply, at least one firm fails to realize its planned employment level and hence is rationed.

Firm 2, by paying a slightly higher wage rate than firm 1, is assumed to be able to satisfy its labour demand.[5] For simplicity both nominal wage rates, w_1 and w_2, are rigid and hence stay constant. Because $w_2 > w_1$ firm employment levels are given by

$$L_{1,t} = \min\left\{L^d_{1,t}; N_t - L_{2,t}\right\}, \tag{3a}$$
$$L_{2,t} = \min\left\{L^d_{2,t}; N_t\right\}. \tag{3b}$$

Because of the wage differential, there is an asymmetry in the determinants of firm employment levels. Equation (3b) states that firm 2 is rationed only if its *own* labour demand exceeds total supply. For firm 1 matters are more complex. Firm 1 is rationed if *total* labour demand exceeds total supply. If this is the case, firm 1's employment depends on firm 2's accumulated stock of machines. The rivalry of firms for workers in fixed supply is the basis for the mechanism of 'growth predation' (see section 3). Because we focus on this mechanism, we exclude the possibility that firm 2 is rationed on the labour market by an assumption on firm investment behaviour, to which we turn now.

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[4] Note that the assumption of an exogenous population growth rate is quite at odds with the classical perspective, in which the workforce endogenously adjusts to the pace of capital accumulation (Kurz 2008, 2010). It may be motivated by the idea that the structure of productive activities changes faster than the factors which determine population growth.

[5] The extent of this premium depends on the perfection of the labour market. If workers are fully informed and perfectly mobile, a negligibly small premium will attract enough workers (Metcalfe and Steedman, 2013; see also Nelson and Pack, 1999). Note that here the explanation of the wage differential has nothing to do with the skills of workers or the quality of jobs; see Kurz and Salvadori (1995, chap. 11) for an analysis of persistent forces which regulate the structure of relative wages in the long run.

2.2 Investment

After production has taken place, firms pay their workers and decide on investment. In line with the extreme von Neumann hypothesis it is assumed that workers consume their entire income while firm owners do not consume. Further, firms are assumed to be homogeneous with respect to investment behaviour for which profitability plays a decisive role. In order to simplify things, we assume 'auto-catalytic self-reproduction' (Silverberg, 1984), which means that firms only invest in their own business.[6] It follows that accumulation of machines of firm i is exclusively motivated by its own success.

Firm i's measure of success is its 'individual' expected rate of profit, which is given by

$$r_{i,t}^{e} = \frac{1 - \frac{w_i}{p_{i,t}^{e}} l_i}{b_i} u_{i,t}, \tag{4}$$

where $u_{i,t} \leq 1$ is firm i's capital utilization rate, which is the ratio of actual output $x_{i,t}$ to potential output $K_{i,t}/b_i$. Further, $p_{i,t}^{e}$ is the price, firm i expects. Assuming that all firms have *static expectations*, it follows that $p_{i,t}^{e} = p_{t-1}$, where p_{t-1} is the last period's uniform price. The 'individual' expected rate of profit is determined (i) by the output price it expects and the wage rate it pays; (ii) by its purely technical production coefficients; and (iii) by its *current* capital utilization rate. Clearly, a firm which is rationed on the labour market has unused machines; this implies a rate of capital utilization smaller than unity and an *actual* capital coefficient larger than what is technically feasible; consequently, the firm's 'individual' rate of profit is lower compared to the case in which the firm is not rationed.

Further, firms take into account that the supply of labour limits the amount of capital which can be fully utilized. If firms are assumed to know the growth rate of labour supply, they adjust to it by respecting the following inequality constraint:

$$K_{i,t+1} \leq \frac{(1+n)\, N_t}{l_i} b_i, \tag{5}$$

where the right-hand side of eqation (5) gives the amount of capital needed to fully employ *all* workers available in period $t+1$ using method of production i. This condition is a constraint on investment for the innovating firm 2 and implies that firm 2 is never constrained on the labour market in the way firm 1 is. For the incumbent firm 1 this constraint is never binding because of equation (3a).

[6] See Soete and Turner (1984) for a discussion of investment flow adjustments in the context of diffusion and selection.

It follows that investment levels are determined by

$$I_{1,t} = r^e_{1,t} K_{1,t}, \tag{6a}$$

$$I_{2,t} = \min \left\{ r^e_{2,t} K_{2,t}; \frac{(1+n)\, N_t}{l_2} b_2 - K_{2,t} \right\}, \tag{6b}$$

where $I_{i,t} = K_{i,t+1} - K_{i,t}$ denotes *real* investment of firm i. Because the two firms differ in their technical conditions of production, they also differ in their 'individual' profit rates. And via equation (6) this difference translates into a difference in capacity growth of the rivalling firms. This is the basis for the mechanism of differential growth (see section 3).

