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Diffusion of a new intermediate product in a simple ‘classical-Schumpeterian’ model

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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.

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 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 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 concludes.

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.

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

$$\begin{aligned} p_1^{(o)} &= p_1^{(o)} a_{11} + w^{(o)} l_1, \\ 1 &= p_1^{(o)} a_{21}^{(o)} + w^{(o)} l_2^{(o)}, \end{aligned} \tag{2.1}$$

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:

$$\begin{aligned} p_1^{(o)} &= v_1 w^{(o)}, \\ 1 &= v_2^{(o)} w^{(o)}, \end{aligned} \tag{2.2}$$

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:

$$\begin{aligned} x_1 &= a_{11} x_1 + a_{21}^{(o)} x_2^{(o)}, \\ x_2^{(o)} &= w^{(o)} \left[l_1 x_1 + l_2^{(o)} x_2^{(o)} \right]. \end{aligned} \tag{2.3}$$

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.

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

$$\begin{aligned} p_1^{(n)} &= p_1^{(n)} a_{11} + w^{(n)} l_1, \\ 1 &= p_3^{(n)} a_{23}^{(n)} + w^{(n)} l_2^{(n)}, \\ p_3^{(n)} &= p_1^{(n)} a_{31} + w^{(n)} l_3, \end{aligned} \tag{2.4}$$

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

$$\begin{aligned} p_1^{(n)} &= v_1 w^{(n)}, \\ 1 &= v_2^{(n)} w^{(n)}, \\ p_3^{(n)} &= v_3 w^{(n)}. \end{aligned} \tag{2.5}$$

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

$$\begin{aligned} x_1 &= a_{11} x_1 + a_{31} x_3, \\ x_2^{(n)} &= w^{(n)} \left[l_1 x_1 + l_2^{(n)} x_2^{(n)} + l_3 x_3 \right], \\ x_3 &= a_{23}^{(n)} x_2^{(n)}. \end{aligned} \tag{2.6}$$

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.

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.[1]

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

$$p_3 \geq a_{31}p_1^{(o)} + w^{(o)}l_3, \tag{2.7a}$$

$$p_1^{(o)}a_{21}^{(o)} + w^{(o)}l_2^{(o)} \geq p_3a_{23}^{(n)} + w^{(o)}l_2^{(n)}. \tag{2.7b}$$

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 (2.7a), and at the same time low enough such that users of the new good incur no extra costs (2.7b).

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.

[1] 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.

Which case applies can be shown to depend on the technical characteristics of the two alternative techniques: Combining the two conditions (2.7a) and (2.7b) shows that the new intermediate product is 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 2.2) 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:

$$\underline{p}_3 < \overline{p}_3 \iff v_2^{(o)} > v_2^{(n)}. \tag{2.8}$$

In the context of the *choice-of-technique* problem (see Kurz and Salvadori 1995, chap. 5) this finding is not very surprising: From condition (2.8) 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 (2.8).

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 A on page 22 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.

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.

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.[2]

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] This set of assumptions helps us to spot certain long-period forces of structural transformation.

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.

[2] 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)

[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 (2016).

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 exact 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. The pre-innovation situation is this:

$$\overline{x}_1 = a_{11}\overline{x}_1 + a_{21}^{(o)}\overline{x}_2^{(o)}, \tag{3.1a}$$

$$\overline{x}_2^{(o)} = c^{(o)}\overline{L}, \tag{3.1b}$$

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

Shift of existing means: 'New' investment and 'withdrawal' 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, $\overline{x}_1$, 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 $\overline{x}_i$.

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

$$\Delta x_1 = -\alpha \frac{a_{31}\Delta x_3}{a_{11}}, \tag{3.2a}$$

$$\Delta x_2^{(o)} = -\left(1-\alpha\right) \frac{a_{31}\Delta x_3}{a_{21}^{(o)}}, \tag{3.2b}$$

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 $0 \leq \alpha \leq 1$, 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 changes the employment structure and may thus affect total employment. The net employment effect, which is the sum of job destruction

[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)

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 (3.2a) and (3.2b) 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:

$$\frac{\Delta L}{a_{31} \Delta x_3} = \alpha \left(\frac{l_3}{a_{31}} - \frac{l_1}{a_{11}} \right) + (1 - \alpha) \left(\frac{l_3}{a_{31}} - \frac{l_2^{(o)}}{a_{21}^{(o)}} \right). \tag{3.3}$$

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

$$\overline{x}_2^{(o)} + \Delta x_2^{(o)} = \left(c^{(o)} + \Delta c \right) \left(\overline{L} + \Delta L \right), \tag{3.4}$$

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 B). 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 2016), 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.

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 with-

[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).

drawal 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 C 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.

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.

