DAVID HAAS

TECHNICAL CHANGE AND DIFFERENTIAL GROWTH.

Classical-Schumpeterian Models of Diffusion and Creative Destruction

Doctoral Thesis

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Em.o.Univ.-Prof. HEINZ-DIETER KURZ
Graz Schumpeter Centre
Department of Economics, University of Graz

Ao.Univ.-Prof. CHRISTIAN GEHRKE
Graz Schumpeter Centre
Department of Economics, University of Graz

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ABSTRACT

This thesis deals with the problem of technical change, its forms, causes and effects. It treats certain aspects of this large subject from a perspective that may be labelled as 'Classical-Schumpeterian'. The aim is to push the evolutionary theory of differential growth a bit further and to improve the understanding of the problem of technical change and related questions. The study is carried out by means of simple dynamic models which explore different variations and aspects of a common topic: the movements of the economy outside fully-adjusted positions driven by the generation and destruction of variety. This inquiry of what is called a 'traverse' builds on J. A. Schumpeter's analytic schema of the capitalist process and is concerned with the main forces of long-term transformation, in particular with the evolutionary mechanism of differential growth, with the question of diffusion and with its consequences. Chapter 2 discusses the process and effects of differential growth in terms of alternative methods of production in a Classical one-commodity model. It reveals why variety-induced economic change can be expected to be un-steady and shows how the motion of the system depends on the characteristics of the invading method. Chapter 3 exemplifies how broader economic conditions shape the process of technical change by clarifying the effect of a 'macro' full employment constraint on the evolutionary adjustment processes triggered by the arrival of a new method. Chapter 4 studies the case of a new capital good in a simple classical multi-good framework, where production is circular and goods enter into the production of other goods. It spots the role of production links for the mechanism of capital re-allocation and differential accumulation of old and new capital goods. Based on this it renders more precise some of Schumpeter's ideas of 'technological unemployment' and of 'forced saving', which are potential by-products of the capitalist process.

ZUSAMMENFASSUNG

Diese Dissertation behandelt die Formen, Ursachen und Auswirkungen technischen Fortschritts aus einer ‚klassisch-Schumpeterianischen' Perspektive und ergänzt bestehende evolutionsökonomische Ansätze, die Innovation und differenzielles Wachstum als wesentliche Triebkräfte technischen Fortschritts diskutieren. Die dafür entwickelten einfachen dynamischen Modelle orientieren sich am analytischen Gerüst kapitalistischer Dynamik von J. A. Schumpeter. Die drei Aufsätze untersuchen Teil-Aspekte evolutionären Wandels, die in der modell-theoretischen Literatur bisher relativ wenig Beachtung gefunden haben: Kapitel 2 diskutiert die Diffusion neuer Produktionsmethoden im Rahmen eines klassischen Ein-Gut-Modells und beleuchtet die Auswirkungen differenziellen Firmenwachstums auf die aggregierte Wachstumsrate, auf die Beschäftigungsentwicklung und die Einkommensverteilung entlang der Traverse. Am Beispiel zweier rivalisierender Produktionsmethoden wird gezeigt, wie Ausmaß und Art der Innovation im Prozess der kreativen Zerstörung unstetiges Wachstum verursachen. Kapitel 3 argumentiert, ebenfalls in einem Ein-Gut-Modell, dass der evolutionäre Anpassungsmechanismus des differentiellen Wachstums nicht unabhängig von wirtschaftlichen Rahmenbedingungen ist. Eine kausale Analyse zeigt, dass die Voll-Auslastung (Unterauslastung) eines primären nicht-produzierten Produktionsfaktors den zwei rivalisierende Methoden als Input benötigen, ein exponentielles (logistisches) Diffusionsprofil der relativ profitableren Methode bewirkt. Kapitel 4 behandelt die Einführung und Diffusion eines neuen produzierten Produktionsmittels in einer Mehr-Gut-Ökonomie, dessen Produktionssystem sich durch Verflechtungen und Zirkularität auszeichnet. Es erörtert die Umlenkung vorhandener Produktionsmittel und die differenzielle Akkumulation alter und neuer Kapitalgüter als mögliche Ursachen für ‚technologische Arbeitslosigkeit' und ‚erzwungenen Ersparnis' und präzisiert so einige von Schumpeter's Argumenten.

PUBLICATIONS

Some chapters of this thesis are reprints of papers already published:

- Chapter 2 is a reprint of the article "Diffusion Dynamics and Creative Destruction in a Simple Classical Model" published in the peer-reviewed journal *Metroeconomica*, Volume 66, Issue 4, November 2015 (DOI: 10.1111/meca.12085).
- Chapter 3 is a reprint of the article "The Evolutionary Traverse: A Causal Analysis", which has been accepted for publication by the peer-reviewed *Journal of Evolutionary Economics* in October 2016, forthcoming (DOI: 10.1007/s00191-016-0483-3).

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AUTOR'S DECLARATION

Unless otherwise indicated in the text or references, or acknowledged above, this thesis is entirely the product of my own scholarly work. Any inaccuracies of fact or faults in reasoning are my own and accordingly I take full responsibility. This thesis has not been submitted either in whole or part, for a degree at this or any other university or institution. This is to certify that the printed version is equivalent to the submitted electronic one.

Graz, November 2016

David Haas

CONTENTS

1 INTRODUCTION

This thesis deals with the problem of technical change, its forms, causes and effects. It treats certain aspects of this large subject from a perspective that may be labelled as 'Classical-Schumpeterian'.

The core of this thesis is a series of simple dynamic models. They cross-breed classical and evolutionary ideas and concepts and explore different variations and aspects of a common topic: the movements of the economy outside fully adjusted positions due to the generation and destruction of variety. This inquiry of what is called a *traverse*, or a transition process, is concerned with the main forces of long-term transformation, and in particular with the evolutionary mechanism of differential growth in terms of alternative techniques, with the question of diffusion and with its consequences.

The aim is to push the evolutionary theory of differential growth a bit further and to improve the understanding of the problem of technical change and related questions. To this end, this thesis considers and attempts to narrow certain gaps in the literature, namely by means of models which reside at the interface of classical, or Sraffian economics (Kurz and Salvadori 1995; Kurz 2008; 2016) and Schumpeterian, or evolutionary economics (Nelson and Winter 1982; Metcalfe 1998).

The thesis consists of an introduction and three self-contained papers. The introduction outlines the topic, objectives and the method. After that, the results and contribution of the three papers are briefly summarized. The three subsequent chapters contain the papers.

1.1 MOTIVATION AND OBJECTIVES

The problem of technical change has long been studied and is the central subject in the works of Joseph A. Schumpeter (1934, 1939, 2010 [1942]). He argued that different types of innovations are the engine of economic development since they change the economic system 'from within'.

Schumpeter conceived technical change as a process that involves three stages: invention, innovation and diffusion. Through an *invention* new technical knowledge and hence new production possibilities become available. Yet, in itself it has negligible effects on the economy. An *innovation* means the actual use of an invention in the economic sphere, for example in the form of a new product or a new method of production, by some 'new' firm. The successful introduction of the innovation itself has vanishingly small consequences for the system as a whole, but it creates the conditions for the economy to develop through a process of *diffusion*, or adaptation. The innovation thereby gains economic weight and might cause significant economic changes. In modern evolutionary terms, technical change is said to be caused by the generation and the destruction of 'effective variety'.

Schumpeter's analytical skeleton of technical change makes clear that there is no automatism that readily transforms new bits of knowledge, novel ideas and their first economic application into additional wealth. Rather, innovations will take effect only if they spread; and if they don't, they either disappear almost unnoticed or are perceived *ex post* as curiosities that didn't 'make' it. Diffusion hence plays a central role for economic development, especially because it is a time-consuming process and often involves considerable lags.

Schumpeter argued that economic development, or 'economic evolution', is neither harmonious nor steady. Rather, he envisaged it as a process that sweeps away the pre-existing economic situation and creates a new and different one: Due to the displacement of 'old' and inferior practices by 'new' and superior ones, certain existing economic resources are withdrawn from 'old' uses and put to 'new' uses; and, depending on the type of innovation, certain existing resources, once valuable, may become economically obsolete, while hitherto insignificant resources acquire paramount importance. Schumpeter famously argued that innovations fuel a "process of industrial mutation [...] that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism." (Schumpeter 2010 [1942], p. 73) This process manifests itself *inter alia* in the rise and fall of firms, of industries, of products and technological artefacts, of regions, of jobs and of human skills. It creates winners and losers and has the potential to re-distribute wealth within a society.

The transformation of the economic structure also affects the growth path of the economy. According to Schumpeter, innovations have the capacity to generate growth, typically in the form of long waves and cycles; and, they raise material wealth, actually for the broad majority of people. For example, Schumpeter considered technological unemployment to be a possible and likely consequence of diffusion, but argues on empirical grounds that "the capitalist process has always absorbed, *at increasing real wage rates*, not only the unemployment it generated but also the increasing population" (1951[1946], p. 200;

cited in Boianovsky and Trautwein 2010, p. 243; italics in the original). Hence, even if certain innovations may require very rapid, profound and demanding adjustments in order to not fall victim to creative destruction, they can be expected to eventually turn out to be beneficial 'overall', if their absorption increases the surplus of the economy.

Because economic evolution is not a simple growth process, where all activities of the system of production expand uniformly, but involves differential growth of 'old' and 'new' economic activities, its macroeconomic consequences are not obvious *a priori*. The problem is complicated by the fact that the effects of innovations do not show up immediately, such that whatever may be considered as the 'overall' or 'net' effect requires an assessment of the whole period of transformative growth, the duration of which however is uncertain ex ante; and because different types of innovations produce different results, which are furthermore not independent of broader economic conditions in which they are born, the question of innovations and of their wider repercussions cannot be settled once and for all.

Recently, the long-standing debate over technological unemployment has regained a lot of attention: Various studies substantiate the fear that the diffusion of new types of robots and other forms of computer-aided automation, integrated into large-scale cyber-physical systems, will make many categories of work obsolete and will considerably accelerate job destruction rates (see e.g. Frey and Osborne 2013, Brynjolfsson and McAfee 2014, Autor 2015, Mokyr et al. 2015). At the same time, the diffusion of such systems may spur growth and increase productivity at the macro level significantly, possibly in a way that reverses the stagnation tendencies that many advanced economies have shown in the last two decades.

Against this background, this thesis deals with certain aspects of the dynamics of technical and economic change. It aims at a more nuanced understanding of the problem of differential growth and related questions from a theoretical point of view. The focus is on creative destruction as the main force of long-term transformation and hence on the consequences of diffusion of new production techniques for the economy.

1.2 ANALYTIC SCHEMA AND METHOD

In *Theory of Economic Development* (1934), Schumpeter developed and used a simple analytic schema in order to elucidate what he considered to be the true nature of the capitalist process. Later, in *Business cycles* (1939), he used a refined version of it to frame and organise his empirical study. In this schema, the complex process of economic evolution is reduced to a simple, orderly sequence of well-defined phases:

OLD CIRCULAR FLOW Initially, the economy is said to be in a stationary state. It neither grows nor evolves but is exactly reproduced year after year by means of a set of established and uniform 'old' routines.

PHASE OF INNOVATION Entrepreneurs, or innovators, deviate from incumbent routines, start to employ existing means in a different way and thereby break the circular flow.[1]

PHASE OF DIFFUSION AND OF CREATIVE DESTRUCTION Agents of the old production system and agents of the new one engage in competition. If the innovation turns out to be economically superior, it is absorbed through different forms of adjustments.

NEW CIRCULAR FLOW After old routines are replaced, the capacity of the economy to evolve exhausts and the innovation itself becomes part of a new set of well-established routines. The renewed circular flow defines the conditions for the next innovation.

This analytic schema resorts to a certain notion of 'equilibrium'.[2] For the 'old' fully-adjusted economy, the innovation acts as a *centrifugal* force and creates variety, which is the pre-condition for a diffusion process; this process in turn acts as a *centripetal* force that brings the system towards a 'new' fully-adjusted state.

The view of technical change as a sequential, step-by-step process is quite narrow and simplistic, in particular because variety is continually created and continually destroyed and innovation and diffusion processes can be expected to mutually influence each other. However, this analytic schema makes a complex problem more tractable. It hence has some heuristic value for the understanding of what we may call an 'evolutionary traverse'; that is the path of an economy that evolves, i.e. one that changes its structure, because of an initial increase in variety and its gradual erosion. Therefore, this thesis adopts Schumpeter's analytic schema and expands on what may be called a 'process approach' by applying it to various cases.

1 In *Business Cycles*, Schumpeter (1939, p. 84) defines innovation as "the setting up of a new production function". Later he speaks of a 'creative response', which is defined as the special kind of behaviour of doing "something that is outside of the range of existing practice" (Schumpeter 1947, p. 150).

2 As Andersen (2009, p. 12) puts it, "Schumpeter is applying a very untraditional concept of equilibrium [...] The initial equilibrium has not come about by the deliberations of actors with perfect foresight and flexible behaviour. Instead, it is the outcome of a process of bankruptcy, job destruction, and stressful learning."

The study is carried out by means of simple dynamic models. Compared to verbal reasoning, a formal treatment has the advantage that it requires making all assumptions explicit. Thereby the logical structure of the argument becomes more transparent. And, it allows working in terms of typologies, examples and counterfactuals. This helps to qualify certain bold generalisations and to come up with a more precise picture of the problem under consideration. The main drawback of this approach is that it involves not only rather harmless forms of abstraction, through which unnecessary details, considered to have negligible effects, are set aside. Frequently, if not always, it also requires imposing dubious and 'unrealistic' assumptions for the sole purpose of making the problem under consideration (more) tractable. This holds particularly true for the type of dynamic models considered here, where this problem is amplified by the fact that one is confronted with a plethora of reasonable hypotheses about how different types of adjustments operate and interact. In order to alleviate the problem of 'overly specific' models at least to some extent and to extend their 'heuristic function', a *series of models* is provided: All three deal with the problem of differential growth and creative destruction, but in different settings and circumstances.

1.3 RESULTS AND CONTRIBUTION

The thesis consists of three self-contained papers. Their main results and contribution are:

PAPER 1 The first paper "Diffusion Dynamics and Creative Destruction in a Simple Classical Model" (Haas 2015) discusses the process and effects of differential growth in terms of alternative methods of production in a Classical one-commodity model (Kurz and Salvadori 1995, chap. 2) along the lines exemplified by Metcalfe and Steedman (2013) and by Rainer (2014).

In a first step, the relation between the prevailing variety of alternative methods, the structure of the system of production in terms of their output shares and the aggregate growth rate is established in order to identify the various channels through which the destruction of variety affects growth. This discussion prepares the ground for the examination of the features of an adapting economy, in which initially two alternative methods exist and where differential firm growth effectuates the diffusion of the relatively superior method. The path of growth and employment, the diffusion pattern and the effects on income distribution are discussed for different types of innovation.

Overall, the paper reveals why variety-induced economic change can be expected to be un-steady and how the motion of the system depends on the characteristics of the invading method. The main contribution consists in a rich typology of innovations, which takes into account two dimensions, namely the factor-saving bias and the extent of the bias. In particular the latter is important for the mechanism of differential firm growth, or 'competitive selection', since it determines the strength of the selection pressure on incumbent firms; this has repercussions on aggregate growth and the magnitude and rate of technical change. In the context of evolutionary selection models, this is a novel aspect.

The paper also shows that models associated with the modern classical theory and evolutionary population models can be fruitfully integrated since they share certain basic premises. From the perspective of the former approach, which is primarily concerned with the analysis of long-period positions, the paper indicates that the evolutionary adjustments through with variety is destroyed may play a vital role for the economy's overall tendency towards its long-period positon, which the economy can be expected to reach if innovations were not perpetual.

PAPER 2 The second paper, which is entitled "The Evolutionary Traverse: A Causal Analysis" (Haas 2016a), deals with the sequential generation and destruction of variety in terms of methods of production in a simple one-good model.

In contrast to the first paper, this model assumes that labour supply grows at an exogenously given rate and that there is full employment initially. This assumption implies the possibility of a shortage of the primary input, which is required by several rival methods of production. The main objective is to clarify the role of such a 'macro' constraint, or rather a population constraint, for the evolutionary adjustments triggered by the arrival and absorption of a new method of production.

This question is discussed by means of a sequential, causal analysis, where the adaptation path is compared to the pre-innovation steady state path along which there is no technical change but full employment. The main result is this: If surplus labour exists, differences in the ability to accumulate imply a logistic, S-shaped diffusion pattern in terms of the rival methods' output shares. This pattern is what evolutionary diffusion models typically produce. But, if there is a shortage of labour, competition for workers entails an exponential replacement pattern, hence a shorter transition period with a relatively higher average rate of technical change. This result is a novel aspect within the literature on evolutionary diffusion processes; it has some heuristic value because it clarifies the conditions which make diffusion curves logistic in such models.

The paper further shows that certain types of innovations cause temporary technological unemployment in the beginning of the path, if, as Schumpeter argued, the introduction of the innovation requires the withdrawal of the fully utilized produced inputs from incumbent firms. Yet, later on, when the new firm accumulates at an above-normal rate, the unemployed can eventually be employed again. This exemplifies that along such a traverse the net job creation rate may be negative first, but then may turn positive. Overall, like many other evolutionary models suggest, the rate of job creation and rate of destruction in general cannot be expected to be balanced all the time. Additionally, the appendix shows that the traverse towards a fully automated system causes profound difficulties, which go beyond the problem of temporary unemployment.

PAPER 3 The third paper "Diffusion of a new intermediate product in a simple 'classical-Schumpeterian' model" (Haas 2016b) deals with the problem of variety generation and destruction in a classical multi-good framework, where production is circular and goods enter into the production of other goods.

It addresses the role of produced means of production and of circularity for the innovation and the development process. This is a largely neglected problem in the theoretical literature on evolutionary change, which usually treats evolution within a single industry in isolation and tends to focus on final goods industries. Such studies typically cannot fully grasp creative destruction concerning alternative means of production (and methods using them) and are not well suited to spot the channels through which the establishment of some new activity somewhere in the economy can have significant repercussions by provoking adjustment in broad range of existing industry because of direct and indirect production links. For example, Rainer (2014) shows that because of production links, market share dynamics in term of alternative methods of production within single industries, i.e. 'competitive selection', is influenced by what is going on in other industries. Industries typically co-evolve, since evolution of one industry changes the economic circumstances under which competitive selection within other industries takes effect; hence diffusion processes in general cannot be treated in isolation. Rather, the direction and velocity of technical change at the level of industries are interdependent.

In order to understand a few contour lines of the problem of innovation and adaptation for an simple multi-good economy with produced means of production, the specific case of a new intermediate product, which is produced by means of the existing basic capital good and used to produce the existing consumption good, is studied. Although this type of innovation is what can be called a non-basic innovation, its construction and its diffusion is shown to affect all existing activities of the economy and overall performance.

This exercise in particular spots the role of production links for the mechanism of capital re-allocation and differential growth in terms of alternative systems of production using distinct production techniques with distinct surplus rates. Based on this, some of Schumpeter's ideas concerning 'technological unemployment' and 'forced saving' are rendered more precise and shown to be potential by-products of the capitalist process for the case at hand.

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2

DIFFUSION DYNAMICS AND CREATIVE DESTRUCTION IN A SIMPLE CLASSICAL MODEL

ABSTRACT The paper explores the impact of the diffusion of new methods of production on output and employment growth and income distribution within a Classical one-sector framework. Disequilibrium paths are studied analytically and in terms of simulations. Diffusion by differential growth affects aggregate dynamics through several channels. The analysis reveals the non-steady nature of economic change and shows that the adaptation pattern depends both on the innovation's factor-saving bias and on the extent of the bias, which determines the strength of the selection pressure on incumbent firms. The typology of different cases developed shows various aspects of Schumpeter's concept of creative destruction.[1]

2.1 INTRODUCTION

In this paper elements of the modern classical approach to economics and elements of evolutionary economics are combined to study the process of diffusion of a new and economically superior production method and its impact on output and employment growth and income distribution. This task is accomplished by adapting the Classical one-commodity model of Kurz and Salvadori (1995, chap. 2) for the case in which several production methods are operated at the same time.

The study is inspired by two papers which explore the interface between the two schools of thought: Kurz (2008), who investigates the impact of different types of innovations on relative prices and wages using the long-period method; and Metcalfe and Steedman (2013), who analyse the path connecting two long-period positions (hereinafter *LPP*). Although the two papers differ in method and scope, both base their considerations on Schumpeter's (1934) vision

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of the process of technical change as a stylised sequence of invention, innovation and diffusion; and they agree that it is the process of diffusion which determines the economic effect of new ways of doing things. Further, both stress that the consequences for the system depend on the type of innovation. However, the above two papers emphasize different mechanisms that drive the process of adaptation: For Kurz (2008) as for Schumpeter (1934) imitation is key to adaptation, whereas Metcalfe and Steedman (2013) view differential growth as the prime mechanism of diffusion. The latter mechanism is central to the evolutionary account of economic selection and creative destruction. It causes adaptation through the change of the relative importance of innovators and non-innovators within the population of firms and implies that investments are a necessary precondition for exploiting the economic potential of new methods of production (Silverberg and Verspagen, 2005).