The investment functions show that a lack of essential inputs slackens capital accumulation in two different ways: If firm 1 is rationed on the labour market, its lower rate of capital utilization depresses its individual profit rate; this results in slowed accumulation. Firm 2 would face this problem only after it has become too big and if it grows too rapidly. Since firms know the growth rate of labour supply but not the accumulation plans of rivals, the innovating firm avoids being rationed by adjusting its investments according to condition (5).

What has become visible so far is that the problem of a lack of essential inputs may affect different types of firms in different ways. And that while some implications of bottlenecks may instantly show economic effects, others remain in the shadow and enforce economic movements only after the system passed some tipping point. The third element of the model is output market interaction, which is explained next.

2.3 Pricing

In the output market firms sell the part of their production, which they do not set aside for investment. It is assumed that all firms sell at the same price which is determined by *market clearing*. At the time of market interaction total *real* supply S_t and total *nominal* demand D_t are given magnitudes determined by prior decisions on production and investment: The amount of goods supplied to the market equals total output minus total investments; and total *nominal* demand is the total wage bill since workers do not save and capitalists do not consume. Market coordination thus can only be brought about by a variation of the price. In the case of perfect coordination assumed here, the price p_t adjusts such that real supply S_t and real demand D_t/p_t coincide:

$$p_t = \frac{D_t}{S_t} = \frac{w_1 L_{1,t} + w_2 L_{2,t}}{x_{1,t} + x_{2,t} - I_{1,t} - I_{2,t}}. \tag{7}$$

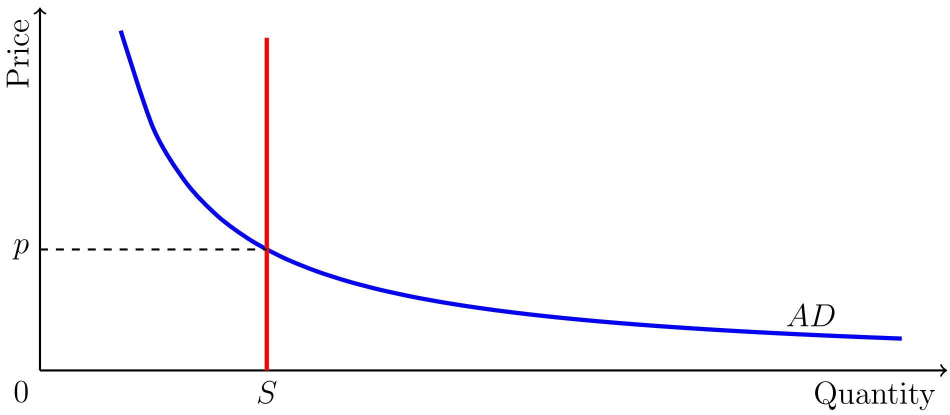

Figure 1: Aggregate real demand curve AD, aggregate real supply S and the market clearing price p.

This is illustrated in figure 1. As the amount of goods supplied is fixed, the supply curve (the line S) is a vertical. The aggregate real demand curve (the line AD) shows the relation between the amount of goods workers are able to purchase and the market price for their *given* nominal income. Obviously, if the price rises, the quantity of goods a worker can buy falls. The price at which the two lines intersect clears the market and is the one at which all supplied goods change hands.[7]

There is one implication of this pricing rule which greatly simplifies our analysis: As long as both firms' investments are purely profit-led, the price does not change. This can easily be verified by applying equation (4) together with $I_{i,t} = r^e_{i,t}K_{i,t}$ for $i \in \{1, 2\}$ to the pricing rule (7). As long as the price does not change, the growth rate of the innovative firm is constant and the rate at which the established firm accumulates changes due to rationing only. The stylized 'mechanics' at hand may thus put quantity adjustments unfolding in the course of adaptation into sharp relief.[8] But this is not to say that price dynamics are not important here. To the contrary, as will be shown below, condition (5) sooner or later gets binding and the resulting price movements play a decisive role in restoring equilibrium. That the price does not gradually adapt reflects one central theme of this study, namely that the forces that move the system may not remain the same over time. Rather, one force may shape economic movements in one phase, but at the same time it may pave the grounds for new forces. And if they gain momentum and prevail, the behaviour of the system may change and new phenomena may arise. Thus

[7]Note that the *Law of One Price* holds on the output market but not on the labour market, which implies inequality within the group of otherwise homogeneous workers.

[8]Also Metcalfe and Steedman (2013) assume that prices and wages do not change during adaptation.

something can be learned from the study of the sequence of mechanisms and their interplay.

Before we deal with this question, let us summarize the model in order not to loose sight of its data, variables and (behavioural) relations. Figure 2 illustrates the basic structure of the model. The givens consists of the set of firm-specific data $\{l_i, b_i, w_i\}$ where $i \in \{1, 2\}$. Also the rate at which the labour supply grows, namely n, is exogenously given. The endogenous variables, whose evolution we seek to explain, are the aggregate stock of machines $K_t = \sum_i K_{i,t}$, aggregate employment $L_t = \sum_i L_{i,t}$, aggregate output $x_t = \sum_i x_{i,t}$ and the market share of firm 2, denoted by $q_t = x_{2,t}/x_t$, which shows the economic weight of the innovation.