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

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

$$(1+g_3) = \frac{x_{3,t}^{(n)}}{x_{3,t-1}^{(n)}} = \frac{x_{2,t}^{(n)}}{x_{2,t-1}^{(n)}} = \frac{x_{1,t}^{(n)}}{x_{1,t-1}^{(n)}} = \frac{L_t^{(n)}}{L_{t-1}^{(n)}}, \tag{3.5}$$

where $L_t^{(n)}$ denotes total employment of the new system of production in period t, given by $L_t^{(n)} = l_1 x_{1,t}^{(n)} + l_2^{(n)} x_{2,t}^{(n)} + l_3 x_{3,t}^{(n)}$. Because of the assumption of full utilisation, the production links between the three components of the new SoP imposed by its technique imply that

$$\begin{aligned} x_{1,t-1}^{(n)} &= (1+g_3)\left(a_{11}x_{1,t-1}^{(n)} + a_{31}x_{3,t-1}^{(n)}\right), \\ x_{3,t-1}^{(n)} &= a_{23}^{(n)} x_{2,t}^{(n)}, \end{aligned} \tag{3.6}$$

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. 3.5) and is 'well-proportioned' in the sense that the new SoP is able to sustain a self-sustained growth path (eq. 3.6). 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.

[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.

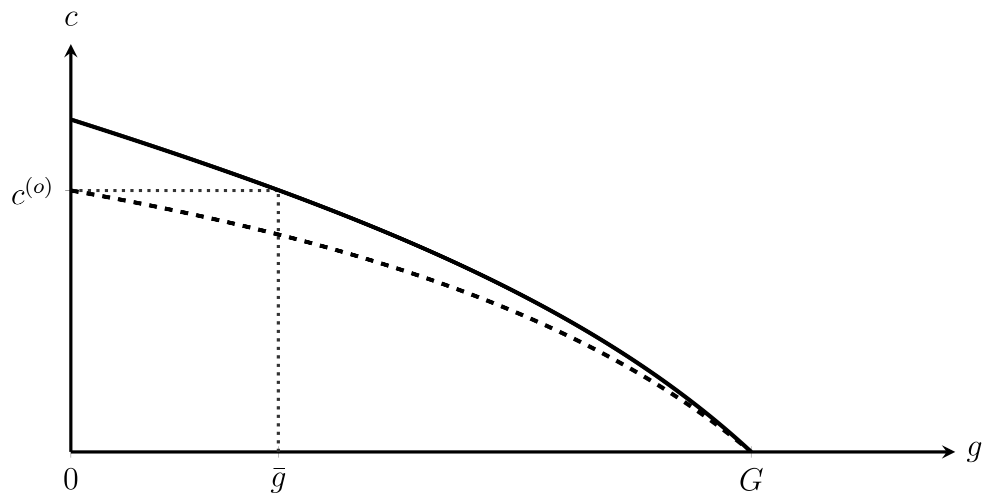


Figure 1: Illustration of consumption-growth curves for the old system of production (dashed line) and the new system of production (solid line).

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 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 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.

Differential growth of techniques: Employment dynamics Total employment in the economy as a whole is given by $L_t = L_t^{(n)} + L_t^{(o)}$. 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.

[7]The numerical values are those of the first example discussed in appendix A.

Because the old system exhibits zero growth and the new one grows at rate g_3, employment expands at rate

$$\frac{L_t - L_{t-1}}{L_{t-1}} = g_3 \frac{L_{t-1}^{(n)}}{L_{t-1}}, \tag{3.7}$$

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 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

[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.

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:

$$c_t = \frac{x_{2,t}}{L_t} = \frac{x_{2,t}^{(o)}}{L_t^{(o)}} \frac{L_t^{(o)}}{L_t} + \frac{x_{2,t}^{(n)}}{L_t^{(n)}} \frac{L_t^{(n)}}{L_t} = c^{(o)} + \frac{L_t^{(n)}}{L_t} \left(c^{(n)} - c^{(o)} \right). \tag{3.8}$$

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 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').

[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.

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 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 equi-proportional 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 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 (2.8) 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 $0 \leq r < R$, 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 $r = R$.

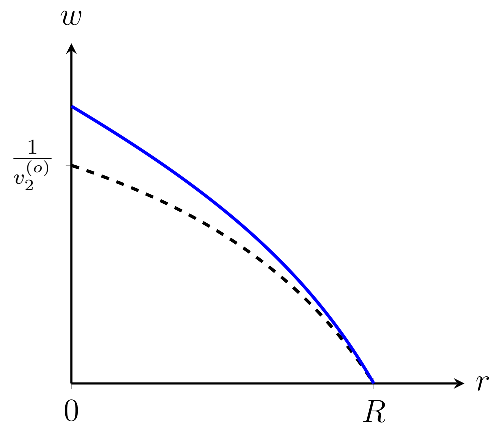
Since the two techniques use different methods to produce the common nonbasic good, i.e the consumption good, indexed by 2, they can exhibit different maximum wage rates, which are given by the respective inverses of quantities of labour embodied in one unit of the consumption good. We shall call a new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

Figure 2a 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 $0 \leq r < R$ given the old technique. Figure 2b 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.