The paper adds to the literature on how the economy adapts by differential firm growth. The focus is on the question of how the type of innovation affects aggregate output growth, employment growth and income distribution. It is argued that innovations differ along two dimensions: The first dimension is the innovation's factor-saving bias. The second dimension is the degree or extent of its bias, which is important because it determines the strength or intensity of the selection pressure on non-innovators. In the paper we call the first dimension the *innovation bias* and the second one the *innovation intensity*. Both the implications of the innovation intensity and the impact of innovations on income distribution have not received much attention in the literature.

Adaptation paths are explored analytically and in terms of simulations. The study of disequilibrium paths is relevant for two reasons: Firstly, understanding the dynamics outside equilibrium is crucial. Secondly, it adds to our understanding of how equilibria come about and it illuminates phenomena characterising the process of adaptation. The paper shows that (1) the diffusion process drives aggregate performance via a number of effects which differ in direction and magnitude; (2) both the pattern of disequilibrium paths and the long-term impact of the diffusion process depend on the bias and the intensity of the innovation; (3) the process of creative destruction depends on the characteristics of the innovation and under certain circumstances the destructive side of this process outweighs the creative one.

The paper proceeds in three steps. Section 2.2 presents the basic relations and concepts needed to deal with multiple methods of production within a classical one-sector framework and identifies the various channels through which diffusion affects aggregate growth. Based on this, a simple model of diffusion-driven growth is specified in section 2.3. Section 2.4 explores the dynamics of the model and develops a typology of different cases allowing one to identify various forms and dimensions of Schumpeter's concept of creative destruction. Section 2.5 concludes.

2.2 HOW VARIETY AFFECTS GROWTH

The classical one-sector growth model of Kurz and Salvadori (1995, chap. 2) is based on the following assumptions: In a one-commodity world, a homogeneous good is produced by means of homogeneous labour and the good itself. Production functions are of the Leontief-type and returns to scale are constant. Labour is available in abundance and wages are paid ex post. The good is taken as numéraire and the Law of One Price holds both with respect to the product and labour.

Variety is introduced into this framework by the assumption that in period t, I production methods contribute to total output. Method $i \in I$ uses a_i units of circulating capital and l_i units of labour per unit of output. Given the uniform real wage rate w_t, method i yields an 'individual' profit rate

$$r_{i,t} = \frac{1 - w_t l_i - a_i}{a_i}. \tag{2.1}$$

Each production method i is identified with a firm, which produces $x_{i,t}$ units of output by employing $\kappa_{i,t} = a_i x_{i,t}$ units of productive capacity and $L_{i,t} = l_i x_{i,t}$ units of labour. Aggregate output is then given by $x_t = \sum_i x_{i,t}$, aggregate productive capacity by $\kappa_t = \sum_i \kappa_{i,t}$ and aggregate employment by $L_t = \sum_i L_{i,t}$. The market share of firm i in period t is given by $q_{i,t} = x_{i,t}/x_t$. Given the structure of production reflected by market shares, the average amount of capital and the average amount of labour needed to produce one unit of output are computed as

$$\bar{a}_t = \frac{\kappa_t}{x_t} = \sum\nolimits_i q_{i,t} a_i \tag{2.2}$$

and

$$\bar{l}_t = \frac{L_t}{x_t} = \sum\nolimits_i q_{i,t} l_i. \tag{2.3}$$

The average production method $(\bar{a}_t, \bar{l}_t)$ reflects the average conditions of production at time t and thus is an abstract measure of the state of technical knowledge actually implemented. In addition, the *general rate of profit*

$$r_t = \frac{\sum_i r_{i,t}\kappa_{i,t}}{\sum_i \kappa_{i,t}} = \frac{1 - w_t\bar{l}_t - \bar{a}_t}{\bar{a}_t} \tag{2.4}$$

equals the profit rate of the average production method. Equation (2.4) further shows that the Classical inverse relationship holds between the general profit rate and the real wage rate for a *given* value of q.

Assume, that every firm ploughs back a fraction s of its profits into expansion of its own capacity such that firm i's growth rate is given by

$$g_{i,t} = \frac{x_{i,t+1} - x_{i,t}}{x_{i,t}} = sr_{i,t}. \tag{2.5}$$

The investment propensity s is assumed to be uniform across firms. The growth rate of aggregate output then equals the weighted average of firm growth rates, where the weights are the firm market shares:

$$g_t = \frac{x_{t+1} - x_t}{x_t} = s\sum_i q_{i,t}r_{i,t} = s\bar{r}_t. \tag{2.6}$$

If individual rates of profit and thus firm growth rates differ, the structure of production changes over time. A little calculation shows that the market share of firm i evolves according to

$$\frac{q_{i,t+1} - q_{i,t}}{q_{i,t}} = \frac{s\left(r_{i,t} - \bar{r}_t\right)}{1 + s\bar{r}_t}. \tag{2.7}$$

This implies that if the individual profit rate $r_{i,t}$ is larger (smaller) than $\bar{r}_t$, the market share of firm i increases (decreases). We refer to the gradual rise of some q_i over time as the diffusion of production method i by *differential growth*.

A further relation helps dealing with the problem at hand. It is given by the following link between the evolution of total productive capacity and the general rate of profit:

$$\begin{aligned} g_{\kappa,t} &= \frac{\kappa_{t+1} - \kappa_t}{\kappa_t} \\ &= s\sum_i \frac{\kappa_{i,t}}{\kappa_t} r_{i,t} = s\frac{1}{\bar{a}_t}\sum q_{i,t}\left(1 - w_t l_i - a_i\right) = sr_t. \end{aligned} \tag{2.8}$$

As one can see by comparing equations (2.6) and (2.8), output growth depends on market share weighted average profit rate, while capacity accumulation depends on the general rate of profit. According to equation (2.2), the two growth rates do not necessarily coincide but are related by

$$g_t = \frac{1 + g_{\kappa,t}}{1 + \alpha_t} - 1. \tag{2.9}$$

This reveals that – given perfectly flexible labour supply – output growth has two sources: capacity growth, indicated by $g_{\kappa,t}$, and capital biased technical change, indicated by rate $\alpha_t = (\bar{a}_{t+1} - \bar{a}_t)/\bar{a}_t$. As both result from the process of investment, the two sources cannot be separated. Instead, the quantitative aspect of capacity accumulation and the qualitative change of the production structure appear as intertwined.

The above framework allows to identify different channels through which a diffusion process affects aggregate growth dynamics. A direct and an indirect channel can be distinguished. Both channels emanate from the mechanism of differential growth indicated by equation (2.7). The direct effect of diffusion is its impact on the average capital input coefficient. As one can see from equation (2.9), the output growth rate and the growth rate of the average capital coefficient are inversely related. We refer to that as the *technology effect* of diffusion. It may either be positive, negative or zero.

The indirect channel emanates from the fact that the diffusion process changes the average production method. In general, $\bar{a}$ and $\bar{l}$ will change such that at least one of the distributive variables increases. Any change of the general profit rate in turn affects aggregate capacity accumulation and hence output. Whether and to what extent this *general accumulation effect* is expansionary depends on the dynamics of the real wage rate. If the real wage adjusts, two complications emerge: Firstly, if the real wage rate changes, all 'individual' profit rates change. If they change to different extents, the speed of structural change varies. Thus there is a feedback between the dynamics of the real wage rate and the process of diffusion. We call it the *wage feedback effect*. Secondly, if the real wage rate increases such that some of the 'individual' profit rates turn negative, some firms are forced to decline or even to exit. This *differential accumulation effect* provides a further indirect channel, which dampens capacity accumulation and hence output growth.

Because of the multiple effects and complications involved, the consequences of a change of the production structure for aggregate dynamics are not obvious a priori. As some effects might accelerate whereas others might decelerate growth, it is not even clear whether the diffusion process speeds up or slows down growth. Rather, the implications depend (1) on the bias and intensity of the innovation,

(2) on the behavioural responses of firms, and (3) on the dynamics of the real wage rate.

In order to shed some light on the relation between a change in the production structure and aggregate dynamics, the remaining parts of the paper presents and analyses a simple model of diffusion-driven growth in which we consider only two methods of production and only some of the above effects.[2] The focus is on the implications of the innovation bias and intensity for the dynamics of output, employment and income distribution. Both transitional effects and long-term impacts on output and employment levels are explored. A typology of cases for different kinds of innovations is developed and allows us to identify the various forms and dimensions of Schumpeter's concept of creative destruction involved in the restructuring process.

2.3 A SIMPLE MODEL OF DIFFUSION-DRIVEN GROWTH

For analytical convenience the following analysis concentrates on the stylized case of two rival methods of production; further, the problem of how the innovation emerges is set aside as both methods are assumed to be already in place.

Let method 1 denote the established one and method 2 the innovation. The two 'individual' profit rates are given by equation (2.1). The output share of method 2 is given by $q_t = x_{2,t}/x_t$ and the market share of the incumbent method 1 by $1 - q_t = x_{1,t}/x_t$. The two central assumptions the model is based on concern a simple wage setting rule (Subsection 2.3.1) and a refined version of the investment function (2.5), which includes the case of negative individual profit rates (Subsection 2.3.2).

2.3.1 *Wage dynamics*

As already mentioned, the Classical inverse relationship holds between the general profit rate and the real wage rate for a *given* value of q. But since the superior method 2 allows for a higher surplus of production, there is the question of how this additional surplus is distributed amongst capitalists and workers when q increases.[3]

---

2 Also the problems of credit creation and of the non-neutrality of money, which are central elements in Schumpeter's analysis of innovation and adaptation, are set aside in this paper; see Caiani et al. (2014) who trace the interdependencies between the 'real' process of structural change and financial dynamics within a 'monetary theory of production' framework.

3 In the literature on diffusion dynamics different wage setting rules can be found: In Nelson (1968) the uniform wage rate is pushed up by the increase of the profit share. Nelson and Winter (1982, chap. 10) impose a neoclassical upward-sloping labour

We impose a wage adjustment rule which determines the wage rate endogenously but keeps things as simple as possible. It is assumed that the real wage rate w adjusts to a change in q by taking the general profit rate as constant and exogenously given. As $r_t = r$, equation (2.4) turns into the wage setting rule

$$w_t = \frac{1-(1+r)\bar{a}_t}{\bar{l}_t}. \tag{2.10}$$

This wage setting rule has some 'Classical' flavour, since one of the two distributive parameters is assumed to be constant and exogenously given, whereas the other is determined by the conditions of production, which are changing in our case. It may be motivated by the empirical observation that the general profit rate is a trend-less magnitude. However, this assumption implies that the diffusion process does not influence aggregate growth via the *general accumulation effect*. Attention therefore focuses on the remaining channels which are put in sharp relief.

From the wage setting rule (2.10) it follows that the real wage rate is bound to rise during diffusion: In the LPP before the innovative method has entered the system ($q = 0$), the wage rate is determined by method of production 1 only, which is characterised by (a_1, l_1) and an 'individual' profit rate $r_1 = r$. If $q = 1$, production method 2 just obtains a profit rate $r_2 = r$ and the corresponding wage rate is determined by method of production 2 only. If q gradually rises from 0 to 1, $\bar{a}$ and $\bar{l}$ change such that the real wage rate increases via equation (2.10). This in turn reduces all 'individual' rates of profit via equation (2.1) but leaves unchanged the general rate of profit.

As the general rate of profit is constant, define the *rate of extra profits* of method i as $\rho_i = r_i - r$, where

$$\rho_i = \frac{1-wl_i-(1+r)\,a_i}{a_i}. \tag{2.11}$$

By comparing r_i and r, the relative superiority of some method of production is specified. Methods of production which yield positive (negative) extra profits have a cost advantage (disadvantage) compared to the average conditions of production and are economically superior (inferior).

supply curve. In Silverberg (1984) the real wage rate rises as the employment ratio increases. Englmann (1992) compares the implications of different wage adjustment rules for employment in a simulation study. The case of wage dispersion is explored by Nelson and Pack (1999) and Metcalfe and Steedman (2013), who assume that innovators pay a fixed wage premium. Apart from the latter, labour is assumed to be in flexible supply in this literature; the view that the availability of labour is not a binding constraint to accumulation is also a distinguishing feature of the classical approach to growth and distribution (Michl 2000).

An important implication of the proposed definitions of the general rate of profit and of the rate of extra profits, given by equations (2.4) and (2.11) respectively, is that in each period *total extra profits* sum up to zero:

$$(1-q_t)\rho_{1,t}a_1 + q_t\rho_{2,t}a_2 = 0. \tag{2.12}$$

This relation is central for the analysis of the dynamics of growth and income distribution (see Section 2.4).

2.3.2 *Investment behaviour*

We implement a simple form of retained earning dynamics based on the following assumptions: (1) Investment behaviour is uniform across firms.[4] (2) If firm i invests, it ploughs back part of its profits into building capacity i. Although firm investment does not adapt to differential profitability, over time the fraction of total investment which flows into capacity expansion of the innovative process increases due to differential growth. (3) Firms operate at *full capacity* throughout. As we only consider circulating capital, productive capacity of i is determined by last period's investments into i.

According to equation (2.11), the output of a firm using i at time t, $x_{i,t}$, is the sum of wage payments, capital investment to maintain the output-level and profits:

$$x_{i,t} = w_t l_i x_{i,t} + a_i x_{i,t} + (r + \rho_{i,t})a_i x_{i,t}.$$

To determine next period's output produced by method of production i, $x_{i,t+1}$, the following variation of the classical investment hypothesis formulated at the level of firms is adopted: Let $s \in (0, 1]$ be the propensity to invest in case of a positive rate of profit $r + \rho_{i,t} > 0$ and let $C_{i,t} \geqslant 0$ denote consumption out of profits; there are no savings out of wages. Three cases can be distinguished:

Case 1: $r + \rho_{i,t} > 0$. If the firm yields a positive rate of profit it has the potential to grow. After paying wages, the amount of investible resources $x_{i,t} - wl_i x_{i,t}$ splits up into replacement investment $a_i x_{i,t}$, net investment $s(r + \rho_{i,t})a_i x_{i,t}$ and capitalist consumption $(1-s)(r + \rho_{i,t})a_i x_{i,t}$. As net investment is positive, the firm accumulates and its output increases. Hence, $C_{i,t} > 0$ and $x_{i,t+1} > x_{i,t}$.

Case 2: $-1 < r + \rho_{i,t} \leqslant 0$. In this case net investment is negative because the amount of investible resources $x_{i,t} - wl_i x_{i,t}$ is smaller

4 See Metcalfe (2012) for an analysis of how diffusion proceeds if firms differ both in their profitability and in their investment behaviour.

than replacement investments $a_i x_{i,t}$. As capitalist consumption is non-negative, the firm devotes the whole amount of its investible resources $(1 + r + \rho_{i,t})a_i x_{i,t}$ to capacity construction. This implies that $C_{i,t} = 0$ and that $x_{i,t+1} \leqslant x_{i,t}$.

Case 3: $r + \rho_{i,t} \leqslant -1$. Since now $w l_i x_{i,t} \geqslant x_{i,t}$, the firm using production method i is just able to pay for the total wage bill or even fails to pay for it. As no resources remain with the firm, it is no longer able to continue its business but is forced to exit. In this case the firm pays its workers what it can and then leaves the market. Hence, $x_{i,t+1} = 0$.

Summing up, output growth of firm i is given by

$$g_{i,t} = \frac{x_{i,t+1} - x_{i,t}}{x_{i,t}} = \begin{cases} s\,(r + \rho_{i,t}) & \text{in Case 1: } r + \rho_{i,t} > 0 \\ r + \rho_{i,t} & \text{in Case 2: } -1 < r + \rho_{i,t} \leqslant 0 \\ -1 & \text{in Case 3: } r + \rho_{i,t} \leqslant -1. \end{cases} \tag{2.13}$$

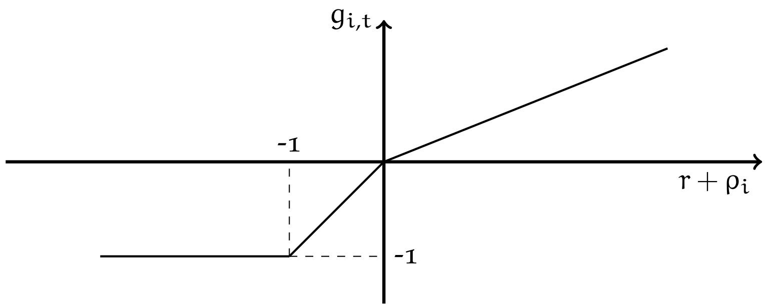

Figure 2.1: Kinked investment function for $s = 0.4$.

The investment function is illustrated in Figure 2.1. Comparing the three cases shows an asymmetry between a firm's growth and decline. This asymmetry reflects a basic difference between a firm that reaps profits and a firm that incurs losses. On the one hand, a positive rate of profit implies a potential to grow and allows the firm to *decide* on how much to expand its capacity. This decision is reflected by its propensity to invest. On the other hand, a negative rate of profit implies a loss and *enforces* a firm to reduce its capacity.

Moreover, a firm facing a loss is confronted with the question of whether to continue production or not. Instead of the conventional argument that the firm stops producing and shuts down as soon as the price falls below the average variable costs (i.e. when $r + \rho_{i,t} \leqslant 0$), we assume that firms stay in business as long as they can. This assumption relies on arguments put forth by Kahn (1989 [1929]), who argues that a firm facing a loss is likely to stay in business in order to preserve its operational capability and business connections which otherwise would be lost. Further, (psychological) restrictions may retard fundamental changes of firm policies in the short run. However, the ability to continue production at a loss ultimately exhausts. This is reflected in Cases 2 and 3 of the investment hypothesis: Firms decide to maintain production and continue business at a loss. Their output declines via a disinvestment process and they gradually run out of means of production. While a firm in the second case still is able to continue production at a smaller scale, the firm in the third case ceases to be able to maintain business.

$$
\begin{tikzcd}
 & \text{Quantities } (t) & \text{Technology } (t) & \text{Profits } (t) & \text{Quantities } (t+1) \\
\textbf{Micro} & x_{i,t} \arrow[d] & (a_i, l_i) \arrow[r] \arrow[d] & r + \rho_{i,t} \arrow[r, "(2.13)"'] & x_{i,t+1} \arrow[d] \\
\textbf{Macro} & q_t \arrow[r] & (\bar{a}_t, \bar{l}_t) \arrow[r, "(2.10)"'] & w_t \arrow[u, "(2.11)"'] & q_{t+1} \\
 & x_t = \sum_i x_{i,t} & & & x_{t+1} = \sum_i x_{i,t+1}
\end{tikzcd}
$$

Figure 2.2: Logic of the model.

Figure 3.2 illustrates the logic of the model. At the beginning of each period t, production starts. Given $x_{i,t}$, q_t is computed. Given the market share, the average conditions of production are computed. In the second step, the surplus is distributed and the real wage rate w_t is determined by equation (2.10). Given the technical coefficients a_i and l_i, individual profit rates $r + \rho_{i,t}$ are determined as residuals by equation (2.11). Given profit rates, investment is determined by equation (2.13) which is the basis for production in period $t + 1$.

2.4 FORMS AND DIMENSIONS OF CREATIVE DESTRUCTION

In this section, we adopt the model presented above in order to analyse how the diffusion process shapes aggregate dynamics. The effects involved in the restructuring process and its consequences are shown to depend on the type of innovation. Overall, the analysis reveals that the process of *creative destruction* (Schumpeter, 2010 [1942], chap. VII), the replacement of old methods of production by new ones, manifests itself in different forms and dimensions.

Subsection 2.4.1 present a typology of innovations along two dimensions, bias and intensity. The dynamics of aggregate growth are analysed in Subsection 2.4.2 and the pattern of diffusion in Subsection 2.4.3. In Subsections 2.4.4 and 2.4.5 the implications for employment and the wage share for different types of innovations is discussed.

2.4.1 *Bias and intensity of innovations*

In the following, we use the concept of the factor space in order to define and illustrate different types of innovations. Basically, any invading method 2 is characterized by its *innovation bias* reflecting its factor saving characteristics with respect to the incumbent method of production 1 and by the degree of its bias, which determines the intensity of the selection pressure on the incumbent firm. The innovation bias depends on the sign of the relative change of the capital and labour input coefficients

$$\Theta_a = \frac{a_2 - a_1}{a_1} \geqslant -1 \quad \text{and} \quad \Theta_l = \frac{l_2 - l_1}{l_1} \geqslant -1,$$

and the innovation intensity relates to the magnitude of these two measures.

