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Technical Change, Consumption and Time Use: The Employment Effect of Innovations when Consumption takes Time

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Abstract

The paper studies the long-term employment effect of innovations in a model where consumption takes time. It takes into account both the time required to produce goods and the time required to consume them by treating bundles of goods and time as inputs into consumption activities. By means of the long-period method some implications of the consumption-time problem for the innovation-employment nexus are derived. Key results include: (1) Because consumption time and work exhaust available time, new consumption activities necessarily displace existing ones. As the mix of activities changes, so does the composition of demand for goods and hence employment. (2) Therefore, a new product increases employment only if the corresponding new activity consumes a bundle of goods per unit of time which embodies more labour than the bundles of displaced activities; the 'labour intensity' of an activity is here determined by the vertically hyper-integrated labour productivity of the goods involved and, crucially, also by the rates at which they are consumed. (3) Productivity-enhancing new production methods lower employment and increase consumption. Under certain circumstances, however, some profitable innovations decrease labour productivity and hence are 'labour-friendly'. (4) Labour displaced by productivity-enhancing technical change cannot be expected to be fully compensated via more consumption or via more growth. In fact, if consumption takes time, only structural shifts towards more labour-intensive activities via new products can achieve a full compensation of displaced labour.

1 INTRODUCTION

The current wave of technological changes and automation has revived the debate on the possible employment consequences of innovations (Kurz et al. 2018). The question of 'technological unemployment' dates back to David Ricardo's famous chapter 'On Machinery' in 1821 (Ricardo 1951) and is usually discussed in terms of the balance between labour displacement effects and various compensation effects (Vivarelli 2014, Calvino and Virgillito 2017).

This paper adds to this literature by dealing with the long-term employment effect of innovations in a model where consumption takes time and available time is limited. It takes into account both the time to produce goods and the time to consume them by treating bundles of goods and time as inputs into consumption activities. It aims at clarifying the conditions under which innovations do or do not reduce employment when consumption takes time. In addition, some light is shed on the labour-displacement and the various compensation effects involved for selected types of process and product innovations.

The fact that every consumption activity requires time to perform plays some role in consumer theory (most notably, see Steedman 2001), but is put on one side in models dealing with growth and innovations. This paper fills this gap by studying the implications of the consumption-time problem for the innovation-employment nexus by means of the long-period method (Sraffa, 1960; Garegnani, 1976; Kurz and Salvadori, 1995).

In the model it is assumed, that the economy is closed, that produced goods are fully utilized, and that the economy is *fully commercialised*, meaning that consumption time and work exhaust available time. As we focus on consumption and employment per head of population, we implicitly assume representative agents. For simplicity, we put the problem of durable goods on one side. Another central assumption of our model is that the rates of consumption are taken to be fixed, as in activity models of Steedman (2001) and others; in the standard consumption-leisure model, a linear relationship between consumption quantities and consumption time, or leisure time, would result from maximizing a Leontief-type utility function, where goods and leisure time are treated as perfect complements. In our discussion, the assumption of fixed consumption rates helps us to disentangle proportional changes in activity levels from shifts in the mix of activities. The latter is shown to play an important role for the employment effect of innovations.

The upshot of this paper is this: If consumption takes time, labour displaced by productivity-enhancing technical change cannot be expected to be fully compensated via *more consumption* or via *more growth*. In fact, only shifts towards more 'labour-intensive' activities caused by *new products* can achieve a full compensation of labour displacement. However, new products are not labour-friendly per se: Because time is limited, new activities necessarily displace existing ones such that most types of new products reduce the demand for existing products.

The rest of the paper is organized as follows. In section 2 we start with a simple 'time accounting' exercise in order to clarify the relationship between consumption activities and employment. Then, in section 3, the sign and the composition of the net employment effect of different innovations are discussed. Section 4 summarizes key results and provides an outlook.

2 Consumption Activities and Employment

We begin with a simple 'time accounting' exercise to illustrate the relation between the mix of consumption activities and work for an economy as a whole.