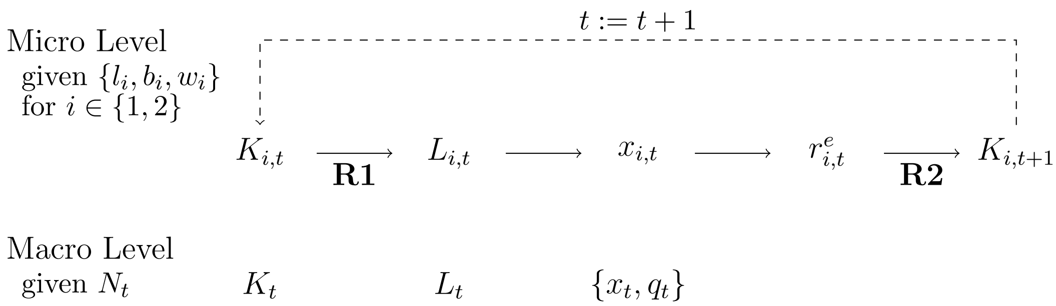

Figure 2: Logic of the model.

Firm variables $\{K_{i,t}, L_{i,t}, x_{i,t}\}$, where $i \in \{1, 2\}$, from which aggregates build up, evolve according to two *micro rules*, which establish relations between firm variables: the production function (1) and the investment function (6). The *macro rule* (2) determines labour supply, describes the environment in which firms act and defines channels through which they interact. There are two *interaction rules*: Equation (3) establishes a functional relationship between firm variables yielding firms' employment levels as outcomes of labour market interaction; and through coordination rule (7) firms interact via the market-clearing output price.

As discussed, for the case that labour supply grows at an exogenously given rate two forms of rationing can occur, which are referred to as **R1** and **R2**:

R1 Firm 1 is rationed, if total labour demand is larger than supply. This implies that its capacity-determined employment level is strictly larger than its labour-supply-determined level ($L^d_{1,t} > N_t - L_{2,t}$). If this is the case, we say that **R1** holds.

R2 From condition (5) it follows that firm 2 is 'investment rationed' if its profit-determined level of investments is larger than its labour supply-determined full-utilization level of investments. If this is the case, we say that **R2** holds.

3 Adaptation and growth

This section turns to the relationship between the adaptation process and aggregate growth. The focus is on two questions: (i) How does adaptation proceed, given that labour supply growth is exogenously given? (ii) What are the effects for the system as a whole in terms of output and employment?

In order to grasp the overall effect caused by innovation, a causal analysis is performed. For this purpose we compare the *adaptation path* of the system, which starts with the innovative impulse and ends with the restoration of a new equilibrium, with the *reference path*, which is defined by the original system not upset by the innovation. The causal effect of the innovation is then given by the difference between the two paths.[9]

In this study the reference path is defined by the LPP growth path characterized by: (i) method of production 1 with l_1 and b_1 operated by all firms; (ii) a uniform, constant and non-negative real wage rate w_1/p; (iii) full employment growth: $g_1 = r_1 = n$. Consistency requires that $n \leq 1/b_1$.

Based on this, the implementation of the new method of production and the causal effects it implies are considered in section 3.1. In section 3.2 we turn to the diffusion period, in which the new firm conquers the system at the expense of the old one. Emphasis is put on the fact that different types of innovation lead to different adaptation paths and effects.

3.1 The implementation period

At the beginning of the implementation period 0 the 'innovating' firm 2, which uses a new method, arises. It is assumed that it grows out of existing resources and comes into being through the 'mutation' of some small part of the capital stock. This transformation is a singular, exogenous event and to some extent violates the assumption that installed machines cannot be transformed in order to serve another purpose. One may think of a chemical reaction gone wrong. Saying that innovation is an obscure and unintended 'accident' rather than the result of economic motives and deliberate action will make it sufficiently clear that an explanation of the process of innovation itself is not intended here.

[9]This method has been employed by Kalmbach and Kurz (1992) in their empirical study of employment effects of diffusion processes. Hicks (1983) describes the *causal analysis* as follows:

> We compare two alternative paths that extend into the future. Along one of those paths some new 'cause' is not operating; along the other it is. The difference between the paths is the effect of that cause. The difference itself extends over time [and] it is the *whole* of the difference between the paths which is the effect of the cause (p. 109; *Hicks's italics*).