The two measures Θ_a and Θ_l are the axes of the factor space, which is illustrated in Figure 2.3 for a given general rate of profit $r = 0.1$ and a given maximum rate of profit of method 1, $R_1 = (1 - a_1)/a_1 = 4$. The incumbent method of production is located at the origin. The line $\overline{BCD}$ is characterised by $\Theta_l = -1$ (i.e. by $l_2 = 0$) and the line $\overline{BAE}$ is characterised by $\Theta_a = -1$ (i.e. by $a_2 = 0$). The downward sloping *iso-profit rate line*

$$\overline{DE}: \quad \Theta_l = -\frac{1+r}{R_1 - r}\Theta_a$$

defines the set of all methods of production which have the same unit costs of production as the incumbent method at the ruling wage rate. Hence, methods of production lying within the triangle ΔDEB are potential innovations, since they permeate the system if introduced. Methods of production lying above $\overline{DE}$ are inferior compared to the incumbent method and do not succeed if introduced. They can be termed inventions that will not become innovations.[5] The set of potential innovations given by the triangle ΔDEB can be partitioned

5 Whether some method of production is a potential innovation or not depends on the prevailing economic conditions. For example, if the wage rate is lower, the *iso-profit rate line* is steeper with the origin $O = (0, 0)$ as pivot point. This implies that some formerly inferior (superior) methods turn into potential innovations (inventions). See Kurz (2008) for a discussion of invention and innovation in a two-sector setting.

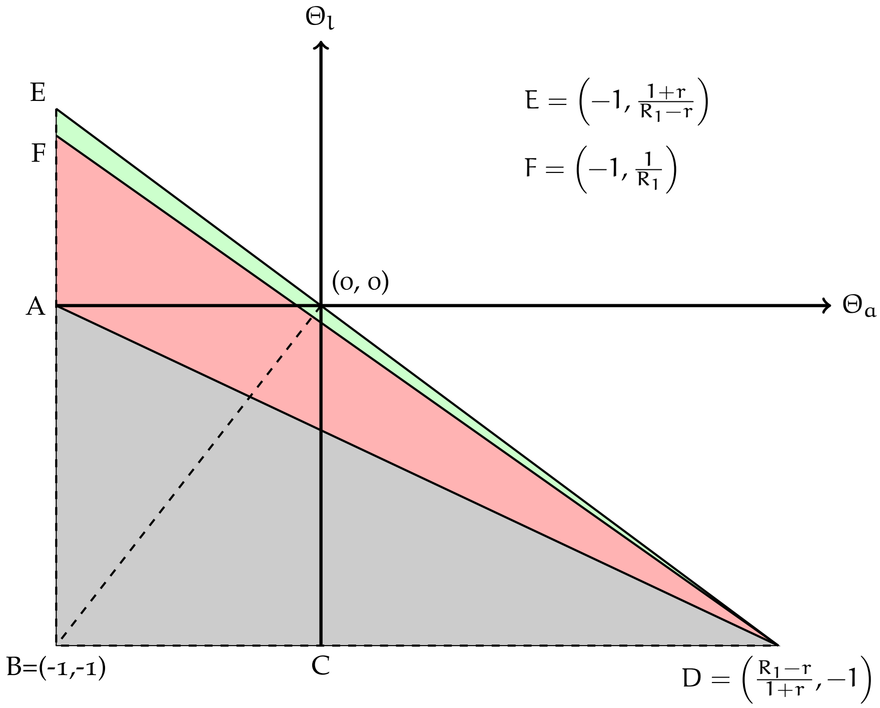

Figure 2.3: Factor Space for $r = 0.1$ and $R_1 = 2$.

according to the innovation bias. Table 2.1 provides a list with all possible types of innovation biases.

The magnitude of the two biases determines the innovation intensity. Three types thereof can be distinguished according to what happens to the 'individual' rate of profit of the incumbent method after the diffusion process is accomplished. The line

$$\overline{DF}: \quad \Theta_l = -\frac{r}{R_1} - \frac{1+r}{R_1}\Theta_a$$

defines the set of all innovations for which the incumbent method generates exactly zero total profits in the *new* LPP: $r + \rho_1|_{q=1} = 0$. And the line

$$\overline{AD}: \quad \Theta_l = -\frac{1+r}{1+R_1}(1+\Theta_a)$$

defines the set of all innovations for which the incumbent method is just able to pay the total wage bill in the *new* LPP: $r + \rho_1|_{q=1} = -1$. These two lines classify potential innovations into three types of innovation intensity differing with respect to intensity of selection pressure on the incumbent firm and its ability to survive. The ultimate fate of the incumbent firm is one central dimension of the process of *creative destruction* which takes one of three forms:

Innovation bias	technical coefficients	in Figure 2.3
capital saving and labour using	$\Theta_a < 0$, $\Theta_l > 0$	ΔOEA
labour saving and capital using	$\Theta_a > 0$, $\Theta_l < 0$	ΔOCD
pure capital saving	$\Theta_a < 0$, $\Theta_l = 0$	$\overline{OA}$
pure labour saving	$\Theta_a = 0$, $\Theta_l < 0$	$\overline{OC}$
combined factor saving	$\Theta_a < 0$, $\Theta_l < 0$	$\Delta OABC$
neutral	$\Theta_a = \Theta_l < 0$	$\overline{OB}$
dominantly capital saving	$\Theta_a < \Theta_l < 0$	ΔOAB
dominantly labour saving	$0 > \Theta_a > \Theta_l$	ΔOBC

Table 2.1: Different forms of innovation biases.

LOW SELECTION PRESSURE If the invading method lies within the triangle ΔDEF in Figure 2.3, the incumbent firm yields a positive rate of profit in the new LPP. It follows that it is neither forced to decline in absolute terms nor forced to exit. It rather co-exists with the innovative firm even in the long run.

MEDIUM SELECTION PRESSURE If the invading method lies within the triangle ΔDFA, the 'individual' rate of profit of the incumbent firm lies between -1 and 0 in the new LPP. It is still able to continue business but it asymptotically declines in absolute terms due to losses. Thus only the innovative firm survives as time approaches infinity.

HIGH SELECTION PRESSURE Any invading method lying within the triangle ΔDAB implies an 'individual' rate of profit smaller than -1 for the incumbent method in the new LPP. Thus the incumbent firm is forced to exit in finite time; firm exit is the strongest evidence of creative destruction in this setting.

Note that the above comparative analysis is independent of the proposed wage adjustment rule but solely relies on the assumption that the diffusion process has no lasting effect on the general rate of profit. Yet, the intensity of some innovation and thus the incumbent firm's ability to survive depends on the general rate of profit: A high general rate of profit tends to protect the incumbent firm against the more severe consequences of decline and exit as the wedge representing innovations of low intensity ΔDEF is bigger for a higher r. However, this wedge is very narrow for reasonable values of r. Thus the cases of medium and high selection pressures or intensity are decisive. In the following analysis we focus on the case of medium intensity and abstract from the latter cases; in this way we keep the number of firms constant.

2.4.2 *Aggregate growth*

In this section we explore how innovation bias and innovation intensity shape the aggregate output growth rate. Because of equations (2.13) and (2.6), the growth rate of aggregate output is given by

$$g_t = \begin{cases} s\,(r + \bar{\rho}_t) & \text{if } r + \rho_{1,t} > 0 \\ s\,(r + \bar{\rho}_t) + (1-s)(r + \rho_{1,t})(1 - q_t) & \text{if } -1 < r + \rho_{1,t} \leqslant 0 \\ s\,r & \text{if } r + \rho_{1,t} \leqslant -1, \end{cases} \tag{2.14}$$

where $\bar{\rho}_t = (1 - q_t)\,\rho_{1,t} + q_t \rho_{2,t}$ denotes the market share weighted average rate of extra profits, and the growth rate of aggregate productive capacity by

$$g_{K,t} = \begin{cases} s\,r & \text{if } r + \rho_{1,t} > 0 \\ (1 - q_t)\frac{a_1}{\bar{a}_t}(r + \rho_{1,t}) + q_t \frac{a_2}{\bar{a}_t} s(r + \rho_{2,t}) & \text{if } -1 < r + \rho_{1,t} \leqslant 0 \\ s\,r & \text{if } r + \rho_{1,t} \leqslant -1. \end{cases}$$

These two equations form the basis for the analysis of how the diffusion process affects output growth. Because of the proposed wage setting rule the general rate of profit r is constant and therefore the general accumulation effect does not affect aggregate growth. The two effects we focus on are the *technology effect* and the *differential accumulation effect*. They are analysed in the following.

TECHNOLOGY EFFECT Consider the extreme case $s = 1$, in which the kink in the investment function and thus the asymmetry between firm growth and decline vanishes. The aggregate growth rate is then given by $g_t = r + \bar{\rho}_t$. From equation (2.12) it follows that

$$\bar{\rho}_t = (1 - q_t)\rho_{1,t} + q_t \rho_{2,t} = -q_t \rho_{2,t} \Theta_a. \tag{2.15}$$

It furthermore holds that q_t and $\rho_{2,t}$ are strictly positive implying that the sign of $\bar{\rho}_t$ is the negative of the sign of Θ_a. Thus three cases can be distinguished:

1. $\bar{\rho}_t < 0$ in the case of labour saving and capital using innovations ($\Theta_a > 0$);
2. $\bar{\rho}_t = 0$ in the case of pure labour saving innovations ($\Theta_a = 0$);

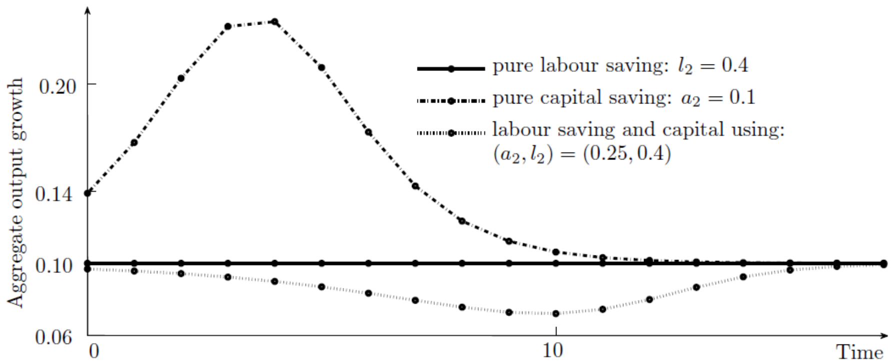

Figure 2.4: Technology effect for $(a_1, l_1) = (0.2, 0.5)$ and $r = 0.1$.

3. $\bar{\rho}_t > 0$ in the case of capital saving innovations ($\Theta_a < 0$).

Figure 2.4 illustrates the three possible patterns arising due to the technology effect. Whereas the diffusion of the pure capital saving method accelerates aggregate growth, labour saving and capital using technical change slows down economic growth. Only the diffusion of the pure labour saving method does not affect output growth via this channel.[6]

DIFFERENTIAL ACCUMULATION EFFECT Let us now turn to the implications of the asymmetry between firm growth and decline reflected by the kinked investment function (2.13). This effect depends on the innovation intensity and dampens aggregate growth via decelerating aggregate capacity accumulation. If the invading method lies within the area ΔDAF, the real wage rate lies above the maximum wage rate process 1 can pay without making losses, given by $\hat{w}_1 = (1 - a_1)/l_1$, for all $q_t \in (q_0, 1]$.[7] The respective threshold market share q_0 is determined by

$$q_0 = \frac{-r}{(1+r)\Theta_a + R_1\Theta_l}.$$

For $s < 1$ and $q_t \in (q_0, 1]$ the differential accumulation effect influences aggregate growth. This is illustrated in Figure 2.5 for different investment propensities s and for the case of a pure labour saving innovation, which shows no technology effect. The value of q_0 is negatively correlated with the propensity to invest and the differential accumulation effect is stronger for smaller values of s.

6 Note that the dynamics of adaptation heavily hinge on the assumption of surplus labour and full utilisation of capacity. The relation between innovation bias and the technology effect is different if labour is inflexibly supplied and full employment prevails (Metcalfe and Steedman, 2013).

7 We here only explore the consequences of firm decline but not the impact of firm exit, which occurs if the invading method lies within the area ΔDAB.

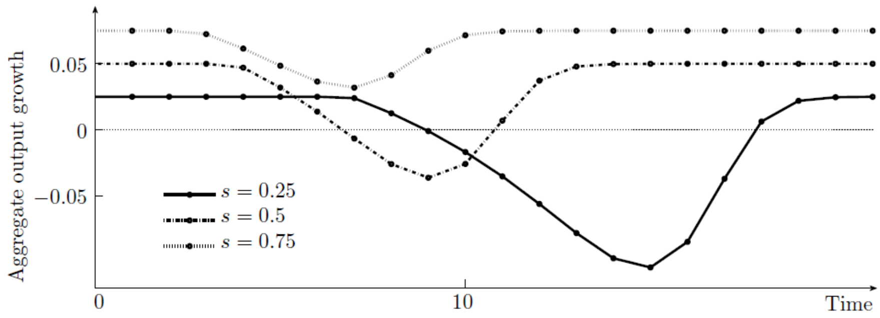

Figure 2.5: Differential accumulation effect for $(a_1, l_1) = (0.2, 0.5)$ and $(a_2, l_2) = (0.2, 0.4)$, with $r = 0.1$.

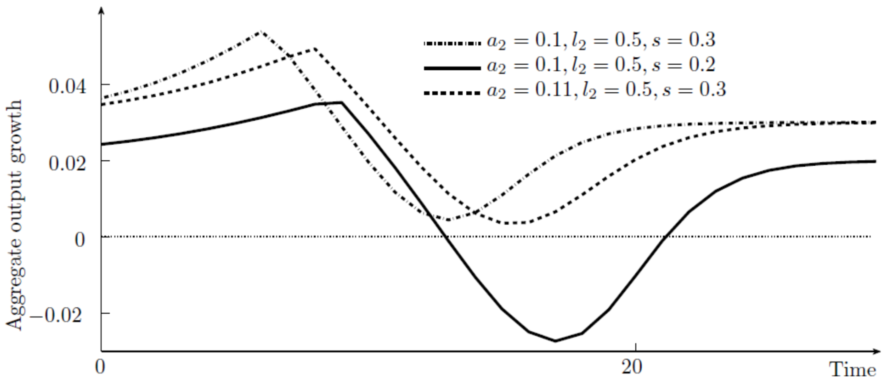

Figure 2.6: Interaction of the technology and the differential accumulation effect for $(a_1, l_1) = (0.2, 0.5)$ and $r = 0.1$.

INTERACTION OF EFFECTS The diffusion of a new method of production with $\Theta_a < 0$ small enough to turn the profit rate of the inferior method negative at some q_0 leads to a wave-like path of the aggregate growth rate for the following reasons: Initially all firms experience a positive rate of profit and the technology effect accelerates growth. Yet, as soon as the profit rate of firms using the old method turns negative, aggregate growth is dampened due to the differential accumulation effect. Figure 2.6 provides an illustration for different examples of pure capital saving innovations.

LONG-TERM IMPACT To assess the long-term impact of the diffusion process on growth, the non-steady growth path is compared with the steady-state output path defined by $q_t = 0$. In this latter *business-as-usual* (BAU) scenario the innovation is not introduced and output at time T is given by $\hat{x}_T = (1 + s\hat{r})^T x_0$ with $\hat{r} = r$ for some

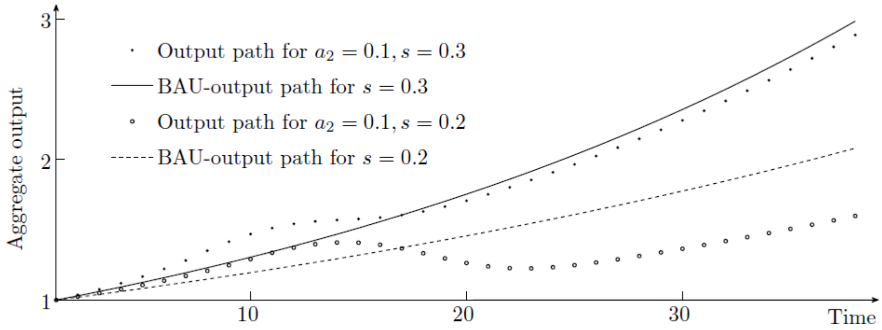

Figure 2.7: Long-term effect on the output level for $(a_1, l_1) = (0.2, 0.5)$ and $r = 0.1$.

initial output x_0 and propensity to save s. The two output levels at time $T > 0$ are related by

$$\Delta_s(T) = \frac{x_T}{\hat{x}_T} = \prod_{t=1}^{T} \frac{1+g_t}{1+sr}.$$

This product series provides an assessment of the overall long-term impact of diffusion-driven growth. For the first two examples of Figure 2.6 with $a_2 = 0.2$, one gets $\Delta_{0.3}(38) = 0.967$ and $\Delta_{0.2}(38) = 0.768$. Thus, for $s = 0.3$ ($s = 0.2$) the long-term output is 3.3% (23.2%) smaller than BAU output. How these two output paths compare with their respective BAU paths is illustrated in Figure 2.7.

The analysis and numerical examples show that although the diffusion process does not affect the LPP growth rate, short-term fluctuations have long-term implications on the output level. Moreover, the differential accumulation effect may outweigh the technology effect. If they are working in opposite direction, the economy may get on a path on which the output level is persistently below the BAU output.

Summing up, non-constant aggregate growth is a further aspect of creative destruction. The effects shaping the time profile of aggregate output depend on the bias and the intensity of the invading innovation. As the gradual replacement process involves both growth-enhancing and growth-depressing effects, the growth regime may flip during the process and the destructive impact may well predominate the creative one.

2.4.3 *Diffusion pattern*

Based on the above discussion, this section explores how the two dimensions characterising an innovation shape the pattern of diffusion. As the growth rate of the innovating firm is given by equation (2.13) and the evolution of total output is given by equation (2.14), the market share $q_t = x_{2,t}/x_t$ of the innovation evolves according to

$$\frac{q_{t+1}}{q_t} = \begin{cases} \frac{1+s(r+\rho_{2,t})}{1+s(r+\bar{\rho}_t)} & \text{if } r+\rho_{1,t} > 0 \\ \frac{1+s(r+\rho_{2,t})}{1+s(r+\bar{\rho}_t)+(1-s)(r+\rho_{1,t})(1-q_t)} & \text{if } -1 < r+\rho_{1,t} \leqslant 0 \\ 1 & \text{if } r+\rho_{1,t} \leqslant -1. \end{cases} \tag{2.16}$$

Generally, the mechanism of differential growth generates a sigmoid diffusion pattern and mimics the stylised fact of S-shaped curves of diffusion processes (Stoneman, 2002). But they to not resemble a simple logistic curve, because total output evolves at a non-constant rate (Metcalfe and Steedman, 2013).

Additional complications arise if the wage rate adapts endogenously: The rise of the real wage rate reduces the (extra) profit rates to different extents if the two methods of production differ with respect to their capital intensity l_i/a_i. To see this, equation (2.16) for Case 1 can be rewritten as follows:

$$\frac{q_{t+1}-q_t}{q_t} = \frac{1+s\,(1-q_t)\,\Delta\rho_t}{1+s(r+\bar{\rho}_t)},$$

where $\Delta\rho_t = \rho_{2,t} - \rho_{1,t} > 0$ denotes the profit rate differential, given by

$$\Delta\rho_t = \left(\frac{1}{a_2} - \frac{1}{a_1}\right) - w_t\left(\frac{l_2}{a_2} - \frac{l_1}{a_1}\right).$$

It follows that if the innovation is capital saving and labour using, the increase of the wage rate decelerates the diffusion speed. But if the innovation is capital using and labour saving, the increase of the wage rate accelerates the diffusion speed. Only in the case of a neutral innovation, this *wage feedback effect* does not alter the speed of adaptation. Note that although the speed of diffusion might be affected, the direction at which market shares change does not vary in the case of two methods of production. In addition, also the intensity of the innovation bias determines the magnitude of the profit rate differential $\Delta\rho_t$ and thus the speed of diffusion.

The speed of the diffusion process and its overall pattern provides a further element involved in the process of creative destruction, which depends on the bias and intensity of the innovation and takes different forms: (1) an asymptotic diffusion path due to absolute growth but *relative decline* of incumbent firms in the case of a low innovation intensity; (2) an asymptotic diffusion path accelerated by the *absolute decline* of incumbent firms in the case of medium innovation intensity.