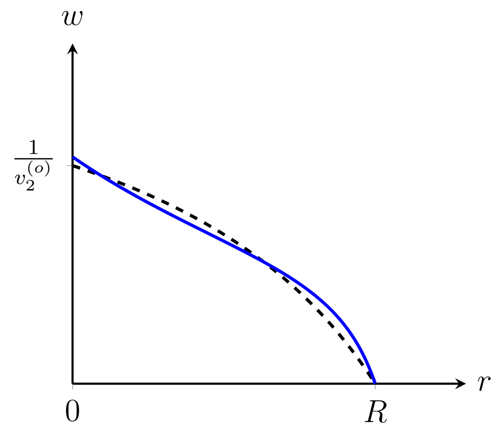
Figure 2c shows a 'labour-neutral' new technique which has three switches, including one at $r = 0$ since $v_2^{(n)} = v_2^{(o)}$. Nonetheless, it is an innovation if r lies above a certain level (but below R); this example indicates that the relative curvature of the two wage-profit curves play a role in certain circumstances. As figure 2d 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 $v_2^{(n)} < v_2^{(o)}$ is not a *necessary* condition for the new technique to be strictly economically viable in general.

Appendix B Construction: 'Forced saving'

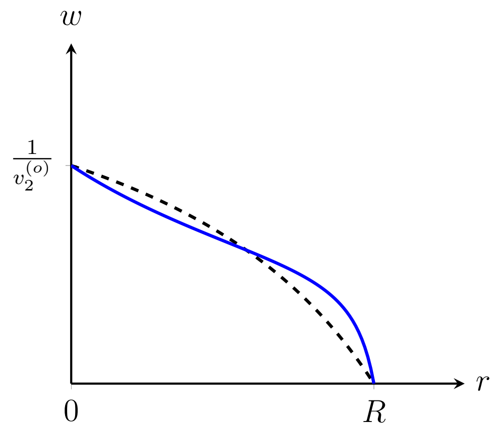
We here consider the question of 'forced savings', which we define as a situation where means of production are shifted towards the construction of a new capital good with the effect that consumption per head falls. It is shown that if the withdrawal of resources reduces the output of the consumption good industry



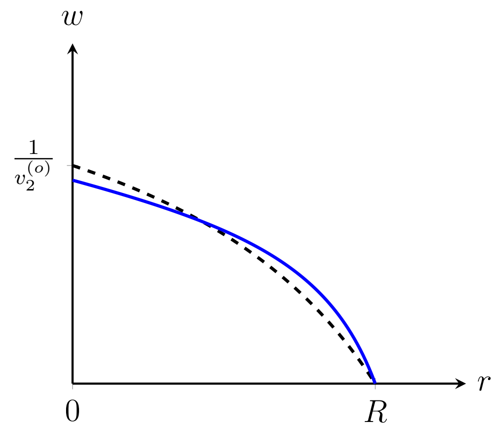
(a) A labour-saving new technique that is an innovation for $r < R$.



(b) A labour-saving new technique that is an innovation for certain ranges of $r < R$.



(c) A 'labour-neutral' new technique that is an innovation for a certain range of $r < R$.



(d) A 'labour-using' new technique that is an innovation for a certain range of $r < R$.

Figure 2: 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. 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 2a, $(a_{31}, l_3) = (0.45, 1.75)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.60, 2.50)$; for 2b, $(a_{31}, l_3) = (0.10, 2.30)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (1.60, 1.00)$; for 2c, $(a_{31}, l_3) = (0.10, 5.00)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.85, 0.78)$; for 2c, $(a_{31}, l_3) = (0.25, 1.75)$ and $(a_{23}^{(n)}, l_2^{(n)}) = (0.70, 4.00)$.

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 (3.2b) the change in production of good 2 is

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

and, according to equation (3.3), the change in employment is determined by

$$\Delta L = \underbrace{l_2^{(o)} \Delta x_2^{(o)}}_{\text{job destruction}} + \underbrace{l_3 \Delta x_3}_{\text{job creation}} = \left(\frac{l_3}{a_{31}} - \frac{l_2^{(o)}}{a_{21}^{(o)}} \right) a_{31} \Delta x_3. \tag{B.2}$$

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 (3.4) 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 (B.1) and (B.2) 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:

$$\Delta c < 0 \iff \frac{\Delta L}{\Delta x_2} < \frac{1}{c^{(o)}} \iff -\frac{l_3}{a_{31}} < v_1.$$

This shows that if all the means of innovators are withdrawn from resources of existing producers of the consumption good industry, 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 Construction: 'Second-order shifts'

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

$$a_{31}\Delta x_3 = -a_{11}\Delta x_1 - a_{21}^{(o)}\Delta x_2^{(o)}, \tag{C.1a}$$

$$\Delta x_2^{(o)} = c^{(o)}\Delta L, \tag{C.1b}$$

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

$$\Delta x_1 = -\underbrace{\left(\frac{v_3 a_{11}}{v_1 a_{31}}\right)}_{=\hat{\alpha}} \frac{a_{31}\Delta x_3}{a_{11}}, \tag{C.2a}$$

$$\Delta x_2^{(o)} = c^{(o)}\Delta L = \underbrace{\frac{a_{11}}{v_1}\left(\frac{l_3}{a_{31}} - \frac{l_1}{a_{11}}\right)}_{=-(1-\hat{\alpha})} \frac{a_{31}\Delta x_3}{a_{21}}. \tag{C.2b}$$

Compared with the case above (see equations 3.2a and 3.2b), 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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