However, the initial capital share of firm 2 is given by $K_{2,0}/K_0$, where K_0 is the amount of total capital available in period 0. Endowed with $K_{2,0}$ the new firm 2 uses the new method, which is characterized by labour coefficient l_2 and full-capacity capital coefficient b_2. And it pays a nominal wage rate w_2 which is higher than the normal level w_1 paid by the established firm. Because we are interested in successful methods, only cases are considered for which

$$r_2 > r_1 \qquad \text{implying} \qquad l_2 < \frac{(1 - r_1 b_2)}{e w_1}$$

holds, where $e = w_2/w_1$ is the ratio of the wage paid by firm 2 and that paid by firm 1. A method for which this condition does not hold fails to yield an above-normal rate of profit and to pay a sufficiently high wage differential at the same time, given the prevailing real wage rate. Hence it is not an innovation but a mere invention. This definition of innovation as a new method of production passing the 'profitability test' is based on the idea that current economic conditions determine which methods are successful and which are not (see Kurz, 2008). It implies that because $r_1 = n$ before the innovation enters, firm 2's individual profit rate r_2 is higher than n. This will turn out to be important in the discussion of adaptation.[10]

Two things deserve attention: Firstly, the set of potential innovations defined by the above condition depends on the wage differential. As already noted, its extent varies with the perfection of the labour market in terms of information and mobility of workers. This amounts to saying that institutions influence which methods are successful and which are not. Obviously, the higher the wage differential, the greater the fringe of new methods the established firm needs not to fear.

Secondly, even if a new method passes the 'profitability test' it does not necessarily exhibit lower (physical) *real unit costs* of production than the established method. If we define the real unit costs h_i for firm i as the amount of goods actually destroyed in the course of production, it follows that h_i equals the firm's wage payments *in real terms* since machines are assumed not to depreciate: $h_{i,t} = w_i l_i / p_t$. Method 2 exhibits higher real unit costs than method 1, if

$$h_2 > h_1 \qquad \text{or} \qquad e l_2 > l_1.$$

[10]This definition of innovation has one major drawback, because it excludes cases in which the new method fails to pass the above 'ex-ante' profitability test, where r_2 is compared to the normal level $r_1 = n$, but becomes more profitable than the established method if implemented. That is the case if the blind 'mutation' of $K_{2,0}$ implies that firm 1 becomes rationed and therefore yields a below-normal 'individual' rate of profit, which then might be lower than r_2. However odd this may sound, it indicates the possibility that the introduction of new methods may change the environment in a way such that the new method eventually becomes successful.

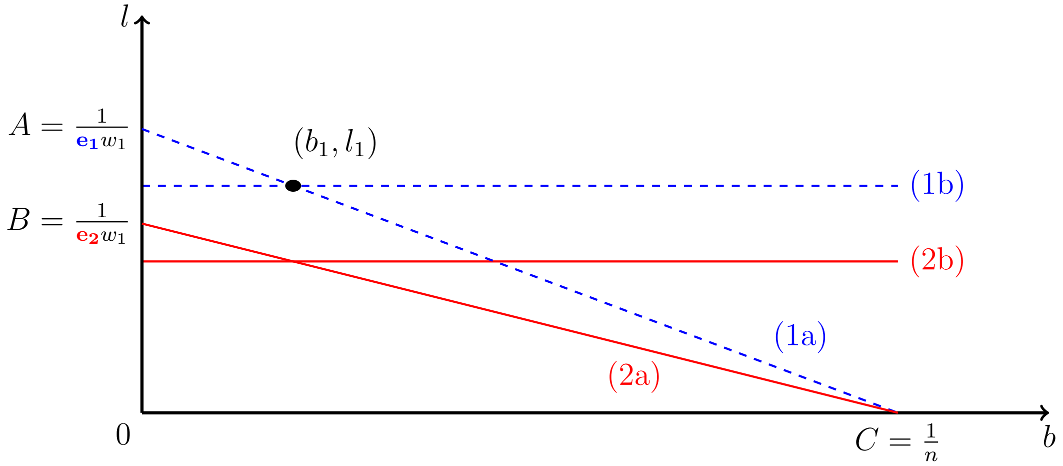

Figure 3: Iso-profit-rate line $l_2 = (1 - nb_2)/ew_1$ and iso-cost line $l_2 = l_1/e$ for $r_1 = n = 0.1$, $p = 1$, $(b_1, l_1) = (2, 4)$. Iso-profit-rate line (1a) and iso-cost line (1b) $e_1 = 1$; iso-profit-rate line (2a) and iso-cost line (2b) $e_2 = 1.5$.

As one can see, higher real unit costs of the innovator result from a high wage premium, a strong labour-using bias, or a combination thereof. Methods of production for which both $r_2 > r_1$ and $h_2 > h_1$ hold belong to the subset of potential innovations which imply a more resource-intensive way of production.