This can be seen by looking at the negative term $(1-s)(r+\rho_{1,t})(1-q_t)$ in the denominator of Case 2 which indicates the impact of the incumbent firm's absolute decline; (3) in the case of high intensity the diffusion process is accomplished in finite time by the extinction of the incumbent method of production.

2.4.4 *Employment growth*

This section explores how the innovation bias and its intensity affect the evolution of total employment $L = L_1 + L_2$. Given equations (2.2) and (2.3), aggregate employment evolves according to

$$g_{L,t} = \frac{L_{t+1} - L_t}{L_t} = (1 + g_{\kappa,t}) \frac{(1+\lambda_t)}{(1+\alpha_t)} - 1, \tag{2.17}$$

where $\lambda_t = \left(\bar{l}_{t+1} - \bar{l}_t\right)/\bar{l}_t$ is the rate at which the average labour coefficient changes. From equation (2.17) it follows that employment growth is influenced by the innovation intensity via the differential accumulation effect and the innovation bias.

Restricting our attention to the latter, let

$$\Gamma_t = \frac{(1+\lambda_t)}{(1+\alpha_t)} = \frac{1+q_t\Theta_a}{1+q_{t+1}\Theta_a} \frac{1+q_{t+1}\Theta_l}{1+q_t\Theta_l}.$$

As $q_{t+1} > q_t$ and $\Theta_a, \Theta_l \geqslant -1$, three cases can be distinguished:

1. $0 < \Gamma_t < 1$ in cases for which $\Theta_a > \Theta_l$, e.g. in the case of a dominantly labour saving innovation.
2. $\Gamma_t = 1$ in the case of a neutral innovation ($\Theta_a = \Theta_l$).
3. $\Gamma_t > 1$ in the case for which $\Theta_a < \Theta_l$, e.g. in the case of a dominantly capital saving innovation.

This list indicates job creation and destruction as another aspect of the process of creative destruction. For example, the diffusion of a pure labour saving innovation of low intensity decelerates the job creation rate such that the resulting employment path lies below its BAU employment path. If a dominantly labour saving innovation of medium intensity diffuses, the incumbent firm's absolute decline results in the destruction of jobs, which outweighs the creation of new jobs due to the differential accumulation effect. Again, as some new jobs are created and some old jobs are destroyed at the same time, the overall long-term impact of the diffusion process on the employment level may be negative.

2.4.5 *Income distribution*

In this section we explore the change of the income shares due to the diffusion of a process innovation. The wage share ω_t is defined as $\omega_t = W_t/(W_t + P_t)$ with W_t denoting total wage payments and P_t total profits at time t. It evolves according to

$$\omega_t = \frac{w_t \bar{l}_t x_t}{w_t \bar{l}_t x_t + r\bar{a}_t x_t} = 1 - \frac{r}{R_t}, \tag{2.18}$$

where $R_t = (1 - \bar{a}_t)/\bar{a}_t$ denotes the maximum rate of profits of the average production method.

Equation (2.18) reveals two basic channels through which the diffusion process affects the wage share: To begin with, there is an inverse relationship between the wage share and the general rate of profit, given R_t. This is due to the fact that the *sum* of total extra profits is zero throughout (see equation 2.12); even if the average *rate* of extra profits is non-zero, differential 'individual' extra profits imply a re-distribution of income within the group of capitalists without affecting income shares. The direction of change of the wage share therefore is closely related to the dynamics of the real wage rate.

In the case assumed here, the general rate of profit r is constant. The diffusion process therefore affects the direction of change of the wage share only via its impact on the maximum rate of profits of the average production method. This measure in turn depends on the innovation bias.

To see how it affects the wage share, let $R_i = (1 - a_i)/a_i$ denote the maximum rate of profits of production method i. The wage share in the LPP with method of production (a_i, l_i) being used then is given by

$$\omega_i = 1 - \frac{r}{R_i}.$$

A comparison of the wage share before the innovative process enters the system (ω_1) with the wage share which prevails after the diffusion is accomplished (ω_2) shows the following:

1. If the innovation is capital using ($\Theta_a > 0$), $R_2 < R_1$ and the wage share falls: $\omega_2 < \omega_1$.

2. If the innovation is pure labour saving ($\Theta_a = 0$), $R_2 = R_1$ and the wage share does not change: $\omega_2 = \omega_1$.

3. If the innovation is capital saving ($\Theta_a < 0$), $R_2 > R_1$ and the wage share increases: $\omega_2 > \omega_1$.

Because the difference between the two maximum rates of profit is given by $R_2 - R_1 = -\Theta_a/a_2$, there is a symmetry between the technology effect on growth and the change in the wage share: Pure labour saving technical change neither affects aggregate growth nor does it affect the income shares, whereas capital using technical change dampens aggregate growth and reduces the wage share. All other forms of technical change increase both aggregate growth and the wage share. But, while the technology effect is related to the average rate of extra profits, the effect on income distribution arises from the change of the maximum rate of profit.

2.5 CONCLUSIONS

The paper has discussed the consequences of a changing structure of production for firms and for the economy as a whole. The analysis uses a simple one-commodity framework in which two methods of productions initially co-exist. Adjustment of the structure of production is brought about by differential growth of firms. This mechanism implies that economically superior methods of production gradually supersede inferior ones.

Our study shows that economic development proceeds in a non-constant way and involves a number of effects that differ in direction and magnitude. It is demonstrated that the diffusion of new methods of production need not always result in higher output and employment growth. Rather, the overall impact on economic performance depends on the relative strength of counteracting tendencies, which can be traced back to the type of innovation. Both the innovation bias and intensity are major determinants of the process that unfolds after an innovation has upset the system. The typology of different cases developed reveals that the process of creative destruction involves different forms and dimensions. These findings suggest that a steady-state analysis is not sufficient to fully grasp the mechanisms and consequences involved in the process of technical change.

There are two issues that deserve further attention: Firstly, firms are assumed not to respond to profit differentials: neither do they try to imitate nor to adjust their investment flows. How the above results change if firm behaviour is assumed to be less inertial is a topic for further investigation. Secondly, by assuming a given and constant general rate of profit one effect on aggregate dynamics of the diffusion process is excluded from the analysis. An exploration of the general accumulation effect is linked to the question of how labour market conditions interact with the process of diffusion. For a study along this line the wage adjustment mechanism proposed may serve as a benchmark.

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3

THE EVOLUTIONARY TRAVERSE: A CAUSAL ANALYSIS

ABSTRACT This paper explores the process of adaptation to new methods in a simple model where the growth rate of labour supply is exogenously given and constant. It shows that competition for a primary input in short supply changes the mechanism of adaptation and its consequences: If surplus labour exists, differential capacity accumulation effectuates adaptation and leads to a logistic replacement pattern; but if labour is in short supply, 'growth predation' undermines the former mechanism and leads to an exponential replacement pattern. The consequences of the quantitative adjustment mechanisms for aggregate growth are discussed by means of a 'causal analysis', which focuses on the properties of the traverse between two full-employment steady states. The analysis reveals that different types of new methods lead to different adaptation paths and results. Overall, adaptation entails unsteady growth and it is not always the case that the diffusion of a new method boosts aggregate growth.[1]

3.1 INTRODUCTION

We study the evolutionary traverse in a one-commodity model where labour is supplied inelastically. The aim of this exercise is to clarify the consequences of a resource constraint for the evolutionary adjustments triggered by the arrival of new methods of production.

In the evolutionary approach to technical change adaptation is recognized as a selection process, where differences in the efficiency of used methods, certain routines of firms and the economic as well as the institutional environment determine the rise of superior methods and the decline of inferior ones. This 'restructuring' is seen as a vital source of growth and technical change and typically exhibits a logistic pattern (Metcalfe 1998, 2008).

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In simple variation-cum-selection models which prefer a macroeconomic interpretation, such as Nelson and Winter (1982, chap. 10) and Silverberg (1984), labour supply conditions play an important role for the selection process and its effects. For example, Englmann (1992) shows that the response of the real wage rate to selection dynamics shapes the overall employment effect of the diffusion of a new method.

Although different wage adjustment mechanisms are explored, the common assumption made in simple variation-cum-selection models is that there always is enough labour to fully employ the capital stock. In this context, Metcalfe and Steedman (2013) argue that this implicit assumption of surplus labour is not as innocuous as it may seem. They draw attention to the fact that the nature of adaptation depends on whether surplus labour exists or not: If the supply of labour is unlimited, adaptation is driven by the differential abilities to invest by means of retained profits. But if the supply of labour is fixed and in short supply, a different mechanism called 'growth predation' here effectuates adaptation. It relies on the idea that firms using the superior method can attract workers employed elsewhere through offering wages that are higher than what firms employing inferior methods can pay. Through this the superior method displaces the inferior one not only in relative but also in absolute terms through depriving the inferior one of the basis of its very existence. A further important difference between the two cases is that in the surplus labour case the amount and distribution of capital limits total output, whereas in the labour shortage case the amount and distribution of labour limits total output. This has important implications for the growth effect of competitive selection, which depends both on the bias of the innovation and the state of labour supply; see Haas (2015) for a typology of new methods and their growth effect for the case of surplus labour.

The paper develops the idea of 'growth predation' in a simple model in order to put into sharp relief the effects of a resource constraint that potentially limits output at the population level. A causal analysis helps to shed light on the crucial forces and features of what may be called an 'evolutionary traverse', i.e. the path from one full-employment steady state to another when the original steady state is disturbed by an innovation. With minor differences, this approach resembles Schumpeter's (1934) analytical scheme for understanding economic development based on the concept of what he called the circular flow (Kurz 2008).

In line with Metcalfe and Steedman (2013), adaptation is brought about by output share dynamics only; the problem of imitation is not discussed. In contrast to Metcalfe and Steedman (2013), we assume that capital is not circulating but perennial and non-malleable. This means that capital does not depreciate and cannot be transformed to serve other purposes. Thus in the case of a labour shortage some firms have to accept that part of their equipment lies idle. Note that under-utilisation of capital results from a lack of complementary means to employ it and not from a lack of effective demand; the latter problem is neglected in this paper.

The main findings include: (i) The implementation of certain types of new methods causes unemployment which is relieved through the above-normal growth potential of 'new' firms; (ii) as long as unemployment prevails, adaptation through differential accumulation features a logistic replacement pattern, a typical feature of evolutionary models, whereas adaptation through 'growth predation' leads to an exponential replacement pattern; (iii) the aggregate growth rate depends both on the question of whether there is full employment or not and the bias of the innovation. Growth is unsteady and the diffusion of an innovation is not always expansionary.

The paper is organized as follows: Section 3.2 presents a simple growth model with two rival firms. In section 3.3 the relation between adaptation and growth for different types of innovations is explored by means of a causal analysis. Section 3.4 concludes. The Appendix shows that the traverse towards a fully automated system differs fundamentally from other cases.

3.2 A SIMPLE EVOLUTIONARY GROWTH MODEL

This section presents a simple 'macro' selection model, where labour supply grows at an exogenous rate and firms use distinct technologies. For analytical convenience we deal with the simplest case of two rival groups of firms, namely users of the 'old' technology and users of the 'new' technology. For a greater ease of reading, we will call the former group 'old firm' (indexed by 1) and the latter one 'new firm' (indexed by 2).

As we are concerned with basic relationships in evolutionary selection models and how certain assumptions drive results, we work with a set of premises that is typical for such models. In particular, it is assumed that variety in terms of methods is not renewed through innovation and that there is no imitation.[2] Rather, economic change

2 The first evolutionary diffusion model dates back to Nelson (1968). Further important contributions include Nelson and Winter (1982, chap. 10), Soete and Turner (1984), Silverberg (1984), Englmann (1992), Metcalfe (1997; 1998), Nelson and Pack (1999), Metcalfe and Steedman (2013); see also Haas (2015). See Metcalfe (1998) for a concise elaboration of the economic theory of selection. For an overview of the

at the macro level results exclusively from changes in the economic weight of rival technologies. Through this process of competitive selection the economy as a whole is able to adapt even though there are strong inertial forces at the micro level.[3]

3.2.1 *Production*

We assume a closed economy in which firms produce a single good which serves both as an investment and as a consumption good. Output of firm $i \in \{1, 2\}$ is determined by the fixed-coefficients method of production

$$x_{i,t} = \min\left\{\frac{L_{i,t}}{l_i}; \frac{K_{i,t}}{b_i}\right\}, \tag{3.1}$$

where $x_{i,t}$, $K_{i,t}$ and $L_{i,t}$ are the output, the stock of perennial capital ('machines') and employment of firm i in period t. Because the two rivals use distinct technologies, labour coefficient l_i and *full-utilisation* capital coefficient b_i are firm-specific parameters.

Before production starts, firms hire workers. To avoid the problems of heterogeneous labour and of skill formation, workers are treated as homogeneous in skills and efficiencies and both methods are assumed to require the same type of labour. This is crucial here, because the two rivals compete for the same primary input which is not in unlimited supply. Rather, labour supply N grows at a given and constant rate $n > 0$ such that[4]

$$N_t = (1 + n)\, N_{t-1}. \tag{3.2}$$

Assume that firm i wants to produce full capacity output, which means that its labour demand, or desired employment, is given by

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

Because the quantity of labour available is limited and inelastic, *total actual* employment, which we denote by $L_t = \sum_i L_{i,t}$, in any case must satisfy the inequality condition

$$L_t \leqslant N_t.$$

evolutionary perspective on growth and technical change see Santangelo (2003) and Silverberg and Verspagen (2005).

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

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.

Clearly, if the firm population demands more labour than is available, i.e if $\sum_i L^d_{i,t} > N_t$, this condition binds in such a way that at least one firm is rationed on the labour market and hence must produce below full capacity.

How could this be resolved? We follow Metcalfe and Steedman (2013) who argue that an input shortage, faced by the firm population as a whole, may influence different firms differently. The argument is this: Firms which use distinct technologies in general yield different rates of profit; and because of this they differ in their ability to attract workers by offering a wage that is higher than what rivals can pay.

Assume that the 'new' firm 2 pays a slightly higher wage rate than firm 1 and as a result is able to satisfy its labour demand. The extent of this wage differential 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).[5] For simplicity both nominal wage rates, w_1 and w_2, are rigid and hence stay constant. Because $w_2 > w_1$, there is an asymmetry in the determinants of firm employment levels given by

$$L_{1,t} = \min\left\{L^d_{1,t}; N_t - L_{2,t}\right\}, \tag{3.3a}$$

$$L_{2,t} = \min\left\{L^d_{2,t}; N_t\right\}. \tag{3.3b}$$

Equation (3.3b) states that new firm 2 is rationed only if its *own* labour demand exceeds total supply. For the old firm 1 matters are more complex. It is rationed if *total* labour demand exceeds total supply. If this is the case, its employment depends on the accumulated stock of machines of the new firm. This interaction that results from competition for a limited quantity of labour is the basis for the mechanism of 'growth predation' (see sect. 3.3) that effectuates diffusion.

Because we focus on this mechanism, we exclude the possibility that firm 2 is rationed on the labour market by an additional assumption on firm investment behaviour, to which we turn now.

3.2.2 *Investment*

After production has taken place, firms pay their workers and decide on investment. In order to simplify the analysis, we assume the extreme von-Neumann-hypothesis: Workers consume their entire in-

5 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.

come and capitalists do not consume.[6] Further, firms only invest in their own business, an assumption that Silverberg (1984) terms 'auto-catalytic self-reproduction'.[7]

For the investment process of firm i, its 'individual' expected rate of profit plays a decisive role, which depends (i) on the goods price it expects and the nominal wage rate it pays; (ii) on its technology; and (iii) on its capital utilisation rate:

$$r^e_{i,t} = \frac{1 - \frac{w_i}{p^e_{i,t}} l_i}{b_i} u_{i,t}, \tag{3.4}$$

where $u_{i,t} \leqslant 1$ is firm i's current capital utilisation rate, which is the ratio of actual output $x_{i,t}$ to potential output $K_{i,t}/b_i$. Further, $p^e_{i,t}$ is the price firm i expected. Assuming that all firms have *static expectations*, it follows that $p^e_{i,t} = p_{t-1}$, where p_{t-1} is the last period's uniform price.

Clearly, a firm which is rationed on the labour market exhibits a rate of capital utilisation that is smaller than unity, or, stated differently an *actual* capital coefficient that is larger than it could be on purely cost-minimizing grounds. As a consequence, its 'individual' rate of profit is lower compared to the case in which it is not rationed. This detrimental effect of 'new' technology on 'old' capacity may be taken as a reflection of the process of creative destruction (Schumpeter 1934; 2010 [1942]); this is ultimately enforced by a lack of complementary inputs in the presence of a more profitable opportunity to employ them.

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

$$K_{i,t+1} \leqslant \frac{(1+n)\, N_t}{l_i} b_i, \tag{3.5}$$

where the right-hand side of the weak equation (3.5) gives the amount of capital needed to fully employ *all* workers available in period $t+1$ using method i. For our case of just two rivals, this condition means a constraint on investment for the new firm 2 and implies that it is never constrained on the labour market in the way firm 1 is. For the old firm 1, constraint (3.5) is never binding because of equation (3.3a).

6 The classical saving hypothesis according to which workers do not save and investments depend on capital incomes is a typical assumption made in evolutionary growth models; see e.g. those cited in footnote 2 and Dosi et al. (2010).

7 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

$$I_{1,t} = r^e_{1,t} K_{1,t}, \tag{3.6a}$$

$$I_{2,t} = \min\left\{ r^e_{2,t} K_{2,t};\, \frac{(1+n)\, N_t}{l_2} b_2 - K_{2,t} \right\}, \tag{3.6b}$$

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 (3.6) this difference translates into differential capacity accumulation of the two rivals. This is the basis for the well-known mechanism of differential growth (see sect. 3.3).

The investment functions show that a lack of complementary inputs slackens capital accumulation in two different ways: If old firm 1 is rationed on the labour market, its lower rate of capital utilisation depresses its individual profit rate; this 'de-valuation' of its capacity results in decelerated accumulation. New firm 2 would face this problem only after it has become 'too big' and if it grows too rapidly. Because firms are treated as knowing the growth rate of labour supply but not the accumulation plans of rivals, the new firm avoids being rationed by adjusting its investments according to condition (3.5).

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

3.2.3 *Goods market*

In the goods market firms sell the part of their production which they do not use to grow capacity. 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.

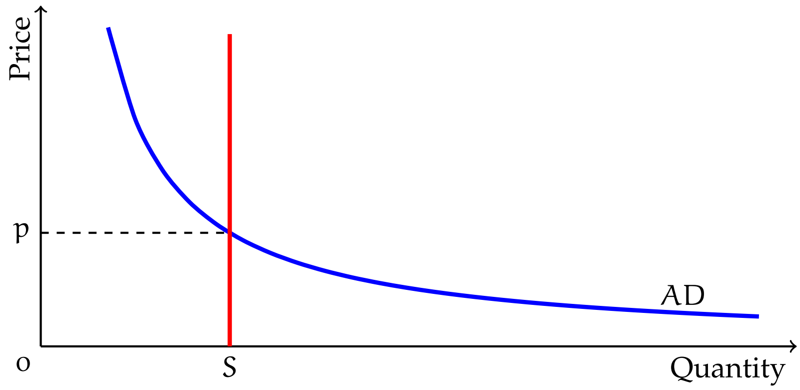

Figure 3.1: Aggregate real demand curve AD, aggregate real supply S and the market clearing price p.

For the goods market to clear, the price p_t adjusts such that real supply S_t and real demand D_t/p_t coincide:

$$p_t = \frac{D_t}{S_t} = \frac{w_1 L_{1,t} + w_2 L_{2,t}}{x_{1,t} + x_{2,t} - I_{1,t} - I_{2,t}}. \tag{3.7}$$

Figure 3.1 illustrates this: As the amount of goods supplied is fixed, the supply curve (the line S) is a vertical line. 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. 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. Note that because the *Law of One Price* holds on the goods market but not on the labour market, employees of firm 2 receive a slightly higher real wage than employees of firm 1 such that there is inequality within the group of otherwise homogeneous workers.

One implication of this pricing rule greatly simplifies our analysis of the evolutionary traverse (see sect. 3.3): As long as both firms' investments are purely profit-led, the price does not change. This can easily be verified by applying equation (3.4) together with $I_{i,t} = r^e_{i,t} K_{i,t}$ for $i \in \{1, 2\}$ to the pricing rule (3.7). As long as the price does not change, the growth rate of the new firm is constant and the rate at which the old 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 (3.5) sooner or later

8 This feature of the model mimics the hypothesis of Metcalfe and Steedman (2013) who treat the real wage rate, except for a small wage premium, as constant during the adjustment process on the basis of the principle of the marginal firm.

gets binding and the resulting price movements play a decisive role in restoring equilibrium. The fact that the price does not gradually adapt reflects one central theme of this study, namely that the forces which 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 way for new forces. And if they gain momentum and prevail, the behaviour of the system may change and new phenomena may arise. Thus something can be learned from the study of the sequence of mechanisms and their interplay.