Table 1 shows the amounts of goods consumed and the amounts of time spent in three available activities. In total, activity $j = 1,2,3$ is performed for T_j units of time, during which B_{ji} units of good $i = 2,3$ are consumed. Activities 1 and 2 are consumption activities, activity 3 is called a 'pure' leisure activity because it requires only time as an input.

	Quantities consumed		
	Product 2	Product 3	Length of time
Activity 1	B_{12}	B_{13}	T_1
Activity 2	B_{22}	B_{23}	T_2
Activity 3	0	0	T_3

In activity j one consumes $b_{ji} = B_{ji}/T_j$ units of good i per unit of time. We refer to b_{ji} as the rate of consumption and to its reciprocal value, which is $t_{ji} = 1/b_{ji}$, as the consumption-time coefficient of good i in activity j, i.e. the amount of time required to consume one unit of good i in activity j. For simplicity, we assume hereinafter that the rates of consumption are given and fixed. We obtain table 2.

	Rates of consumption		
	Product 2	Product 3	Length of time
Activity 1	$b_{12} = B_{12}/T_1$	b_{13}	1
Activity 2	$b_{22} = B_{22}/T_2$	b_{23}	1
Activity 3	0	0	1

The production of b_{ji} units of good i requires b_{ji}/λ_i units of direct and indirect labour (work time), where λ_i denotes the vertically *hyper-integrated* labour productivity. Its reciprocal value, the vertically hyper-integrated labour coefficient, denotes the amount of labour necessary to produce one unit of good i, to replace the means of production, and, additionally, to produce the amount of means necessary to expand production at the given rate of growth (see Kurz and Salvadori 1995, chap. 6; Pasinetti 1988). We obtain table 3.

	Direct and indirect labour		
	Product 2	Product 3	Length of time
Activity 1	$h_{12} = \frac{b_{12}}{\lambda_2}$	$h_{13} = \frac{b_{13}}{\lambda_3}$	1
Activity 2	$h_{22} = \frac{b_{22}}{\lambda_2}$	$h_{23} = \frac{b_{23}}{\lambda_3}$	1
Activity 3	0	0	1

The bundle of goods consumed per unit of time in activity j hence contains $h_j = \sum_{i=1}^{2} h_{ji}$ units of labour. Put differently, h_j units of work are needed to provide the means to perform one unit of activity j. Including work time gives table 4.

	Work Time	Consumption Time	Sum
Activity 1	$h_1 = h_{12} + h_{13}$	1	$1 + h_1$
Activity 2	$h_2 = h_{22} + h_{23}$	1	$1 + h_2$
Activity 3	0	1	1

Because the time constraint is an identity, the sum of labour time and consumption time must be equal to available time. Let N be the number of people and T the time available per person and per period. Aggregate available time then is given by $N * T$. The individual "time budget", T, is fixed, because time can neither be stored nor discarded. Hereinafter, N is given and T is normalized to one. We also assume that the economy is closed and that produced goods are fully utilised. It follows: (1) Available activities are alternative ways to spend time: more time to one activity implies less time in other activities. (2) The time use pattern of a society in terms of the average labour time and average consumption time depends on the activities performed.

To illustrate this, we look at three cases: In case 1 only consumption activity 1 is used, in case 2 only activity 2 and in case 3 only activity 3. Table 5 shows the amounts of work time and of consumption time per head of population for each case.

	Work Time (Per-Capita Employment)	Consumption Time	Time Budget
Case 1: Only activity 1	$\frac{h_1}{1+h_1}$	$\frac{1}{1+h_1}$	1
Case 2: Only activity 2	$\frac{h_2}{1+h_2}$	$\frac{1}{1+h_2}$	1
Case 3: Only activity 3	0	1	1

In case 3 employment per head is zero, because the 'pure' leisure activity does not require goods as inputs. Consequently, final demand is zero. If consumption activity 1 replaces the pure leisure activity, employment per head increases, since $h_1 > 0$. And if consumption activity 2 replaces activity 1, employment per head increases only if h_2 is greater than h_1.