Figure 3 illustrates the above two points by means of an example where the established method is given. In case (1) the wage premium is zero ($e_1 = w_2/w_1 = 1$) and the set of potential innovations is found in the area $\overline{A0C}$, which is bounded from above by the iso-profit curve (1a). Potential innovations above the iso-cost line (1a) are those with higher real unit costs. In case (2) the innovator pays a higher wage rate ($e_2 = 1.5$). This implies that the iso-profit curve (2a) compared to (1a) rotates inwards with $C = 1/n$ as an invariant point and the iso-cost curve (2b) shifts parallel downwards compared to (1b). The new set of potential innovations is given by the area $\overline{B0C}$. Again, there are innovations which exhibit higher real unit costs than method 1; they lie below (2a) but above (2b).

Innovations can be further characterized by their *innovation bias*. The typology of innovations used here rests on the two measures

$$\Theta_b = \frac{b_2 - b_1}{b_1} > -1 \quad \text{and} \quad \Theta_l = \frac{l_2 - l_1}{l_1} > -1.$$

Here, Θ_b is the relative deviation of firm 2's full-capacity capital coefficient from firm 1's; and Θ_l is the relative deviation of firm 2's from firm 1's labour coefficient. The bias of an innovation is defined by the sign of the two measures. Note that both Θ_b and Θ_l are strictly larger than -1, which means that both the capital good and labour are essential to the innovation.

Let us now turn to the causal effects on aggregate output and employment the implementation of an innovation entails. To determine them, total output x_0 and employment L_0 of the adapting economy are compared to their reference values, where in both the adapting and the reference economy the same stock of capital K_0 and the same amount of labour N_0 is available. The employment effect and the output effect are described in the following and summarized in table 1 for different types of innovations.

The effects of implementation on aggregate output and employment depends first of all on whether firm 1 is rationed already in the innovation period (**R1** holds) or not. **R1** holds in the innovation period if

$$\frac{l_2}{b_2} > \frac{l_1}{b_1} \qquad \text{or} \qquad \Theta_l > \Theta_b .$$

We see that **R1** holds if the labour intensity, the relative proportion of labour to capital, is higher for the innovating firm than for the established firm.

The instant employment effect is defined as the relative deviation of the implementation period's aggregate employment L_0 from the reference level $L_R = N_0$ and is given by:

$$\frac{\Delta_{L,0}}{L_R} = \frac{L_0 - N_0}{N_0} = \begin{cases} 0 & \text{if } \mathbf{R1} \text{ holds } (\Theta_l > \Theta_b), \\ \dfrac{K_{2,0}}{K_0}\left(\dfrac{\Theta_l - \Theta_b}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ does not hold } (\Theta_l \leq \Theta_b)\,. \end{cases} \tag{8}$$

Because a full employment reference path is assumed, the employment effect is either zero or negative. It is zero in cases in which the innovation is more labour intensive than the established one; thus if **R1** holds full employment prevails in the implementation period, but some of firm 1's machines lie idle. Also if a neutral innovation ($\Theta_l = \Theta_b$) gets implemented, the employment effect is zero. In this case, however, also the capital stock is fully employed in the innovation period. But if the innovation is less labour intensive ($\Theta_l < \Theta_b$), installed capacity is fully utilized but some workers lose their job.

From equation (8) we also see that the extent of technological unemployment not only depends on the innovation bias but also on firm 2's initial capital share. For example, if the innovation is capital using and labour saving, where $\Theta_b = 0.25$ and $\Theta_l = -0.25$, the employment effect amounts to $\Delta_{L,0}/L_R = -0.1$, if $K_{2,0}/K_0 = 0.25$. But if the whole capital stock mutates instanteneously ($K_{2,0} = K_0$), the employment effect is $\Delta_{L,0}/L_R = -0.4$.[11]

[11] It is the latter case, on which David Ricardo (1951, chap. 31) based his argument on the harmful consequences of new machinery for workers.

Innovation type	**Bias**	**R1**	$\mathbf{\Delta_{x,0}/x_R}$	$\mathbf{\Delta_{L,0}/L_R}$
capital saving and labour using	$\Theta_b < 0\ ,\ \Theta_l > 0$	Yes	-	0
labour saving and capital using	$\Theta_b > 0\ ,\ \Theta_l < 0$	No	-	-
pure capital saving	$\Theta_b < 0\ ,\ \Theta_l = 0$	Yes	0	0
pure labour saving	$\Theta_b = 0\ ,\ \Theta_l < 0$	No	+	-
combined factor saving	$\Theta_b < 0\ ,\ \Theta_l < 0$			
neutral	$\Theta_b = \Theta_l < 0$	No	+	0
dominantly capital saving	$\Theta_b < \Theta_l < 0$	Yes	+	0
dominantly labour saving	$\Theta_l < \Theta_b < 0$	No	+	-

Table 1: Causal effects in the innovation period.