3.2.4 *Summary*

Before we deal with this question, let us summarise the model in order not to lose sight of its data, variables and (behavioural) relations. Figure 3.2 illustrates the basic structure of the model. The givens consist of the set of firm-specific data $\{l_i, b_i, w_i\}$ where $i \in \{1, 2\}$ and the rate at which the labour supply grows, n. The endogenous variables 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.

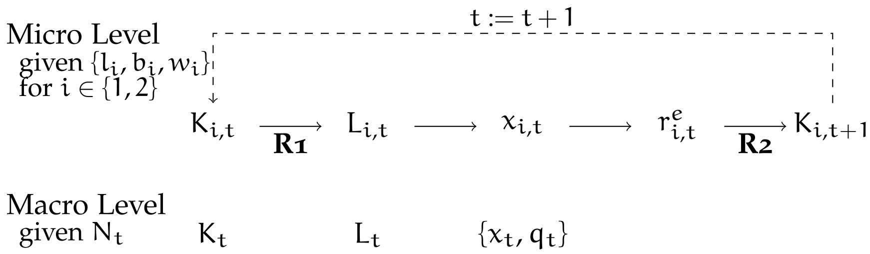

Figure 3.2: Logic of the model.

Firm variables $\{K_{i,t}, L_{i,t}, x_{i,t}\}$, where $i \in \{1, 2\}$, from which aggregates are built, evolve according to two *micro rules*, which establish relations between firm variables: the method of production (3.1) and the investment functions (3.6). The *macro rule* (3.2) determines labour supply, describes the environment in which firms act and defines channels through which they interact. There are two *interaction rules*: Equation (3.3) establishes a functional relationship between firm variables yielding firms' employment levels as outcomes of labour market interaction; and through coordination rule (3.7) firms interact via the market-clearing output price.

As already mentioned, 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 ($L^d_{1,t} > N_t - L_{2,t}$).

R2 From condition (3.5) it follows that firm 2 is 'investment rationed' if its profit-determined level of investments is larger than its labour supply-determined full-utilisation level of investments.

3.3 ADAPTATION AND GROWTH

This section turns to the dynamic process of adjustment in order to clarify the central forces and features of the evolutionary traverse. To put them into precise terms, we perform a 'causal analysis'. For this purpose we compare the path of the adapting economy with its reference path. The adaptation path starts when some particular innovation disrupts the 'old' steady state and ends when a 'new' steady state is reached. Along the reference path no innovation takes place such that the economy remains in its 'old' steady state. The causal effect of the innovation then is the difference between the two paths.[9] We assume that in the 'old' steady state all firms use the same method, namely 'old' method 1 with l_1 and b_1 as unit requirements and pay the same uniform and constant real wage rate w_1/p; the price of the good equals unity in the old steady state. Further, there is full employment and the system grows at rate $g_1 = r_1 = n$. Consistency requires that $n \leqslant 1/b_1$.

Unlike most evolutionary selection models which start with given variety of methods, this approach requires us to not only consider the diffusion process, or the process of variety destruction, but also the process by which variety is created. For the study here, two questions of the innovation process are important. The first question concerns

9 This method has been employed by Kalmbach and Kurz (1992) in their empirical study of employment effects of diffusion of new methods of production. 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*).

the conditions that the new method must satisfy in order to trigger a successful traverse (see subsect. 3.3.1). The second one pertains to the way in which the new method could emerge within a system where there are no unemployed resources and the effects this produces (see subsect. 3.3.2).

3.3.1 *Types of new methods*

We distinguish between different types of new methods based on both their innovation bias and their economic superiority or inferiority.

Potential new methods, i.e. those not (yet) used, are grouped according to their *innovation bias*. The capital bias and the labour bias of the (new) method 2 compared to the (old) method 1 are given by the measures

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

where Θ_b (Θ_l) is the relative gain in physical efficiency with respect to capital (labour). Note that both measures are assumed to be strictly larger than -1 so that both inputs are necessary to operate the new method.[10] The bias of an innovation is defined by the combination of signs of the two measures. For example, new methods for which $\Theta_b = 0$ and $\Theta_l < 0$ are pure labour saving innovations. Table 3.1 lists all types innovation that are possible in a one-good model given the above condition. Below we show how the features of the innovation in terms of physical efficiencies, not just absolutely but relative to what is already there, crucially shape the path of diffusion and aggregate growth of the traversing economy.

Second, we distinguish between methods which are economically superior to the old method and methods which are inferior. In contrast to an inferior method, a superior method is defined as one that would successfully spread and displace the old method along the traverse, if it were implemented. In our model a method is superior if it yields a rate of profit which is strictly higher than that of the old method and yet pays a wage rate that is sufficiently above the wage

10 The appendix on page 53 discusses the case of a fully automated method ($\Theta_l = -1$) and shows that it differs fundamentally from cases where the new method requires labour.

rate of the old firm (see equations 3.3 and 3.6).[11] This condition implies that some (new) method 2 is superior to the (old) method 1 if

$$r_1 b_1 \left(\frac{b_2 - b_1}{b_1} \right) + \frac{w_1}{p} l_1 \left(\frac{e l_2 - l_1}{l_1} \right) < 0. \tag{3.8}$$

We see that the new method yields a higher rate of profit only if at least one of its two unit requirements is strictly smaller compared to the old method. Although a greater physical efficiency with respect to one input is necessary for a new method to be superior, in some cases it is not sufficient: If either one of the two unit requirements is higher for the new method and/or if its labour costs per unit of output are higher because of the wage differential, the ruling income distribution in terms of the wage share and the profit share determine the superiority or inferiority of the new method.

Hence, economic and institutional conditions play an important role for the success of new methods (Kurz 2008). The institutional conditions that play a role here are those which determine the size of e. As already noted, the size of e depends on the perfection of the labour market in terms of information and mobility of workers (Metcalfe and Steedman 2013, p. 169-170).

In the remainder of this study only the case of a superior method is studied. Notice that we also exclude 'dynamic re-switching' where a new method is superior initially but becomes inferior because the income distribution changes in response to its diffusion.

3.3.2 *The implementation period*

At the beginning of the implementation period, which is period 0, firm 2 using the new method 2 is set up. By assumption it grows out of existing resources and comes into being through the 'mutation' of some small fraction of the 'old' capital stock. This 'mutation' is taken to be a singular, exogenous event and to some extent violates our assumption that installed machines cannot be transferred as between firms. But, in the words of Schumpeter, the important point is that an innovation requires "a 'withdrawal of goods' from their previous uses" (Schumpeter 1934, p. 108) as there are no unemployed resources available in a steady state. This is crucial because this influences the aggregate quantity effects of implementing a new method.[12]

11 In the following, $e = w_2/w_1 > 1$ denotes the ratio of the two wage rates and reflects the assumption that the new firm pays a higher wage rate in order to compete away workers from the old firm; the size of e is assumed to be constant and given.

12 The argument that broader economic conditions play an important role for the process of innovation and effects has been emphasised by both Schumpeter (1934, 1939)

In order to determine the effects of implementing a new method on aggregate output and employment, total output x_0 and employment L_0 of the adapting economy are compared to the reference economy, where in both cases the same stock of capital K_0 and the same amount of labour N_0 are available. The difference between the two cases is that in the adapting economy some fraction $K_{2,0}$ is used by the new firm. The instant employment and output effects are described below. The findings are summarised in table 3.1 for different types of new methods.

The effects of implementation on aggregate output and employment depend 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 is higher for the innovating firm than for the old 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:

$$\frac{\Delta_{L,0}}{L_R} = \frac{L_0 - N_0}{N_0} = \begin{cases} 0 & \text{if } \mathbf{R1} \text{ holds,} \\ \frac{K_{2,0}}{K_0}\left(\frac{\Theta_l - \Theta_b}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ does not hold.} \end{cases} \tag{3.9}$$

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 old one. Hence, if **R1** holds, full employment prevails in the implementation period, but some of firm 1's machines lie idle. If a neutral innovation ($\Theta_l = \Theta_b$) gets implemented, the employment effect is zero, but the capital stock remains fully employed in this period. If the innovation is less labour intensive ($\Theta_l < \Theta_b$), installed capacity is fully utilised but some workers are unemployed.

We also see from equation (3.9) that the extent of what may be considered technological unemployment does not only depend on the innovation bias but also on firm 2's initial capital share. For example, if the innovation is capital using and labour saving with $\Theta_b = 0.25$ and $\Theta_l = -0.25$, the employment effect is $\Delta_{L,0}/L_R = -0.1$ for

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. This difference led them to put forth different views on innovation-driven change (Kurz 2015b).

$K_{2,0}/K_0 = 0.25$. But if the whole capital stock mutates instanteneously ($K_{2,0}/K_0 = 1$), the employment effect is $\Delta_{L,0}/L_R = -0.4$.

Innovation type	Bias	R1	$\frac{\Delta_{x,0}}{x_R}$	$\frac{\Delta_{L,0}}{L_R}$
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 3.1: Causal effects in the innovation period.

The instant output effect is the relative deviation of the implementation period's aggregate output x_0 from its reference x_R:

$$\frac{\Delta_{x,0}}{x_R} = \frac{x_0 - x_R}{x_R} = \begin{cases} -\frac{K_{2,0}}{K_0}\left(\frac{\Theta_l}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ holds,} \\ -\frac{K_{2,0}}{K_0}\left(\frac{\Theta_b}{1+\Theta_b}\right) & \text{if } \mathbf{R1} \text{ does not hold.} \end{cases} \tag{3.10}$$

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 with each other: If the innovation is more labour intensive than the old one, we know that **R1** holds. It follows from equation (3.10) 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 3.1).

The next section shows in what way economic circumstances, in particular whether there is full employment or not, interact with the process of differential growth that is initiated by the implementation of the new method and shapes its path of diffusion.

3.3.3 *The diffusion period*

In this section we study the diffusion period during which the new method gradually gains weight in terms of its output share. This quantitative restructuring drives aggregate output and employment growth. The exercise below shows that the type of innovation under consideration crucially shapes the way its diffusion is effectuated and the effects this entails. As shown above, the implementation of some types of new methods makes workers redundant. It will turn out that the *instant* employment effect shapes the adjustment path.

The argument is the following: In case the new method is less labour intensive than the old method, i.e. if $\Theta_l < \Theta_b$, implementation causes technological unemployment. This means that there is a phase during which no firm is rationed. As long as this situation prevails, diffusion is effectuated by differential capacity accumulation. Through this the new firm gradually gains economic weight in terms of its output share. This adjustment mechanism shapes things in the *re-absorption phase* where neither **R1** nor **R2** holds.

The re-absorption phase through which the system moves only if $\Theta_l < \Theta_b$ eventually ends because the new firm grows at an above-normal rate and by doing so re-establishes full employment. The system then enters a different phase, during which firm 1 is rationed on the labour market, while firm 2 still expands at an above-normal rate by attracting workers from firm 1. This kind of predatory interaction shapes things during the *predation phase* where **R1** holds but **R2** does not.

Also this phase ends, because the new firm eventually exhausts its potential to grow at an above-normal rate by luring away workers from firm 1. If then condition (3.5) 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 leads to a strong fall in the output price as a consequence of which the system enters a new steady state.

THE RE-ABSORPTION PHASE During this phase technological unemployment prevails because an innovation which is less labour intensive than the old method has been 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 rate of profit because the market price does not change (see subsect. 3.2.3). As no firm is rationed their output growth rates are given by

$$g_1 = \frac{x_{1,t+1} - x_{1,t}}{x_{1,t}} = r_1 = n,$$

and

$$g_2 = \frac{x_{2,t+1} - x_{2,t}}{x_{2,t}} = r_2 > n.$$

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

$$g_t = \frac{x_{t+1} - x_t}{x_t} = n + \underbrace{q_t \, (g_2 - n)}_{\text{(re-absorption effect)}} > n, \tag{3.11}$$

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.

The structure of production in terms of output shares of the two rivals changes due to the mechanism of differential accumulation at a rate which is proportional to the difference in profit rates:

$$\frac{q_{t+1} - q_t}{q_t} = \frac{g_2 - g_t}{1 + g_t} = (1 - q_t) \, \frac{(r_2 - r_1)}{1 + g_t}. \tag{3.12}$$

Equation (3.12) defines the diffusion path and shows that the new method displaces the old along a sigmoid curve. This logicstic replacement pattern is a typical result of evolutionary models of the variation cum selection kind for the case of two rival methods (Metcalfe 2008). However note that it is not a simple 'S'-shaped logistic curve, because the aggregate growth rate g_t is not constant but increases over time (Metcalfe and Steedman 2013, p. 164).

Summing up, the re-absorption phase appears bright and prosperous: 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 at first caused unemployment. Further keep in mind that the mechanism of differential growth shapes economic movements and causes a logistic pattern of diffusion.

THE PREDATION PHASE As differential growth eventually restores 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.

As now full employment prevails, 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 rate of profit remains constant and above n. Yet, firm 1's position is less favourable as it is no longer able to maintain full capital utilisation. Idle capital in turn forces down its individual rate of profit such that

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

This detrimental effect of 'new' technology on 'old' capital ensures that the speed at which firm 1 accumulates capacity abates.

But this is not all that happens. Predatory interaction on the labour market by equation (3.6a) implies that the growth rate of the old firm now depends on the growth rate of the new firm:

$$g_{1,t} = n + \underbrace{(-1)\frac{q_t}{1-q_t}(1+\Theta_l)(g_2-n)}_{\text{(predation effect)}} < n. \tag{3.13}$$

Since $g_2 > n$, this equation shows that the faster the innovator grows the slower the old 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 an 'above-normal' growth path. The mechanism of 'growth predation' thus leads to a situation in which

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

where $g_2 = r_2$.

This direct and one-sided dependency shown in equation (3.13) is a novel feature in the context of variation-cum-selection models. What difference does it make for adaptive growth and the path of diffusion?

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

$$g_t = n + \underbrace{(-1)\,q_t\Theta_l\,(g_2-n)}_{\text{(predation effect)}}. \tag{3.14}$$

We see that adaptive growth may differ from reference growth n due to the 'predation effect' of equation (3.14). 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 entail 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 is always above the normal level.

The reason why the labour bias of the innovation is a major determinant of the aggregate growth rate is that the economy hits the full-employment ceiling as 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 the growth rate of the average labour coefficient reveals that output growth rate is smaller than n if a labour-using innovation gains economic weight.

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 'pure logistic law' as a driver of restructuring. 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:

$$\Lambda_t = \begin{cases} (1 - q_{L,t})\,\dfrac{(r_2 - r_1)}{1 + g_{L,t}} & \text{in the } \textit{re-absorption} \text{ phase,} \\ \dfrac{g_2 - n}{1 + n} & \text{in the } \textit{predation} \text{ phase,} \end{cases} \tag{3.15}$$

where $g_{L,t}$ is the rate at which total employment grows in the re-absorption phase ($L_t < N_t$). From equation (3.15) it follows that the same logistic process effectuated by differential growth as in equation (3.12) 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 shows an exponential pattern of restructuring, 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 pure logistic law of replacement may not always hold if looked upon from a purely theo-

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.

retical perspective. 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.

THE RESTORATION PHASE So far we have treated the case in which the old 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 3.2 we argued that the new firm is able to avoid being rationed in the way the old firm is. This assumption resides in constraint (3.5), which enters firm 2's investment function (3.6b). Then, **R2** holds if firm 2's profit-determined level of investments is larger than its labour supply-determined full-utilisation 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 realisation 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 from one to the other is due to the fact that the potential for firm 2 to grow at an above-normal rate by luring away workers from firm 1 eventually exhausts. That firm 2 is 'investment rationed' implies that its growth rate is

$$g_{2,T} = (1+n)\,\frac{\bar{l}_T}{q_T l_2} - 1, \tag{3.16}$$

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. 'Old' capacity now is economically obsolete in the sense that 'new' capacity has grown big enough to employ the whole labour force.

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 (3.7), a price p_T is 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 new firm (through the wage differential) but also workers still employed by the old firm, which therefore is at risk of losing its economic viability.

As noted above, output of firm 1 in period $T+1$ is zero. Its capital stock is economically obsolete and hence ready to expire physically. If free disposal is assumed, the problem of getting rid of it will not have significant economic effects. Because firm 1 vanishes ($q_{T+1} = 1$), it follows from equation (3.16) 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 steady state 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 one 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 strongly reacts after the system passed some turning 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.

3.4 CONCLUSIONS

In this paper we clarified the role of a resource constraint for the evolutionary adjustment process triggered by the arrival of new methods of production. By means of a causal analysis we have obtained two main results.

First, the nature and effects of adaptation to a new method crucially depend on whether surplus labour exists or not. Concerning the nature of evolutionary adjustments we have shown that if there is surplus labour, differential accumulation leads to a logistic pattern of restructuring. But in the case of a labour shortage, growth predation through which firms' output growth rates become interdependent, leads to an exponential replacement pattern. Through a comparison of re-absorption growth and predation growth the state of labour supply in relation to demand has also been shown to play an important role for the effects of new methods on aggregate growth along the traverse.

Second, different types of innovations lead to different adaptation paths and effects. Some innovations cause technological unemployment, which is eventually removed through the new firm's above-normal ability to accumulate. Overall, adaptive growth is not steady and it is not necessarily the case that innovations boost aggregate growth.

By way of a conclusion, even in simple models like the one studied here the effects of innovations are hard to assess. From the objectivist position taken up here, this is so because diffusion is a time-consuming process such that effects extend over time; and because effects depend on the features of the innovation, not just absolutely but relative to what is already there, as well as on the economic circumstances into which they are born and spread. Hence, without taking economic circumstances into account we cannot expect to know how innovations will change the system. And even if the diffusion of an innovation causes some pattern to persist for some time, it may prove a bad guide for the future because forces behind patterns may revise the economic circumstances on which they rely.

APPENDIX: FULL AUTOMATION

Here we deal with the case of a fully automated method and show that the dynamic process of adjustment to it differs fundamentally from the cases discussed so far. The (hypothetical) case where machines have completely replaced human labour is discussed by Ricardo (1951, Works VIII, pp. 399–400). He perceived full automation as the ultimate result of mechanisation that took place in his times and pointed out that this would have tremendous implications for the distribution of income (Kurz 2015a, p. 823).

The fully automated method, or 'robot method', produces without labour, that is by means of *unaided capital* ($l_2 = 0$ and $b_2 > 0$). We may think of 'robot capital' as autonomously acting computer-controlled equipment, which is able to self-replicate.

As above, we assume that it is able to pervade the system (hence $r_2 = 1/b_2 > n$) and that the initial stock of robots is constructed by means of 'old' capital. According to equation (3.9), this causes technological unemployment. But in contrast to the cases above, unemployment is not transitory but is persistent because the new robot firm does not create jobs. Full employment could be restored if the old firm increases its rate of job creation, which is only possible through a (temporary) real wage cut and hence entails a distributional conflict, namely between employed workers, who want to maintain their wage rate, and unemployed workers, who want jobs to be created.

Assume that our investment hypothesis adopted so far, namely that $g_2 = r_2$, applies to the new fully automated firm. This means that its investments equal its output because it pays no wages. As it neither demands labour nor offers goods to consumers it is completely disconnected from the rest of the system (see Metcalfe and Steedman 2013, p. 175) such that the old firm continues to grow at rate n while the new firm grows at a rate larger than n. But, as there is no competition for labour, the economy never enters the predation and restoration phase, which implies that the gradual diffusion of the robot method (i) does not drive the old method from the market in absolute terms; (ii) does not raise the real wages, but (iii) *permanently* increases the average profit rate and the profit share, which approaches unity in the limit. This is in sharp contrast to the cases discussed so far, where workers eventually gain through the price fall and where the (average) profit rate returns to the normal level eventually (see subsect. 3.3.3).

Assume that $n < g_2 < r_2$ and that the fully automated firm invests a constant fraction of its output x_2 (which is equal to its profits) into its own business: $g_2 = (1-c)r_2 = (1-c)/b_2$, where $0 < c \leqslant 1$ is the fraction of output not invested; in period t this amount is $cx_{2,t}$. If robot owners consume it directly, we would have a traverse similar to the case where $g_2 = r_2$, although with a lower diffusion speed. To the contrary, if $cx_{2,t}$ is put on the market the situation is different: The market clearing price falls, because this increment of supply of goods is not accompanied by additional aggregate demand (which is total nominal income of workers). The price drop increases the real wage rate of the old firm and decreases its rate of profit accordingly. As a consequence, the below-normal rate at which it creates new jobs leads to mass unemployment. Hence, as long as the price is not zero the system experiences a rather 'dystopian' traverse with high and persistently increasing unemployment; at the same time workers who still have a job gain from the drop in the price.