It follows: If the time devoted to consumption and work exhaust available time, new consumption activities necessarily displace existing ones. As the mix of activities changes, so does the composition of final demand and employment. A new product therefore increases employment only if the corresponding new activity consumes a bundle of goods which requires more labour to produce than the bundles of displaced activities; the 'labour intensity' of an activity here is determined by the vertically hyper-integrated labour productivity of the goods involved and, crucially, also by the rate at which they are consumed.

In the remainder of this paper we develop and sharpen this intuition by studying the employment effect of different types of innovations.

3 EMPLOYMENT EFFECTS OF INNOVATIONS IN A FULLY COMMERCIALISED ECONOMY

We study the long-run employment effect of innovations in a simple model by means of the long-period method (Garegnani, 1976; Kurz and Salvadori, 1995). Throughout, we assume a closed economy, in which produced goods are fully utilized and available time is exhausted by work and consumption. To simplify our analysis, the problem of durable means of production and of consumption are put on one side. Instead, we focus on the determinants of the net employment effect of different types of innovations and shed some light on the labour-displacing and compensating effects involved.

3.1 STATIONARY CIRCULAR-FLOW WITH ONE PRODUCT AND ONE ACTIVITY

We begin with the case of a stationary circular-flow economy. In such an economy the profit rate is zero and the growth rate is zero (Schumpeter 1934).

In our economy, one capital good (good 1) and one consumption product (good 2) are produced. Both goods are produced by means of the capital good and one quality of labour under constant returns to scale. The quantity system of our circular-flow economy is given by

$$Y_1 = a_1 Y_1 + a_2 Y_2,$$

$$Y_2 = C,$$

where Y_i denotes the production and a_i the capital coefficient of good $i = 1,2$. Final consumption of good 2 is denoted by C. The economy is assumed to produce a surplus ($a_1 < 1$).

We also assume that population is constant and that the economy is *fully commercialised*, meaning that work and consumption time exhaust available time. The time constraint, which is an identity, is given by

$$NT = L + T_C,$$

where N denotes the number of persons in the economy and T denotes the amount of time per person and per period. Employment L (total working hours) is given by $L = l_1 Y_1 + l_2 Y_2$, where l_i denotes the labour coefficient for good i. Pure consumption time T_C is assumed to be proportional to quantity consumed: $T_C = t_c * C$, where the consumption-time coefficient t_c denotes the time required to consume one unit of good 2.

The quantities Y_1, Y_2 and C are determined for given values of N and T, a given production technique (a_1, l_1, a_2, l_2) and a given consumption activity, i.e. a given value of t_C.

In the following we look at per-capita quantities instead of aggregate quantities. Let $c = C/N$ denote consumption and $h = L/N$ employment per head of population. From the quantity system we obtain that

$$c = \frac{C}{N} = \frac{C}{L} * \frac{L}{N} = \lambda * h, \tag{1}$$

where λ denotes the vertically integrated labour productivity.[1] By normalising T to one, the time constraint can be re-written as

$$1 = h + t_c * c. \tag{2}$$

From equations (1) and (2) we obtain that

$$c^* = \frac{\lambda}{1 + t_c * \lambda},$$
$$h^* = \frac{1}{1 + t_c * \lambda},$$

where the term $t_c * \lambda$ indicates the consumption time per unit of work, i.e. the amount of time required to consume the quantity of good 2 produced by one unit of labour.

Figure 1 illustrates the two equations: The line that slopes upwards shows the proportional relationship between consumption and employment for a given production technique (equation 1): For a given level of labour productivity, more consumption requires more work. The line that slopes downwards describes the time constraint for the given consumption activity (equation 2). It passes through the point $(0|1)$ and has a negative slope because of the trade-off between work and consumption time. Clearly, only in the point of intersection the economy is fully commercialised, i.e. there is no "idle" time, and production is fully utilized.