The causal output effect of implementing an innovation is defined as the relative deviation of the implementation period's aggregate output x_0 from its reference x_R and equals:

$$\frac{\Delta_{x,0}}{x_R} = \frac{x_0 - x_R}{x_R} = \begin{cases} -\dfrac{K_{2,0}}{K_0}\left(\dfrac{\Theta_l}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ holds } (\Theta_l > \Theta_b), \\ -\dfrac{K_{2,0}}{K_0}\left(\dfrac{\Theta_b}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ does not hold } (\Theta_l \leq \Theta_b)\,. \end{cases} \tag{9}$$

As we can see, the direction of the instant causal output effect is determined by the two dimensions of the innovation bias and how these compare to each other: If the innovation is more labour intensive than the established one, we know that **R1** holds. It follows from equation (9) that the labour bias Θ_l determines the direction of the output effect in this case. But if the innovation is less labour intensive and hence causes unemployment (**R1** does not hold), it is not the labour bias Θ_l but the capital bias Θ_b that determines the direction of the effect. It follows that in both cases the causal effect can be positive (or negative)—although for different reasons (see table 1). This finding shows that prevailing economic conditions, which may change due to the process of innovation, are relevant for the assessment of the instant effects of innovations.[12]

[12]The idea that broader economic conditions determine the impact of innovations can be found in the discussion between Schumpeter (1934, 1939) and Spiethoff (1925). Whereas Schumpeter assumed that innovations are introduced into a situation of full employment, i.e. what he termed a 'circular flow', Spiethoff argued on empirical grounds that innovations normally are born into a world in which some economic resources lie idle (Kurz, 2013).

3.2 The diffusion period

This section turns to the diffusion period in which the innovation gradually gains economic weight. The way diffusion is effectuated and its consequences for aggregate growth are discussed for different types of innovation.

The above discussion showed that the implementation of some types of innovations makes workers redundant. It will turn out in this section that this *instant* effect of innovation shapes the subsequent behaviour of the system. The basic argument can be summarized as follows. If the innovative method is less labour intensive than the established one, technological unemployment results. As long as this situation prevails, no firm is rationed. Therefore, diffusion is effectuated by differential firm growth; due to this mechanism the relative importance of the innovative firm gradually increases over time because the difference in individual profit rates translates into a difference in growth rates. This process drives the system in the *re-absorption phase*, which is defined by the fact that neither **R1** nor **R2** do hold (see section 3.2.1).

Re-absorption occurs only in cases in which $\Theta_l < \Theta_b$; in all other cases, the economy does not enter this regime. However, this regime eventually ends, because above-normal growth of the innovating firm re-establishes full employment. But then firm 1 becomes rationed, while firm 2's output growth is still purely profit-led and realized by attracting workers from firm 1. This kind of predatory interaction unfolds in the *predation phase*, which is the regime where **R1** holds but **R2** does not (see section 3.2.2).

The last regime the system undergoes starts when the established firm is in its final throes (in economic terms) and the innovative firm has nearly exhausted its potential to grow at an above-normal rate by depriving firm 1 of workers. If then condition (5) becomes binding and not only **R1** but also **R2** holds, the system enters the *restoration phase*, in which the innovator adapts his accumulation speed to the growth rate of labour supply. This unleashes a fierce fall in the output price by which the system falls back into a steady state (see section 3.2.3).

3.2.1 The re-absorption phase

In this phase technological unemployment prevails because an innovation, which is less labour intensive than the established method, got implemented. We call it the re-absorption phase, because jobless workers are gradually re-employed.

The reason why this happens is that the innovation yields an above-normal individual rate of profit while the market price does not change. Since firm 1 is not rationed it holds that firms' output growth rates are given by

$$g_1 = \frac{x_{1,t+1} - x_{1,t}}{x_{1,t}} = r_1 = n \qquad \text{and} \qquad g_2 = \frac{x_{2,t+1} - x_{2,t}}{x_{2,t}} = r_2 > n.$$

The growth rate of aggregate output is the weighted average of firm growth rates, where the weights are firms' market shares. It can be expressed as

$$g_t = \frac{x_{t+1} - x_t}{x_t} = n + \underbrace{q_t\,(g_2 - n)}_{\text{(re-absorption effect)}} > n, \tag{10}$$

where q_t is the market share of firm 2. We see that the aggregate growth rate is larger than n, which is the rate at which the reference economy grows, because of a positive 're-absorption effect'. The same holds for employment growth, which is the weighted average of firm growth rates with firms' employment shares as weights. Isolating the re-absorption effect gives

$$g_{L,t} = \frac{L_{t+1} - L_t}{L_t} = n + \underbrace{q_t \frac{1+\Theta_l}{1+q_t\Theta_l}\,(g_2 - n)}_{\text{(re-absorption effect)}} > n,$$

and shows that its extent also depends on the innovation's labour bias Θ_l: The more the innovation saves on labour, the slower job growth is. This indicates that the length of the re-absorption phase depends on the type of innovation.