The situation in which the robot firm sells part of its output to workers will be better in terms of employment, if robot owners spend their earnings (partly) on something that increases the volume of paid labour. For example, robot owners could demand a personal service which can be produced by means of unassisted labour, i.e. Ricardo's 'menial servants' (Ricardo 1951, Works I, p. 392). In our model, this would mean that the volume of paid work increases through the invention of a new use of labour. The transition towards a situation where the production of the consumed good is fully automated then involves the rise of a service industry, which fulfils desires of robot owners. Whether the demand for servants increases at the normal level or not, is not so clear. Further, total demand for service labour may be bounded from above, if consumption takes time (Steedman 2001) and robot owners eventually run out of time to enjoy all the services they could afford. If the time constraint becomes binding, the number of servants employed stagnates unless new and more labour-using services are invented.

We may conclude our crude discussion of full automation by pointing out a possible use for goods produced by means of robots through which workers gain from automation and eventually have no longer the need to work. A portion of output $cx_{2,t}$ of the robot firm may be taken away, either by taxing robot owners or by their 'voluntary charity', and may be distributed equally across the population. Such a 'basic income' per head $BI_t = (cx_{2,t})/N_t$ will be tiny (and, perhaps, too low to make for a living) in the beginning since robotised production is small. But if $g_2 > n$ still holds, however, basic income per head steadily (and exponentially) increases. Eventually, the basic income rises to a level which exceeds the maximum amount of goods a worker can consume given his time constraint. Then the old firm can be shut down since going to work is no longer necessary.

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4

DIFFUSION OF A NEW INTERMEDIATE PRODUCT IN A SIMPLE 'CLASSICAL-SCHUMPETERIAN' MODEL

ABSTRACT This paper deals with the problem of new intermediate products within a simple model, where production is circular and goods enter into the production of other goods. It studies the process by which the new good is absorbed into the economy and the structural transformation that goes with it. By means of a long-period method the forces of structural transformation are examined, in particular the shift of existing means of production towards the innovation and the mechanism of differential growth in terms of alternative techniques and their associated systems of production. We treat two important Schumpeterian topics: the question of technological unemployment and the problem of 'forced saving' and the related problem of an involuntary reduction of real consumption per head. It is shown that both phenomena are potential by-products of the innovation and development process.[1]

4.1 INTRODUCTION

Innovations and the mechanisms through which they spread are key to growth and structural change. Evolutionary models greatly contribute to our understanding of how single industries evolve through the generation and the destruction of variety. However, most models adopt a partial perspective (Nelson and Winter 1982; Metcalfe 1998) or focus on a set of final goods industries (Montobbio 2002); they hence leave open the role of production linkages and of produced means of production. Dosi and Nelson (2010, p. 90) for example observe that the "dynamics of technique in a multisector 'general disequilibrium' framework" is a largely neglected problem in this literature. Also Metcalfe and Steedman (2013) call for a 'more general evolutionary economics' which takes into account produced means of production. In their view, this would sharpen our understanding of the forces of economic transformation, not least because new capital goods are an important form of innovation.

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In this paper we treat certain aspects of this large subject. It deals with the arrival and diffusion of a new good within a simple model with circulating capital. We limit our attention to the following case: Initially, there are two goods, one pure capital good and one pure consumption good. The former is a basic good as it enters the production of all goods and the latter is a non-basic. This economic structure is disrupted by the arrival of a new intermediate product, which is produced with the existing basic good and used as a means to produce the consumption good. The diffusion and absorption of the new good changes the production structure and establishes an economy with three goods and what may be called a more roundabout technique.

The focus of this study is on the features of the transition from the old economic structure to the new one initiated by the arrival of a new intermediate product, a specific type of innovation. That is, we explore the traverse from what is known as the Hicks-Spaventa two-good economy to the Lowe three-good economy; see Steedman (1998) for a comparison of the two models, both of which have been used to study the problem of the traverse. In general, this concept refers to the path that is initiated by a change in data such as population growth and adopted methods and leads the economy, which initially is in some 'old' steady state, to the 'new' steady state consistent with the new data. Although the existing literature covers certain features of the traversing economy for both models, to the best of my knowledge a thorough analysis of the transition *between* the two economic structures has not been elaborated yet. This paper fills certain gaps since it pays particular attention to the process of adaptation. As new and better machines and materials are an important form of technical change, this type of traverse, which involves a qualitative change of the production structure, is highly relevant.

A specific application of the long-period method helps us to put into sharp relief the long-period forces of structural transformation. In particular, it sheds light on the problem of capital re-allocation, through which the new technique is established; and on the problem of differential 'normal' growth in the presence of production links, which is approached in terms of alternative systems of production using distinct production techniques. Based on these mechanisms, the consequences for the economy are examined. We focus on two Schumpeterian topics, namely on the question of technological unemployment and on the problem of 'forced saving' and the related problem of an involuntary reduction of real consumption per head along the traverse.

The main findings are: (i) Given Schumpeter's zero profit condition, a new intermediate product is economically viable if and only if it reduces labour costs. In a more general model, where the rate of profit is positive this is not necessarily so. (ii) The construction of the new technique requires time and a shift of means devoted to existing uses in the preceding circular flow towards the new production activity. This can be expected to affect employment and the rate of real consumption per head. Under certain circumstances, the innovation produces technological unemployment and/or an involuntary reduction of real consumption per head. (iii) If diffusion of the new good is effectuated through differential growth of the two rival systems of production alone, and the new one grows relatively faster because of the 'innovation surplus' of the new technique, the employment consequences are always positive. During the diffusion phase, the higher the speed of diffusion (and hence the rate of economy-wide technical change) the smaller the rate at which the real consumption per head changes.

The paper is organised as follows: Section 4.2 introduces the notation and the concept of the circular flow. Based on this the question of the economic viability of new intermediate products is examined. This prepares for the study of the adaptation path. Section 4.3 then applies a specific variant of the long-period method and first discusses the construction period. There, we focus on the question of forced saving and of technological unemployment and reveal their relation and common cause. Then, we turn to the problem of diffusion, where we focus on the evolutionary mechanism of differential growth, which we tackle in terms of alternative systems of production differing in techniques and hence in surplus rates. Section 4.4 concludes.

4.2 CIRCULAR FLOWS AND NEW INTERMEDIATE GOODS

The paper cross-breeds Classical and Schumpeterian ideas along the lines proposed by Kurz (2008) and Metcalfe and Steedman (2013). We do so in order to provide some insights into economic change and structural transformation brought about by the arrival and diffusion of a particular type of new technology: namely one that is embodied in a new intermediate product and in the methods that produce and use it and because of which it will diffuse.

We apply the analytic schema of Schumpeter (1934) and hence assume that the economy is both in a stationary circular flow before the innovation occurs and after it has been fully absorbed. A stationary circular flow is a special case of a long-period position and features (i) a cost-minimizing system of production, (ii) no profits, and (iii) no growth. Steedman and Metcalfe (2013) emphasise that an important property of the circular flow is that in each industry a single method of production is used. This lack of 'effective variety' means that the economy cannot evolve but reproduces itself.

We first outline the stationary circular flow in which the economy is assumed to be prior to the arrival of the new good. Then, a viability condition is derived that the new good must satisfy so that it will diffuse successfully.

4.2.1 *The 'old' stationary circular flow*

In the old circular flow two goods are produced by means of the 'old' production technique. This technique consists of the following two methods: Producing one unit of good 1 (the basic capital good) requires a_{11} units of itself and l_1 units of labour, while $a_{21}^{(o)}$ units of good 1 and $l_2^{(o)}$ units of labour produce one unit of good 2 (the consumption good). We assume that the system is strictly technologically viable, i.e. $a_{11} < 1$.

As in a circular flow the rate of profit is zero, the ruling price system with good 2 as the numéraire is

$$\begin{aligned} p_1^{(o)} &= p_1^{(o)} a_{11} + w^{(o)} l_1, \\ 1 &= p_1^{(o)} a_{21}^{(o)} + w^{(o)} l_2^{(o)}, \end{aligned} \tag{4.1}$$

where $p_1^{(o)}$ denotes the relative price of good 1 and $w^{(o)}$ the real wage rate.

Because the rate of profit is zero, the labour theory of value holds (Kurz and Salvadori 1995, p. 111). Consequently, relative prices are proportional to quantities of embodied labour:

$$\begin{aligned} p_1^{(o)} &= v_1 w^{(o)}, \\ 1 &= v_2^{(o)} w^{(o)}, \end{aligned} \tag{4.2}$$

where v_1 and $v_2^{(o)}$ denote the quantities of labour embodied directly and indirectly in one unit of each of the two goods.

As regards quantities, the input-output scheme of the stationary circular flow at the outset is:

$$\begin{aligned} x_1 &= a_{11} x_1 + a_{21}^{(o)} x_2^{(o)}, \\ x_2^{(o)} &= w^{(o)} \left[l_1 x_1 + l_2^{(o)} x_2^{(o)} \right]. \end{aligned} \tag{4.3}$$

Here, production of the capital good 1, x_1, equals the investments needed to reproduce exactly the same quantities that have been used up in the course of production; and production of the consumer good, $x_2^{(o)}$, equals total real wage payments since workers, by assumption, do not save. Consumption per unit of labour $c^{(o)}$ is thus equal to the real wage and the uniform growth rate is zero.

4.2.2 *The 'new' stationary circular flow*

In the new stationary circular flow, a different, 'new' technique is used, which involves the production of three goods: Whereas the method for good 1 is the same as in the old system, now one unit of good 3 (the new intermediate product) requires a_{31} units of good 1 and l_3 units of labour as inputs, and $a_{23}^{(n)}$ units of good 3 and $l_2^{(n)}$ units of labour to produce one unit of good 2.

With this, the price system ruling in the new stationary circular flow is given by

$$\begin{aligned} p_1^{(n)} &= p_1^{(n)} a_{11} + w^{(n)} l_1, \\ 1 &= p_3^{(n)} a_{23}^{(n)} + w^{(n)} l_2^{(n)}, \\ p_3^{(n)} &= p_1^{(n)} a_{31} + w^{(n)} l_3, \end{aligned} \tag{4.4}$$

where $p_3^{(n)}$ is the relative price of the intermediate product.

The labour theory of value also holds in the new circular flow. Thus

$$\begin{aligned} p_1^{(n)} &= v_1 w^{(n)}, \\ 1 &= v_2^{(n)} w^{(n)}, \\ p_3^{(n)} &= v_3 w^{(n)}. \end{aligned} \tag{4.5}$$

The input-output scheme of the new stationary circular flow is given by:

$$\begin{aligned} x_1 &= a_{11} x_1 + a_{31} x_3, \\ x_2^{(n)} &= w^{(n)} \left[l_1 x_1 + l_2^{(n)} x_2^{(n)} + l_3 x_3 \right], \\ x_3 &= a_{23}^{(n)} x_2^{(n)}. \end{aligned} \tag{4.6}$$

Here, $x_2^{(n)}$ is the quantity of good 2 produced by means of the new method (n) and x_3 is the production of good 3.

4.2.3 *Economically viable new intermediate products*

Which types of new intermediate products are economically viable, that is, induce profit-motivated agents to exploit their potential and propel their diffusion?

The diffusion of the new intermediate good is technologically feasible if and only if both a method is known for producing it by means of existing goods ('producer method') and a method is available which uses the new capital good to produce the consumption good ('user method'). This technological interdependency can be expected to delay the proliferation of this type of technological improvements as new goods that embody them and (new) ways of applying them do not occur simultaneously in general.[2]

However, since we are here concerned with the economic viability of a new intermediate product, we assume both methods to be available. Based on Kurz (2008), who deals with the economic viability of new methods for existing goods, the new intermediate product is called economically viable if neither its production nor its adoption incurs extra costs at ruling prices. For the individual producers this is so if

$$p_3 \geqslant a_{31} p_1^{(o)} + w^{(o)} l_3, \tag{4.7a}$$

$$p_1^{(o)} a_{21}^{(o)} + w^{(o)} l_2^{(o)} \geqslant p_3 a_{23}^{(n)} + w^{(o)} l_2^{(n)}. \tag{4.7b}$$

The two inequalities reveal that the relative price of the new good, which is p_3, is crucial: it must be high enough such that producers of the new good obtain non-negative profits (4.7a), and at the same time low enough such that users of the new good incur no extra costs (4.7b).

Let $\underline{p}_3$ ($\overline{p}_3$) be the price at which the producer method (user method) obtains zero profits. Three cases are possible:

- 'Mere' Invention: If $\underline{p}_3 > \overline{p}_3$, there is no price at which both its production and its use is profitable. In this case the new capital good cannot spread successfully, even if the diffusion is technologically feasible in the sense defined above.

- 'Just viable' Invention: If $\underline{p}_3 = \overline{p}_3$, the new capital good could be introduced without extra costs but there would be no incentive to do so.

- 'Innovation' or viable invention: If $\underline{p}_3 < \overline{p}_3$, there is a whole range of prices at which both producing and using the new good is profitable. In this case the new intermediate product can be expected to diffuse.

Which case applies can be shown to depend on the technical characteristics of the two alternative techniques: Combining the two conditions (4.7a) and (4.7b) shows that the new intermediate product is

2 There may be cases where an entrepreneur designs a new good and puts it up for sale, initially only in the hope and expectation that feasible and profitable applications of it will be developed by others. Such *complementary innovations* are said to play a particularly important role for the development and diffusion of what is called a general purpose technology (GPT); on GPTs see Bresnahan and Trajtenberg (1995) and Bresnahan (2010). See Rainer and Strohmaier (2014) and Strohmaier and Rainer (2016) for theoretical and empirical studies of GPT diffusion within a Sraffa-Leontief framework.

an innovation if and only if it incurs relatively lower real unit costs with respect to the consumption good, given the old relative price and the old wage rate:

$$\underline{p}_3 < \overline{p}_3 \iff \underbrace{p_1^{(o)} a_{21}^{(o)} + w^{(o)} l_2^{(o)}}_{=1} > p_1^{(o)} a_{31} a_{23}^{(n)} + w^{(o)} \left(a_{23}^{(n)} l_3 + l_2^{(n)} \right).$$

Because good 2 is the numéraire and the uniform rate of profit is zero in the old circular flow, the 'old' real unit costs are equal to one. Further, given the fact that the old relative prices are proportional to quantities of labour embodied (see system 4.2) shows that the new intermediate product will be an innovation if and only if the new technique requires a smaller amount of embodied labour to produce the consumption good than the old technique:

$$\underline{p}_3 < \overline{p}_3 \iff v_2^{(o)} > v_2^{(n)}. \tag{4.8}$$

In the context of the *choice-of-technique* problem (see Kurz and Salvadori 1995, chap. 5) this finding is not very surprising: From condition (4.8) one can easily infer that the new technique is superior to the old one if and only if it is able to pay a higher wage rate at the given rate of profit, which is the condition typically found in the literature. That this criterion extends also to our case, where certain goods are technique-specific, is shown by condition (4.8).

Notice that this condition crucially depends on the assumption that the rate of profit is zero in the old circular flow. As noted by Kurz (2008, p. 271), the "zero-profits assumption [...] implies that in order for an invention to become an innovation it *must* reduce labor costs". Appendix 4.4 on page 80 shows that a labour-saving bias is neither a sufficient nor a necessary condition for the new technique to qualify as an innovation if the normal rate of profit is not zero.

4.2.4 *Comparison of the two circular flows*

We here compare the old circular flow with the new circular flow for the case in which the new technique is economically viable. This comparison prepares the dynamic analysis below since it shows which types of adjustments can be expected to take place if a new and profitable intermediate product diffuses into the economy.

Comparing the two price systems shows: (1) The real wage rate is higher in the new circular flow since the normal rate of profit is assumed to be zero. (2) As a result, the relative price of good 1 is higher in the new circular flow. Comparing the quantity systems shows: (3) The composition of the capital stock is qualitatively different in the two circular flows because the new technique involves a means of production that is not used in the old circular flow. (4) The relative size of the two established industries, namely industry 1 and industry 2, is different in the new circular flow if and only if $a_{21} \neq a_{31} a_{23}^{(n)}$. Hence, in certain circumstances a technical change that involves a new non-basic alters the whole structure of the economy through a process of structural transformation, however, without making the existing industries disappear altogether. Hence no good becomes obsolete; yet there is obsolescence in terms of methods, since the old method of production of the consumption good industry becomes extinct.

4.3 ADAPTATION AND STRUCTURAL TRANSFORMATION

We now turn to the process by which the new circular flow gradually replaces the old one through its adaptation to an economically viable new intermediate product. We confine our analysis to the quantity side of the problem and only consider a particular type of traverse, which is placed within the long-period method and comes with a 'classical' flavour: We study the features of the adjustment path along which produced goods are fully utilized. Hence, the problems of unused goods, of inconsistent investment plans and of effective demand are set aside such that the (differential) accumulation of different types of capital goods are our central concern. This method is used *inter alia* by Metcalfe (2007) in the context of a single industry model and Steedman and Metcalfe (2013) within a one-commodity growth model. For long-period models of differential but 'normal' growth, see also Metcalfe (1998).

To get a clear picture of the role of real capital formation, we shall assume that expansion of productive capacity matches the expansion of output that is demanded, but that surplus labour exists. That is, the classical variant of Say's Law, which does not include the labour market, is taken to hold along the path.[3]

A further assumption defines the sequence of events within one production period: For simplicity, the production period is uniform for all goods. Further, we assume that capital goods produced in period t are the means to produce goods in period $t + 1$, but that consumption goods produced in period t are also consumed in period t. This set of assumptions helps us to spot certain long-period forces of structural transformation.

3 This is a crucial assumption because the question of whether surplus labour exists or not changes the process by which new methods are absorbed into the system via the investment process (Steedman and Metcalfe 2013); see also Haas (2016a).

4.3.1 *Construction of the new technique*

We here deal with the adjustments through which the new technique emerges 'from within' the economy, which is said to be the old circular flow initially. We consider period -1, in which the new technique is still in the making: The new intermediate product is produced for the first time, but the new user method has not yet been launched, because the means to do so are not yet available.

For our simple case we exemplify two questions: (i) the economy's ability to maintain its old circular flow level of employment; and (ii) the possibility that the construction of the new intermediate product cuts real consumption per head. Both questions play some role in Schumpeter's theory. The first one concerns the problem of *technological unemployment*, which he considers to be an unavoidable but temporary by-product of the innovation and development process (Hagemann 2015, p. 128; see also Boianovsky and Trautwein 2010). The second one relates to the idea of *forced saving*. In Schumpeter (1934, 1939) credit is created for innovators and their demand for the given circular flow quantity of means of production leads to credit inflation. A reduction of real consumption per head is often considered to be a likely but temporary 'real' consequence of credit extension for innovations, in particular if existing means are fully utilised in the pre-innovation situation and if the construction of the innovation involves what is called a gestation period, i.e. a lag between the production of a new producer good and its transformation into additional consumption goods; see Machlup (1943) on the concept of forced saving; see also Hagemann (2010) and Festré (2002).

In the following we develop on that. For our model, which is confined to the analysis to the 'real' aspects of the innovation process, it is shown that the two questions are interrelated and have a common cause.

OLD CIRCULAR FLOW: STATE OF REPRODUCTION We rewrite the input-output scheme of the economy in the old circular flow and indicate circular flow quantities by a bar on top of variables:

$$\bar{x}_1 = a_{11}\bar{x}_1 + a_{21}^{(o)}\bar{x}_2^{(o)}, \tag{4.9a}$$

$$\bar{x}_2^{(o)} = c^{(o)}\bar{L}, \tag{4.9b}$$

where consumption per head $c^{(o)}$ equals the real wage rate $w^{(o)}$ and circular flow employment is $\bar{L} = l_1\bar{x}_1 + l_2^{(o)}\bar{x}_2^{(o)}$. Up to period -2 the economy is assumed to be in this state of exact reproduction.