Both aggregate growth rates increase over time, since firm 2 gradually gains economic weight. The structure of production changes due to the mechanism of differential firm growth at a rate which is proportional to the profit differential $(r_2 - r_1)$:

$$\frac{q_{t+1} - q_t}{q_t} = \frac{g_2 - g_t}{1 + g_t} = (1 - q_t)\,\frac{(r_2 - r_1)}{1 + g_t}. \tag{11}$$

Equation (11) defines the diffusion path and implies that the innovation displaces the established method along a sigmoid curve. Similar to Metcalfe and Steedman (2013), adaptation by differential growth is a logistic process, but it does not necessarily yield a simple logistic curve, since the aggregate growth rate g_t is not constant; on sigmoid diffusion curves see Stoneman (2002).

Summing up, the re-absorption phase is bright and prosperous inasmuch as the economy grows at a rate which is always above of what was feasible before the innovation occurred. But note that this is only possible if the emergence of the innovation caused unemployment. Further keep in mind that as long as unemployment prevails the mechanism of differential growth shapes economic movements and causes a logistic process of structural change in terms of market shares.

3.2.2 The predation phase

After differential growth finally restored full employment, the system enters the predation phase, which is defined by the fact that **R1** holds but **R2** does not. This implies that a new force sets in and shapes the course of things. Since now full employment prevails, it goes without saying that the causal employment effect is zero. We thus focus on the causal output effect.

The explanation of the causal output effect begins with the remark that also in the predation phase the market price does not change. Hence firm 2's individual rate of profit remains constant and above the normal level. Yet, firm 1's position is less favourable as it is no longer able to maintain full capital utilization. Idle capital in turn forces down its individual rate of profit and implies that

$$n > r_{1,t} \qquad \text{and} \qquad r_2 > n.$$

Hence the speed at which firm 1 accumulates capacity abates. But this is not all that happens to it. Predatory interaction on the labour market by equation (6a) implies that the growth rate of the established firm depends on the growth rate of the innovating firm:

$$g_{1,t} = \frac{x_{1,t+1} - x_{1,t}}{x_{1,t}} = n + \underbrace{(-1)\,\frac{q_t}{1-q_t}\,(1+\Theta_l)\,(g_2 - n)}_{\text{(predation effect)}} < n. \tag{12}$$

Since $g_2 > n$, this equation shows that the faster the innovator grows the slower the established firm expands in terms of output. By predation of workers, firm 2 pushes down firm 1's rate of output growth and thereby continues to be able to realize 'above-normal' growth. The mechanism of 'growth predation' thus establishes a situation in which

$$n > g_{1,t} \qquad \text{and} \qquad g_2 > n,$$

where $g_2 = r_2$.

For the system as a whole, growth predation affects aggregate output growth by

$$g_t = n + \underbrace{(-1)\,q_t\Theta_l\,(g_2 - n)}_{\text{(predation effect)}}. \tag{13}$$

We see that adaptive growth may differ from reference growth n due to the 'predation effect' of equation (13). Since $g_2 > n$, the sign of this effect is determined by the innovation's labour bias Θ_l only. Hence innovations do not necessarily unfold an expansionary tendency in the predation phase: Only if the innovation saves on labour ($\Theta_l < 0$) the economy experiences 'above-normal' growth; but if a labour-using innovation ($\Theta_l > 0$) gains economic weight, 'below-normal' growth results; and if $\Theta_l = 0$ the economy grows at its normal rate n. Therefore there are cases in which the aggregate output growth rate flips from an above-normal to a below-normal level, since re-absorption growth always is above the normal level.

The reason why the labour bias of the innovation is a major determinant of aggregate growth is that the economy hits the full-employment ceiling, while it passes from the re-absorption to the predation phase. This means that total output is given by $x_t = N_t/\bar{l}_t$, where $\bar{l}_t$ is the average labour coefficient, defined by $\bar{l}_t = (1 - q_t)\, l_1 + q_t l_2$. Taking growth rates reveals that if the average labour coefficient rises as the economic weight of a labour-using innovation increases, the resulting output growth rate is smaller than the growth rate of labour supply n.

The fact that the system hits the full-employment ceiling does not only change the determinants of adaptive growth but also the adaptation mechanism. Because growth predation breaks the one-to-one relation between the profit differential and the growth differential, it undermines the 'logistic law' as a driver of structural change. To see this, let us turn to the evolution of employment shares, which are more informative than the corresponding output shares here: Let employment share of firm 2 be $q_{L,t} = L_{2,t}/L_t$ and let Λ_t denote the rate at which it changes.[13] The rate of change in employment shares for the re-absorption phase and the predation phase then are:

$$\Lambda_t = \frac{q_{L,t+1} - q_{L,t}}{q_{L,t}} = \begin{cases} (1 - q_{L,t})\, \dfrac{(r_2 - r_1)}{1 + g_{L,t}} & \text{in the } \textbf{re-absorption} \text{ phase,} \\ \dfrac{g_2 - n}{1 + n} & \text{in the } \textbf{predation} \text{ phase,} \end{cases} \tag{14}$$

where $g_{L,t}$ is the rate at which total employment grows in the re-absorption phase ($L_t < N_t$). From equation (14) it follows that the same logistic process effectuated by differential growth as in equation (11) shapes employment shares in the re-absorption phase. In contrast, in the predation phase the problem of labour shortage offsets this mechanism and causes a different adaptation pattern. Economic movements now result from growth predation, a mechanism which results in an exponential pattern of structural change, where the rate of change is constant.[14]