SHIFT OF EXISTING MEANS: 'NEW' INVESTMENT In period −1, the new intermediate product (good 3) is produced for the first time. In order for innovators to be able do so, a shift of existing means of production is required, namely at the end of the preceding period. As Schumpeter (1934, p. 68) insisted, "the new combinations must draw the necessary means of production from some old combinations", if there is full employment of means of production; and that "the carrying into effect of an innovation involves, not primarily an increase in existing factors of production, but the shifting of existing factors from old to new uses" (Schumpeter 1939, p. 110).[4]

At the end of period −2, where the economy still produces circular flow quantities, the available quantity of good 1, $\bar{x}_1$, is divided among three uses: the new one and the two old ones. Because existing means are fully utilised and additional means cannot be withdrawn from idleness, the quantity of 'new' investment must equal the quantity withdrawn from existing uses:

$$\underbrace{a_{31}\Delta x_3}_{\text{'new investment'}} = \underbrace{-a_{11}\Delta x_1 + (-1)\, a_{21}^{(o)}\Delta x^{(o)}}_{\text{'withdrawal'}}.$$

Here, a Δx_i indicates the difference between production of good i in period −1, which is $x_{i,(-1)}$, and in the old circular flow, which is $\bar{x}_i$.

Because there are two old uses, the start of production of the new good 3 is accompanied by either a decrease of production of good 1, or of good 2 or of both. Depending on from which old use existing means are withdrawn, the change in the size of the two existing industries is given by

$$\Delta x_1 = -\alpha \frac{a_{31}\Delta x_3}{a_{11}}, \tag{4.10a}$$

$$\Delta x_2^{(o)} = -(1-\alpha)\frac{a_{31}\Delta x_3}{a_{21}^{(o)}}, \tag{4.10b}$$

where α is the share of 'new investment' withdrawn from industry 1 and $(1-\alpha)$ is the share of 'new investment' withdrawn from industry 2. Since $0 \leqslant \alpha \leqslant 1$, at least one old industry must shrink.

CHANGE IN EMPLOYMENT: JOB CREATION AND JOB DESTRUCTION The shift of existing means of production from old uses towards the new use changes the size of existing industries, thereby

4 In a footnote of *Business Cycles* he considered this to be important for his theory of economic development, in particular because "in the traditional model it was increase in factors, rather than the shifting of factors, that was made the chief vehicle of economic progress. But essential phenomena of the cyclical process depend on that shifting of factors." (Schumpeter 1939, p. 110)

changes the employment structure and may thus affect total employment. The net employment effect, which is the sum of job destruction and job creation, is

$$\Delta L = \underbrace{l_1 \Delta x_1 + l_2^{(o)} \Delta x_2^{(o)}}_{\text{job destruction}} + \underbrace{l_3 \Delta x_3.}_{\text{job creation}}$$

Substituting equations (4.10a) and (4.10b) reveals that the net employment effect per unit of 'new investment' depends in general on the labour intensities of the three involved methods and on the 'withdrawal weights', i.e. on share α:

$$\frac{\Delta L}{a_{31}\Delta x_3} = \alpha \left(\frac{l_3}{a_{31}} - \frac{l_1}{a_{11}} \right) + (1-\alpha) \left(\frac{l_3}{a_{31}} - \frac{l_2^{(o)}}{a_{21}^{(o)}} \right). \tag{4.11}$$

This equation states: (1) If the new producer method has the highest (lowest) labour intensity of all three operated methods, the net employment effect in period -1 is positive (negative). (2) If the labour intensity of the new producer method lies between the two 'old' labour intensities, the sign of the employment effect additionally depends on the withdrawal weights: For a certain range of α, the employment effect will be positive, for another range it will be negative, and for a certain value of α it will be zero.

Overall, in a closed economy where capital is fully utilised, the construction of the new intermediate good can be expected to cause a change in employment, if this is effectuated through a shift of existing means of production. Only in certain special circumstances, for example if all three methods have the same labour intensity, the net employment effect is zero. Technological unemployment, i.e. a reduction of employment compared to the pre-innovation circular flow situation, is likely in the construction phase in cases in which the innovation withdraws most of its resources from relatively more labour intensive old uses.

CHANGE IN REAL CONSUMPTION: THE QUESTION OF 'FORCED SAVING' We have shown that the shift of existing means towards the new use might both decrease the production of the consumption good and might alter employment compared to the previous circular flow situation. If we insist on full utilisation also with respect to the consumption good (good 2), real consumption per head may therefore be forced to adjust.

In our model this is so because production of good 2, employment and real consumption per head are related by

$$\bar{x}_2^{(o)} + \Delta x_2^{(o)} = \left(c^{(o)} + \Delta c \right) \left(\bar{L} + \Delta L \right), \tag{4.12}$$

for period -1. The LHS displays production and the RHS displays total real consumption demand; Δc denotes the change in real consumption per head between period -1 and the circular flow.

From this equation it follows that only in rare cases the old real consumption rate is exactly maintained in period -1, since this requires production of the consumption good and employment to change accordingly: $\Delta c = 0 \iff \Delta x_2^{(o)} = c^{(o)}\Delta L$. In general, the sign of Δc depends on the labour intensities of methods and on the withdrawal shares. Consider the following three cases:

1. Increase of employment ($\Delta L > 0$). Because existing means are shifted towards the production of the new capital good, which will provide new means to increase production of the consumption good (using the new user method), not in this period but only a period later, production of the consumption good cannot increase. Due to this gestation lag, in cases in which the net employment effect is positive, real consumption per head must fall, independently of whether the consumption good industry shrinks or not due to shift of means.

2. Withdrawal only from industry 2 ($\alpha = 0$). If innovators withdraw means only from 'old' firms of the consumption good industry ($\alpha = 0$), their output shrinks ($\Delta x_2^{(o)} < 0$). For this case it can be shown that the reduction of production of the consumption good always outweighs a decrease in employment, if any (see appendix 4.4). As a result, real consumption per head is reduced.

3. Withdrawal only from old industry 1 ($\alpha = 1$). If innovators withdraw means only from existing firms of the capital good industry ($\alpha = 1$), consumption good production remains at the old circular flow level ($\Delta x_2^{(o)} = 0$). In the case that innovators implement a producer method with a relatively smaller labour intensity compared to that of industry 1, employment falls ($\Delta L < 0$), and real consumption per head rises as a result ($\Delta c > 0$).

The first and the second case illustrate the two main conditions under which the construction of the new technique leads to a reduction of real consumption per head. In the first case, this is so because the shift of means towards the production of the new means of production entails an increase of employment. In the second case, the reduction of real consumption per head is caused by the shift of means from producing consumption goods towards producing means of production, a phenomenon which may by called 'forced accumulation'. The third case spots the condition under which real consumption per head is not reduced. This will happen if employment decreases and if the decrease of employment outweighs the reduction of consumption good production.

The second case is the one Schumpeter assumes in his 'pure model' of the capitalist process (Schumpeter 1939, chap. IV). There he discusses the case of a new consumer good that requires a new capital good as an input and assumes that the 'new investment' is withdrawn only from the 'old' firms producing the existing consumption good, i.e. the case in which $\alpha = 0$. Since, he argues that "if there were only one single consumers' good, less of it would be produced now than had been produced in the preceding state of equilibrium. Instead, more producers' goods will be produced [...] The output of consumers' goods will fall in any case unless there is no period of gestation at all." (Schumpeter 1939, p. 135-136) Since he assumes heterogeneous capital goods here, namely an 'old' one and a 'new' one, the statement on "more producers' goods" makes sense only if the stock of old capital does not shrink compared to the situation in the old circular flow, i.e. if $\alpha = 0$. Only in this case, 'forced accumulation' in physical terms can be said to be a by-product of the shift of means, enabled by credit creation.[5] Note that in this case also the *value* of the capital stock (measured at old circular flow prices) clearly increases. However, if at least some resources are shifted from the old capital good industry towards the new one, the *value* of the capital stock might not always be relatively higher in the construction period.

DISCUSSION We argued that both employment and real consumption per head are likely to change if existing means of production are shifted towards the construction of the new technique. We identified the labour intensities of the two old methods and of the new one, and the withdrawal shares as main determinants. In contrast to one-good models (Metcalfe and Steedman 2013; see also Haas 2016a), in multi-good models such as ours there are typically different types of old uses for existing means and, in the case of new capital goods, also gestation lags; this has been shown to be important for the effects of construction, which do not only depend on the type of the innovation, but also on the source of the 'new investment' through which the innovation is brought into the economy.

5 It is interesting to note that Schumpeter (1939, chap. IV) does not refer to the idea of forced saving explicitly and also leaves open the question of a reduction of real consumption per head here (on this see Machlup 1943, p. 27-28). But he clearly indicates the possibility of a reduction by stating that "[i]t should be observed, however, that demand in terms of money for consumers' goods has not decreased. On the contrary, it has increased" (Schumpeter 1939, p. 135-136).

Because the new investment can be expected to be relatively small, also the discussed effects will tend to be very small; in our model they are nonetheless important since they affect the path the economy takes: If the initial shift of means reduces the size of industry 1, or more generally entails a de-accumulation of the 'old' basic self-reproducing system of the economy, also the amount of means that can be used productively in total in the next period is smaller, meaning that the events in the very beginning 'echo' into subsequent periods.

We illustrated various cases in order to put the role of the withdrawal scheme into sharp relief, but we did not provide an argument on what determines the withdrawal shares. To be sure, the specific type of long-period method we applied here appears to be not particularly well suited to deal with this problem, because the monetary aspects of innovations, the short-run market price adjustments and expectations of existing firms are set aside but can be expected to play an important role here.

Furthermore, our argument depends strongly on the implicit assumption that the shift of means from certain old uses to the new one does not provoke any further 'second-order shift' at the end of period -2, namely one that re-proportions the two existing industries in some way. For example, if producers of consumption good industry were assumed not to be completely myopic but would expect that the innovation will cause a change in employment and would be able to adjust their size accordingly, the change in real consumption per head would be relatively smaller. Overall, such 'second-order shifts' would essentially imply that the withdrawal share α, which we here treated as exogenous, becomes endogenous. Appendix 4.4 deals with this issue in an indirect way, namely by assuming that consumption per head remains constant because a second-order shift adjusts production of the consumption good to the change in employment. This exercise gives some insight into this problem.

4.3.2 *Diffusion of the new technique*

Once the conditions for installing the new methods are met and the new intermediate product is available on the market, four methods are used in the economy: the established 'old' method in the basic capital good industry, the 'new' method that produces the new intermediate product, and two methods that produce the consumption good, where one is 'old' and one is 'new'. The economy hence exhibits greater variety, which is the prerequisite for it to evolve through a process of differential growth. Through this process the economic weight of the new technique gradually increases and the economy structurally transforms itself.

VARIETY AND ECONOMIC STRUCTURE: TWO RIVAL SYSTEMS OF PRODUCTION Assume that all four methods are operated in period t. Because two production techniques are operated at the same time, the economy can be viewed as being composed of two *systems of production* (SoP's). The 'old' system of production (o) operates the old technique and requires two distinct activities, or components: Component $1^{(o)}$ (re-)produces good 1 for itself and for component $2^{(o)}$, which in turn produces good 2. The 'new' system of production (n) operates the new technique and consists of three distinct components: Component $1^{(n)}$ (re-)produces good 1 by means of the existing method, namely for itself and for component $3^{(n)}$, which produces the intermediate good; component $2^{(n)}$ produces good 2 using the intermediate good. In period t, total production can thus be thought of as being the sum of outputs provided by the respective components of the two SoP's.

$$\text{Industry 1: } x_{1,t} = x_{1,t}^{(n)} + x_{1,t}^{(o)},$$
$$\text{Industry 2: } x_{2,t} = x_{2,t}^{(n)} + x_{2,t}^{(o)},$$
$$\text{Industry 3: } x_{3,t} = x_{3,t}^{(n)}.$$

This decomposition of industry outputs (LHS) into the contributions of the two systems of production (RHS) is straightforward with respect to the new intermediate product 3, because only the new SoP produces it, and also with respect to good 2, because in this industry the two SoP's here operate different methods. The splitting up of industry 1, where both systems of production use the same method, is purely analytical.

The decomposition of the economy into two systems of production will help us to spot one crucial driver of the adaptation process, namely differential growth of rival systems of production.

DIFFERENTIAL GROWTH OF TECHNIQUES: INNOVATION SURPLUS We use a simple case to illustrate the mechanism of differential growth in terms of systems of production. To put this into sharp relief, two other adjustments are neglected, namely shifts of means from the old SoP towards the new SoP and shifts of means amongst the components of an SoP. Again, in the economy as whole, all three goods are supposed to be fully utilised.

For the adaptation process through which the innovation is absorbed into the system, the new industry plays a special role: Because its size limits the amount of consumption goods which can be produced by means of the new 'user method' and hence determines the economic weight of the new technique, its continual expansion is the central dynamic force through which the new system of production replaces the old one. The pace at which the new industry expands can be expected to be related to the positive profits obtained in this industry: First, because profitable opportunities attract an early 'swarm of imitators' (Schumpeter 1934), who will reallocate additional means in the same way as the innovator has done in the construction phase. Secondly, retained extra profits provide innovators with the internal means to accumulate, an argument that is central to evolutionary models of competitive selection (Metcalfe 1998, Montobbio 2002). Concerning the latter, individual producers of the new industry can be considered to be in a good position to carry out their accumulation plans because they can get inputs by paying (marginally) more for them and can sell their product and by charging (marginally) less than the reservation price of potential customers; this is something that their 'marginal' competitors cannot achieve without failing to break even at the old circular flow prices.

For what we want to show here, it is enough to assume that the new industry grows at some positive rate, namely g_3, which is taken to be constant for simplicity.[6] Since goods are fully utilised, it follows that the three components of the new system of production (and the stock of labour it employs) must also grow at the same rate: Component $1^{(n)}$, which supplies component $3^{(n)}$ and itself with the basic capital good, must expand at rate g_3 in order to be able to satisfy the growing demand over time; and component $2^{(n)}$, which is the only activity demanding the new good, must also grow at the same rate in order to be able to fully absorb the growing supply of the new intermediate good. Hence

$$(1+g_3) = \frac{x^{(n)}_{3,t}}{x^{(n)}_{3,t-1}} = \frac{x^{(n)}_{2,t}}{x^{(n)}_{2,t-1}} = \frac{x^{(n)}_{1,t}}{x^{(n)}_{1,t-1}} = \frac{L^{(n)}_{t}}{L^{(n)}_{t-1}}, \tag{4.13}$$

where $L^{(n)}_t$ denotes total employment of the new system of production in period t, given by $L^{(n)}_t = l_1 x^{(n)}_{1,t} + l^{(n)}_2 x^{(n)}_{2,t} + l_3 x^{(n)}_{3,t}$. Because of the assumption of full utilisation, the production links between the

6 Implicitly this means that we limit ourselves to the profit-propelled accumulation of existing producers, i.e. the innovators plus, perhaps, the early swarm of imitators, and do not take into account continual imitation as otherwise the growth rate of the new industry cannot be expected to remain constant over time. An extension of the proposed model could consist of including continual imitation as a specific form of a shift of existing means from the old SoP towards the new SoP.

three components of the new SoP imposed by its technique imply that

$$\begin{aligned} x_{1,t-1}^{(n)} &= (1+g_3)\left(a_{11}x_{1,t-1}^{(n)} + a_{31}x_{3,t-1}^{(n)}\right), \\ x_{3,t-1}^{(n)} &= a_{23}^{(n)}x_{2,t}^{(n)}, \end{aligned} \tag{4.14}$$

where production of the new intermediate product grows at rate g_3. Notice that g_3 determines, together with the three capital coefficients, the relative size of the three components.

We thus have it that the new system of production grows at a uniform rate (eq. 4.13) and is 'well-proportioned' in the sense that the new SoP is able to sustain a self-sustained growth path (eq. 4.14). Thus, we can rely on the well-known growth-consumption curve to describe the new system of production. This relationship tells us that the higher the growth rate of the new system of production, which is g_3, the lower is the quantity of the consumption good *per unit of labour the new system employs*, i.e. $x_{2,t}^{(n)}/L_t^{(n)}$. In general, this ratio is not equal to average consumption per head, because two systems of production exist side by side which both employ labour and supply consumption goods.

Because, as we have assumed in our simple case, there are no shifts of means between the two systems of production, the old system can be expected to return to a balanced and well-proportioned state of pure re-production after the initial withdrawal of new investments at the beginning of the construction phase. The old system, which grew smaller compared to the old circular flow, has resettled in such a way that the growth rate of its two components is zero, implying that the quantity of the consumption good per unit of labour the old system employs equals the old rate of real consumption per head, i.e. $x_{2,t}^{(o)}/L_t^{(o)} = c^{(o)} = w^{(o)}$.

Figure 4.1 illustrates the consumption-growth curve for a pair of old and new SoP's.[7] Both exhibit the same maximum growth rate, since they operate the same method for producing the basic capital good. Because the new technique is an innovation (see subsection 4.2.3), the new system of production produces a greater *surplus*, in the sense that at the old level of consumption per head $c^{(o)}$, the new system of production can grow.

We now turn to the implications of the process of differential growth of the two SoP's for the evolution of employment and average consumption per head.

7 The numerical values are those of the first example discussed in appendix 4.4.

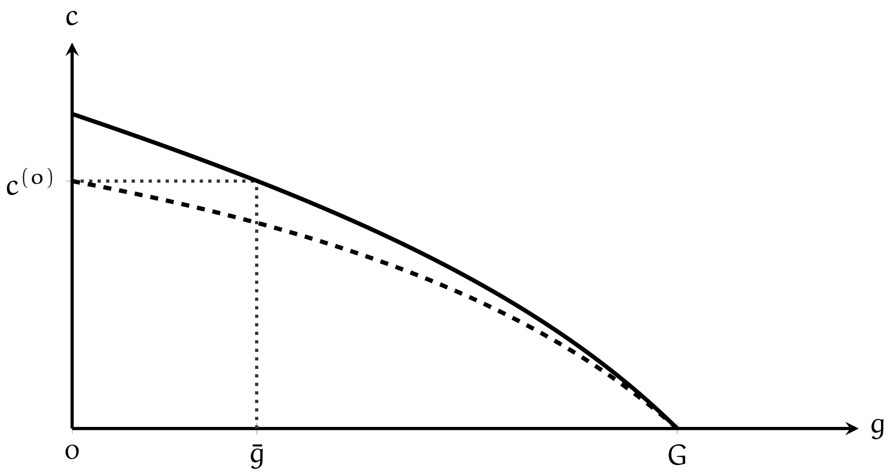

Figure 4.1: Illustration of consumption-growth curves for the old system of production (dashed line) and the new system of production (solid line).

DIFFERENTIAL GROWTH OF TECHNIQUES: EMPLOYMENT DYNAMICS Total employment in the economy as a whole is given by $L_t = L_t^{(n)} + L_t^{(0)}$. In our simple case, where there are no shifts of means, neither between nor within the two systems of production, the rate at which total employment grows equals the weighted average growth rate of the two SoP's employment, with employment shares as weights. Because the old system exhibits zero growth and the new one grows at rate g_3, employment expands at rate

$$\frac{L_t - L_{t-1}}{L_{t-1}} = g_3 \frac{L_{t-1}^{(n)}}{L_{t-1}}, \tag{4.15}$$

where $L_{t-1}^{(n)}/L_{t-1}$ is the employment share of the new SoP in period $t-1$. This growth rate is always positive. The positive employment effect is caused by the innovation's surplus which we assumed to be (partly) used up for expanding the new SoP.[8] At the beginning of the diffusion phase the economic weight, i.e. the employment share, of the new SoP is very small, implying that employment growth is only slightly positive. But over time the employment share of the

8 It is unambiguously positive, because we do not take into account that means are shifted between or within the two SoPs. As we have shown in our study of the construction period, such shifts can cause a net destruction of jobs, depending on the sign of the labour intensity differentials of methods (components) involved. Additionally, the direction of shifts of means, i.e. towards producing more capital goods or towards producing more consumption goods, 'echos' in subsequent periods. For example, a shift of means towards producing more capital goods may cause the net destruction of jobs initially but may increase the stock of means (and hence employment) in the next period.

new system of production increases so that employment growth gains momentum.

Hence, in our simple case, technological unemployment, a potential by-product of the shift of means in the construction period, is gradually removed through the expansion of the new system of production; and after that is accomplished employment grows beyond the old circular flow level since surplus labour is assumed. To some extent, the mechanism of differential growth in terms of alternative systems of production partly sustains Schumpeter's opinion, that "the capitalist process has always absorbed, *at increasing real wage rates*, not only the unemployment it generated but also the increasing population" (Schumpeter [1946] 1951, p. 200; cited in Boianovsky and Trautwein 2010, p. 243; italics in the original).

DIFFERENTIAL GROWTH OF TECHNIQUES: 'FORCED ACCUMULATION' We showed that in the construction period under certain circumstances real consumption per head is reduced because of the shift of existing means towards the new production activity. Part of the argument why innovation causes forced saving was that the new technique involves a gestation lag, suggesting that this problem is only temporary: Before consumption goods can be produced with the new technique, the new means have to be produced in the previous period. Although the new system of production now supplies consumption goods, this argument extends, in a slightly different form, also to the diffusion phase. Since, to produce more consumption goods with the new technique, additional means have to be produced in previous periods. Hence, if the new system grows at a positive rate, it is possible that the new system grows in such a way that reduces *average* consumption per head continually, a case which under our assumptions can be called 'forced accumulation'.

In period t, consumption per head is determined by

$$x_{2,t}^{(n)} + x_{2,t}^{(o)} = c_t \left(L_t^{(n)} + L_t^{(o)} \right),$$

where the LHS is total production of good 2, which is $x_{2,t}$, and the RHS is total real consumption demand, i.e. total employment L_t times real consumption per head c_t. Again, the latter is assumed to adjust in such a way that the consumption good market clears. Furthermore, c_t is the same for all workers, and hence independent of the SoP they work in. Notice that now both systems of production supply consumption goods, which is the important difference between the construction phase and the diffusion phase.

We can re-write this equation as:

$$c_t = \frac{x_{2,t}}{L_t} = \frac{x_{2,t}^{(o)}}{L_t^{(o)}}\frac{L_t^{(o)}}{L_t} + \frac{x_{2,t}^{(n)}}{L_t^{(n)}}\frac{L_t^{(n)}}{L_t} = c^{(o)} + \frac{L_t^{(n)}}{L_t}\left(c^{(n)} - c^{(o)}\right). \quad (4.16)$$

It shows that (average) real consumption per head is the weighted average rate of real consumption of the two SoPs, again with employment shares as weights.[9] Referring back to figure 4.1, three cases are possible:

1. If $g_3 < \overline{g}$, average real consumption per head increases over time compared to the old circular flow level $c^{(o)}$, because the new system of production grows at a low rate, in this way distributing a portion of the innovation surplus to workers.

2. If $g_3 = \overline{g}$, average real consumption per head remains at the old circular flow level. This is so because at this specific growth rate, the quantity of consumption goods produced per hour worked in the new SoP equals the old rate of real consumption per head $c^{(o)}$. Hence in this case the whole innovation surplus is exactly used up in expanding the new SoP.

3. If $g_3 > \overline{g}$, average real consumption per head continually decreases during the diffusion phase, because the new system grows at a rate which is too high to sustain the old rate of real consumption for workers of the new SoP ('forced accumulation').

Hence, in our economy where goods are fully utilised and two alternative systems of production grow at different rates, there is a trade-off between a higher growth rate of the new system of production and a higher economy-wide average rate of real consumption per head: In the first case, the diffusion of the new technique (and hence the rate of technical change at the industry level) is very slow; yet this actually increases the average real consumption per head. In the second case, the rate of technical change is higher, but real consumption stagnates since the whole innovation surplus is used up for accumulation within the new system of production. Compared to the two other cases, in the third case the rate of technical change would be even higher, but average real consumption per head would be continually reduced. This indicates that the problem of a reduction of real

9 More precisely, $c^{(n)}$ is the quantity of consumption goods produced by the new system of production per hour worked in the new SoP. Since there are two SoPs it should be interpreted not as actual or average real consumption per hour worked in the economy.

consumption due to the adjustments of the economy's capital stock might not only be a problem of the very beginning of the traverse, i.e. in the construction period. Rather, it is a phenomenon that can occur over an extended period of time, if agents push the growth rate of the new system of production beyond its innovation surplus because of the extraordinary profits which can be gained by investing into the new capital good industry.

DIFFERENTIAL GROWTH OF TECHNIQUES: 'S'-SHAPED DIFFUSION We can measure the economic weight of the new system of production, or its current diffusion level, in different ways. One is given by the output share of the new user method in industry 2, which we denote by $q_{2,t} = x_{2,t}^{(n)}/x_t$, where $x_{2,t} = x_{2,t}^{(n)} + x_{2,t}^{(o)}$ is total output of good 2 in period t.

In our simple case, the rate at which it changes depends on the extent of the 'dynamism' of the new industry and the market growth rate:

$$\frac{q_{2,t} - q_{2,t-1}}{q_{2,t-1}} = \frac{g_3 - g_{2,t-1}}{1 + g_{2,t-1}} = (1 - q_{2,t-1})\,\frac{g_3}{1 + q_{2,t-1}\,g_3},$$

where $g_{2,t-1}$ is the growth rate of industry 2. This growth rate is given by the weighted average growth rate of the two systems, with output shares as the weights. It adapts every period in response to changes in the economic weights of the two production systems. This equation illustrates that the mechanism of differential growth in terms of the two systems of production generates the well-known sigmoid diffusion pattern, a stylised fact of diffusion research. Note that because the total quantity of good 2 evolves at a non-constant rate it is not a simple logistic curve (Metcalfe and Steedman 2013).

DIFFERENTIAL GROWTH OF TECHNIQUES: STRUCTURAL CHANGE In the case of 'pure' differential growth in terms of systems of production exemplified here, the components of the the new SoP (of the old SoP) were assumed to grow at the same uniform rate, namely g_3 (zero). In other words, we treated the case of differential but equiproportional expansion of distinct SoP's.

For the economy as a whole, this type of differential growth process causes structural change, meaning that the three industries grow at different rates. This is so because industry i grows at the average rate at which the two components $i^{(n)}$ and $i^{(o)}$ grow, where their industry output shares are the weights. The weights of components of the two SoPs are different in the various industries, not least because they depend on the production coefficients. It therefore is impossible to sustain proportional growth at the level of industries in our simple case.

Overall, at the level of industries, the dynamism of new industry provokes a slow and gradual adjustment in terms of growth of those existing, or old industries, to which the new SoP contributes: Because the weight of the new SoP in the new industry 3 is equal to one right from the very beginning of the traverse, the growth rate of industry 3 is g_3 throughout. For a long time the new industry 3 will considerably outpace the two old industries, since their growth rates will start from close to zero initially. But, since the economic weight of the new SoP increases over time, the growth rates of the two old industries gradually increase. And, although at different rates, they will fully catch up in the limit since their growth rates converge towards g_3.

DISCUSSION We treated the problem of diffusion of a new intermediate product within a multi-good model and focused on one main driver, differential growth in terms of the systems of production using distinct techniques: Because of its innovation surplus, the new SoP can be expected to grow faster than the old one, through which the new SoP increases its economic weight. Via this channel, the innovation causes a dynamism that gradually gains momentum and propagates into those 'old' and 'new' production activities that constitute the new SoP, entailing structural transformation.

Amongst other things we have shown that if the new industry is 'overly dynamic', i.e. the case when $g_3 > \overline{g}$, forced accumulation leads to a reduction of real consumption per head also in the diffusion phase. This case is not implausible altogether, especially if the extra profits of the new technique do not percolate evenly into the economy but amass in the new industry which produces the new input, providing the incentive for its fast build-up.

Our simple case provides only a first approximation since it does not take into account the whole range of adjustments that the invasion of the innovation may provoke but dealt with one mechanism in isolation. We set aside responses of agents engaged in the old SoP, in particular shifts of existing means from the old system towards the new one. Such adjustments would complicate the analysis considerably, because then the growth rate of the new system becomes endogenous and the two components of the old system can be expected to grow differently. It has been shown in the discussion of the construction period that such shifts may cause technological unemployment, in which case these secondary adjustments would counteract the effects of the growth of the new SoP.

4.4 CONCLUSIONS

The paper discussed the problem of the arrival and diffusion of a new intermediate product within a simple multi-good economy. It highlighted important 'Schumpeterian' features of the evolving economy in which first the new technique, which brings the new good into the system, is constructed and then diffused. We adopted a specific application of the long-period method, which boiled down to a sequential study of the adjustment path along which two alternative techniques are used, goods are fully utilized and surplus labour exists. This helped to spot the role of capital re-allocation and of differential growth of distinct systems of production for this transformation process. Overall, the theoretical exercise provided a first approximation to the problem of evolutionary growth in the presence of production links amongst the various distinct activities, exemplified with a specific type of innovation.

We may conclude by pointing out that certain findings, such as those related to the gestation lag, depend on the type of innovation we assumed. Yet, the simple analytic schema may well be applicable to various cases. Such an extension could help to clarify how different types of innovations cause different problems along the path and entail different forms of structural transformation. A multi-good framework, which takes into account produced means of production, offers the potential for a rich typology of innovations, forms of creative destruction and of obsolescence and degrees of disruption. To contrast our case, where the new technique brings a new intermediate product into the economy, one can imagine the opposite case of a 'less roundabout technique' through which an existing intermediate product becomes eventually obsolete, perhaps through a process innovation.

APPENDIX A: ECONOMICALLY VIABLE NEW TECHNIQUES

We show that if the rate of profit is not zero, condition (4.8) according to which the new technique *must* save embodied labour in the production of the consumption good in order to become an innovation, is neither sufficient nor necessary.

To this end we illustrate the wage-profit curves of the new and the old technique. In our case, the two techniques differ with respect to the method of production for the non-basic and pure consumption good 2, which is the same in both systems of production. Bharadwaj (1970, p. 416–417) has shown that for two adjacent techniques using different methods in only one of the common non-basic goods, the maximum number of switches is given by the number of different basic and nonbasic goods that are used productively at least by one of the alternative methods of production for the nonbasic good under consideration. For our case, this means that the new technique (n) and the old technique (o) have not more than 2 switches in the range $0 \leqslant r < R$, where r is the uniform rate of profit and R is the maximum rate of profit. Since the two techniques operate the same method of production for the common basic good, which is good 1, the maximum rate of profit is the same for both: $R = R^{(n)} = R^{(o)} = (1 - a_{11}) / a_{11}$. Therefore, the two techniques have an additional switch ar $r = R$.

Since the two techniques use different methods to produce the common nonbasic good, i.e the consumption good, indexed by 2, they can exhibit different maximum wage rates, which are given by the respective inverses of quantities of labour embodied in one unit of the consumption good. We shall call a new technique 'labour-saving' if it exhibits $v_2^{(n)} < v_2^{(o)}$, 'labour-using' if $v_2^{(n)} > v_2^{(o)}$, and 'labour-neutral' if $v_2^{(n)} = v_2^{(o)}$.

Figures 4.2-4.5 on page 83 illustrate wage-profit curves for different types of new techniques. Wage-profit curves of new techniques are graphed as solid lines, the wage-profit curve of the old technique as a dashed curve.[10] Figure 4.2 illustrates the wage-profit curve of a 'labour-saving' new technique which has only one switch, namely at $r = R$. Hence, the new technique is an innovation for every $0 \leqslant r < R$ given the old technique. Figure 4.3 also shows a 'labour-saving' new technique, but one that exhibits two switches with the old technique. Because the new technique is an innovation only for those ranges of r, where its wage-profit curve lies above of that of the old technique, saving embodied labour, i.e. $v_2^{(n)} < v_2^{(o)}$, is not a *sufficient* condition for the new technique to be economically viable in general. Figure 4.4 shows a 'labour-neutral' new technique which has three switches, including one at $r = 0$ since $v_2^{(n)} = v_2^{(o)}$. Nonetheless, it is an innovation if r lies above a certain level (but below R); this example indicates that the relative curvature of the two wage-profit curves play a role in certain circumstances. As figure 4.5 illustrates, also a 'labour-using' new technique can be an innovation for a certain range of R, if there is a switch at some $0 < r < R$. These two examples show that $v_2^{(n)} < v_2^{(o)}$

10 The numerical values of the old techniques are $(a_{11}, l_1) = (0.50, 1.00)$ and $(a_{21}^{(o)}, l_2^{(o)}) = (0.60, 4.00)$. As regards the new techniques, for figure 4.2, $(a_{31}, l_3) = (0.45, 1.75)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.60, 2.50)$; for figure 4.3, $(a_{31}, l_3) = (0.10, 2.30)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (1.60, 1.00)$; for figure 4.4, $(a_{31}, l_3) = (0.10, 5.00)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.85, 0.78)$; for figure 4.4, $(a_{31}, l_3) = (0.25, 1.75)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.70, 4.00)$.

is not a *necessary* condition for the new technique to be strictly economically viable in general.

APPENDIX B: 'FORCED SAVING' IN THE CONSTRUCTION PERIOD

We here consider the question of 'forced savings', which we define as a situation where means of production are shifted towards the construction of a new capital good with the effect that consumption per head falls. It is shown that if the withdrawal of resources reduces the output of the consumption good industry *only*, real consumption per head is lower in the construction period (period -1) compared to the previous circular flow level.

Assume that in period -1 innovators withdraw their new investment from resources devoted to the production of the consumption good in the old circular flow but none from the resources devoted to the production of the basic capital good, i.e. $\alpha = 0$. This shift of means from producing consumption goods towards producing the new intermediate product has two consequences: According to equation (4.10b) the change in production of good 2 is

$$\Delta x_2^{(o)} = -\frac{a_{31}}{a_{21}^{(o)}} \Delta x_3, \tag{4.17}$$

and, according to equation (4.11), the change in employment is determined by

$$\Delta L = \underbrace{l_2^{(o)} \Delta x_2^{(o)}}_{\text{job destruction}} + \underbrace{l_3 \Delta x_3}_{\text{job creation}} = \left(\frac{l_3}{a_{31}} - \frac{l_2^{(o)}}{a_{21}^{(o)}} \right) a_{31} \Delta x_3. \tag{4.18}$$

Production of the consumption good hence shrinks, whereas the sign of the net employment effect depends on the labour intensities of the two involved methods.

From equation (4.12) it follows that real consumption per head falls, i.e. $\Delta c < 0$ if and only if

$$\Delta x_2^{(o)} < c^{(o)} \Delta L.$$

By using equations (4.17) and (4.18) we find that for the case of $\alpha = 0$, real consumption per had must fall regardless of the sign and magnitude of the labour intensity differential:

$$\Delta c < 0 \iff \frac{\Delta L}{\Delta x_2} < \frac{1}{c^{(o)}} \iff -\frac{l_3}{a_{31}} < \nu_1.$$

This shows that if all the means of innovators are withdrawn from resources of existing producers of the consumption good industry,

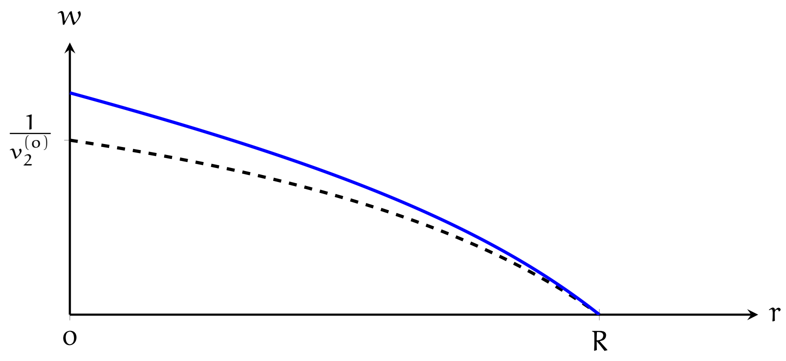

Figure 4.2: A 'labour-saving' new technique that is an innovation for $r < R$.

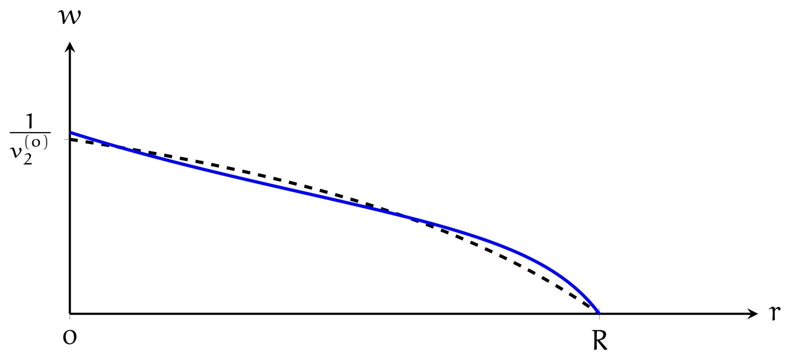

Figure 4.3: A 'labour-saving' new technique that is an innovation for certain ranges of $r < R$.

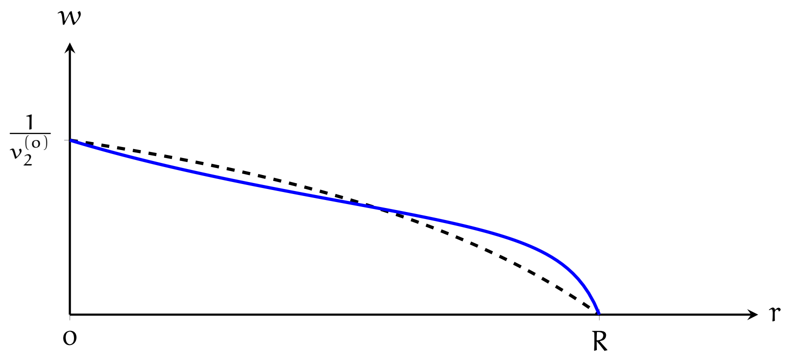

Figure 4.4: A 'labour-neutral' new technique that is an innovation for a certain range of $r < R$.

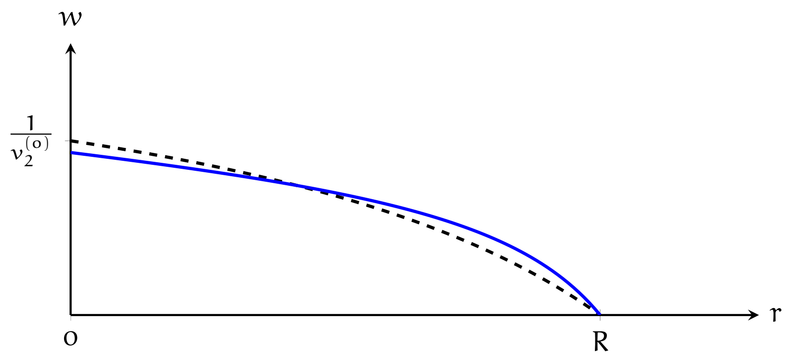

Figure 4.5: A 'labour-using' new technique that is an innovation for a certain range of $r < R$.

consumption per head must fall, since the latter inequality condition is always true for non-negative production coefficients. Only in the special case, in which the new industry operates a fully automated producer method, i.e. $l_3 = 0$, consumption per head would remain at the old circular flow level.

APPENDIX C: 'SECOND-ORDER SHIFTS' IN THE CONSTRUCTION PERIOD

Assume that innovators withdraw resources for 'new investment' from some existing use which provokes an additional 'second-order' shift, which keeps real consumption per head at its old circular flow level. That is, the production of good 2 is endogenously determined by the initial shift towards the new intermediate product and the thereby caused change in employment.

The assumptions of full utilisation and of a constant real consumption per head ($\Delta c^{(o)} = 0$) in period -1 requires that

$$a_{31}\Delta x_3 = -a_{11}\Delta x_1 - a_{21}^{(o)}\Delta x_2^{(o)}, \tag{4.19a}$$

$$\Delta x_2^{(o)} = c^{(o)}\Delta L, \tag{4.19b}$$

where $\Delta L = l_1\Delta x_1 + l_2^{(o)}\Delta x_2^{(o)} + l_3\Delta x_3$. A constant real consumption per head means that the change in production of good 2, i.e. $\Delta x_2^{(o)}$ is now determined by the change in employment, which is ΔL, and not by some exogenous withdrawal shares as above. Rather, if the shift towards the new good increases employment, production is supposed to increase accordingly by an additional shift of existing means from the old industry 1 to the old industry 2.

In this case, the change in the size of the two old industries is given by

$$\Delta x_1 = -\underbrace{\left(\frac{v_3 a_{11}}{v_1 a_{31}}\right)}_{=\hat{\alpha}}\frac{a_{31}\Delta x_3}{a_{11}}, \tag{4.20a}$$

$$\Delta x_2^{(o)} = c^{(o)}\Delta L = \underbrace{\frac{a_{11}}{v_1}\left(\frac{l_3}{a_{31}} - \frac{l_1}{a_{11}}\right)}_{=-(1-\hat{\alpha})}\frac{a_{31}\Delta x_3}{a_{21}}. \tag{4.20b}$$

Compared with the case above (see equations 4.10a and 4.10b), the withdrawal shares $\hat{\alpha}$ are now endogenously determined and depend on the production coefficients of the methods that produce the two capital goods: (1) If the new producer method has a higher labour intensity compared to the method of industry 1, employment increases and production of good 2 increases accordingly. The additional means to do so necessarily come from industry 1 which therefore shrinks faster than compared to the above case, such that in this case $\hat{\alpha} > 1$. (2) If the shift of resources decreases employment (which is the case if the new producer method has a lower labour intensity compared to the method of industry 1), industry 2 shrinks, i.e. $\hat{\alpha} < 1$, and means of production are shifted from old industry 2 to old industry 1. This second-order shift has the effect that indirectly both old industries decrease because of the construction of the new good.

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