One may infer from this finding that if bottlenecks and predatory interaction on input markets play a role, the logistic replacement process as a fundamental 'law' is in serious difficulties from a theoretical point of view. For example, in a world in which industries are interconnected, imbalances of supply and demand of complementary inputs may shift the probability in favour of exponential replacement patterns rather than logistic ones.

[13] The employment share relates to the output share by $q_{L,t}\bar{l}_t = q_t l_2$.

[14] Note that in terms of capital shares $K_{2,t}/K_t$ and $K_{1,t}/K_t$, the logistic law remains intact, although the adaptation speed is higher than in the re-absorption phase. But the point is that the change in capital shares no longer drives structural change.

3.2.3 The restoration phase

So far we treated the case in which the established firm is not rationed and the case in which it is rationed and showed how the re-absorption phase paves the way for the predation phase. This section now turns to the case in which not only firm 1 but also firm 2 is affected by the labour inflexibility assumption. Hence both **R1** and **R2** hold.

In section 2 it is argued that the innovative firm is able to avoid being rationed in the way the established firm is. This assumption resides in constraint (5), which enters firm 2's investment function (6b). Then, **R2** holds if firm 2's profit-determined level of investments is larger than its labour supply-determined full-utilization level. In the first period where **R2** holds, say T, firm 2's real investment therefore is given by

$$I_{2,T} = \frac{(1+n)\,N_T}{l_2} b_2 - K_{2,T} < r^e_{2,T} K_{2,T}.$$

This implies that firm 2 is 'investment rationed' in the sense that the evolution of labour supply de-motivates the realization of potential growth determined by the profit rate. Hence the innovating firm's profit-led growth regime ends during the passage from the predation phase to the restoration phase.

That the system necessarily passes over is due to the fact that the potential for firm 2 to grow at an above-normal rate by depriving firm 1 of workers eventually exhausts. That firm 2 is 'investment rationed' implies that its growth rate is

$$g_{2,T} = (1+n)\,\frac{\bar{l}_T}{q_T l_2} - 1, \qquad (15)$$

where $q_T < 1$. Because in period $T+1$ firm 2 owns exactly that amount of capital required for employing all workers, output of firm 1 in period $T+1$ is zero and $g_{1,T} = -1$. This implies that in period $T+1$ the innovation is fully absorbed into the system.

What completes adaptation is the fact that in the restoration phase the output price erodes: If **R2** holds, $g_{2,T} < r^e_{2,T}$, which means that the amount of goods supplied is greater than the amount which would maintain a stable nominal price. Given the assumption of perfect coordination by equation (7), a price p_T gets established which is smaller than the price which prevailed during the re-absorption and the predation phase. Because the price 'jumps' to a lower level, the real wage rate and the real costs of production increase. The distributional consequences of innovation now affect not only workers employed by the innovating firm through the wage premium but also workers still employed by the established firm.

As noted above, output of firm 1 in period $T+1$ is zero. It no longer contributes to production and its machines are ready to expire. If free disposal is assumed, the problem of getting rid of the collection of artefacts no longer needed will not have significant economic effects. Because firm 1 vanishes into thin air ($q_{T+1} = 1$), it follows from equation (15) that $g_{2,T+1} = n$. Also for this period **R2** holds which means that the price drops again; the price which gets established, say p_2 re-establishes a new equilibrium growth path, along which the profit rate equals n and the real wage rate is given by $(w_1 e)/p_2 = (1 - nb_2)/l_2$.

We may conclude the discussion of the restoration phase by pointing out that the common theme of this study, namely that adaptation forces may not remain constant but change conditions such that new forces set in and new phenomena arise, appears here in the form of non-steady price dynamics: The price is stable first, but fiercely reacts after the system passed some tipping point, which is reached due to the inner logic of change. Above all this hints at the uneven nature of economic change we ought to explain.

4 Summary

Our exploration of adaptive growth for the case of an inflexible supply of labour showed the following main results: (i) The process of adaptation and its effects depends crucially on whether surplus labour exists or not. Thus without taking into account broader economic conditions we can not expect to know how innovations will affect the system. And even if some tendency becomes apparent and persists for some time, it may prove a bad guide for the future because forces shaping economic movements may not remain the same. (ii) Different types of innovations lead to different adaptation paths and effects. Overall, adaptive growth is not steady and it is not necessarily the case that innovations boost aggregate growth. Some innovations lead to technological unemployment, but at the same time they provide the basis for a mechanism which eventually relieves instant effects.

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