[1] The vertically integrated labour productivity is given by

$$\lambda = \frac{C}{L} = \frac{Y_2}{L} = \frac{1}{l_2 + l_1 * Y_1^2} = \frac{1 - a_1}{l_1 a_2 + (1 - a_1) l_2}.$$

Its reciprocal value is known as the vertically integrated labour coefficient. It denotes the amount of direct and indirect labour required to produce one unit of good 2. One unit of good 2 is produced with l_2 units of direct labour and $l_1 * Y_1^2$ units of indirect labour, where Y_1^2 denotes the gross product of good 1 per unit of good 2. Indirect labour hence is required to replace the amount of means of production used up in the production process (see Kurz and Salvadori 1995, chap. 6).

Now, technical changes, which alter labour productivity, the consumption-time coefficient or both can be expected to cause a shift in time use. Most importantly, superior methods of

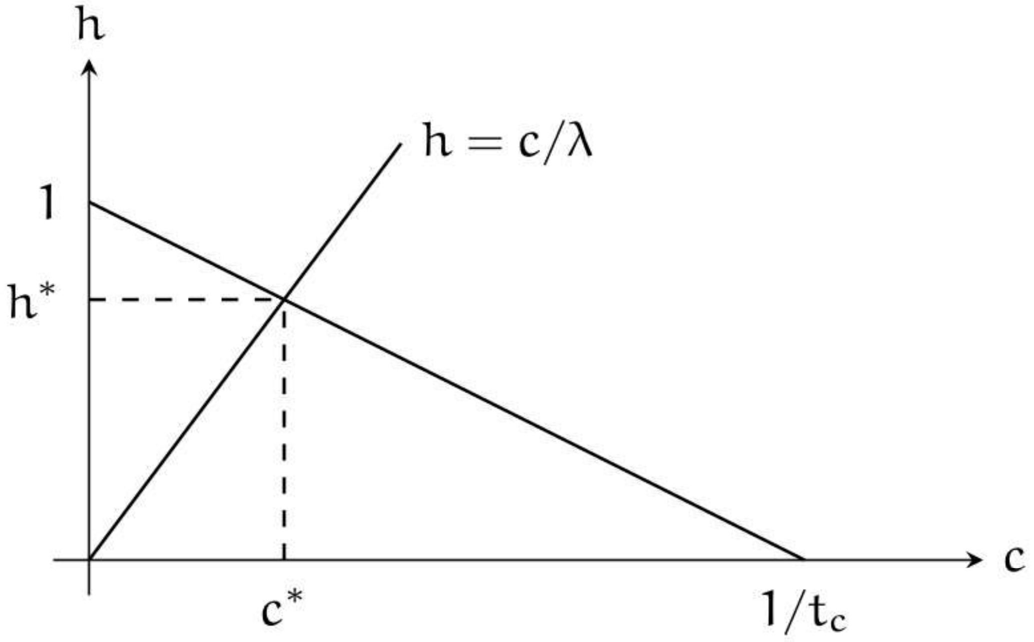

Figure 1: Simultaneous determination of consumption per head and employment per head of population for a given production technique and a given consumption activity.

production which increase labour productivity reduce work time and increase consumption for a given consumption-time coefficient. Put differently, productivity-enhancing innovations displace labour, but real income and consumption increases.

Figure 2 illustrates this point. Initially, the economy is situated at point $o = (c^o|h^o)$. Then, the innovation lowers the slope of the 'productivity line' by increasing productivity from λ^o to λ^n, and brings the economy to point $n = (c^n|h^n)$. The net employment effect is the sum of the negative labour-displacement effect (F) and the positive compensation effect (K): The displacement of labour is caused by the fact that the new technique requires less labour to produce the quantity consumed in the old long-period position (arrow F). But, as time is "freed up" in production, there is room to increase consumption and hence employment (arrow K). However, the net effect, $F + K$, is always negative: Since part of the time saved in production is spent in consuming more, displaced labour can only partly be re-absorbed.

Generally speaking, a full compensation of labour-displacing technical change requires a structural transformation of consumption in terms of the activities performed. In our example, where there is only one product, full compensation would require the adoption of a new activity which exhibits a higher rate of consumption and, consequently, a lower consumption-time

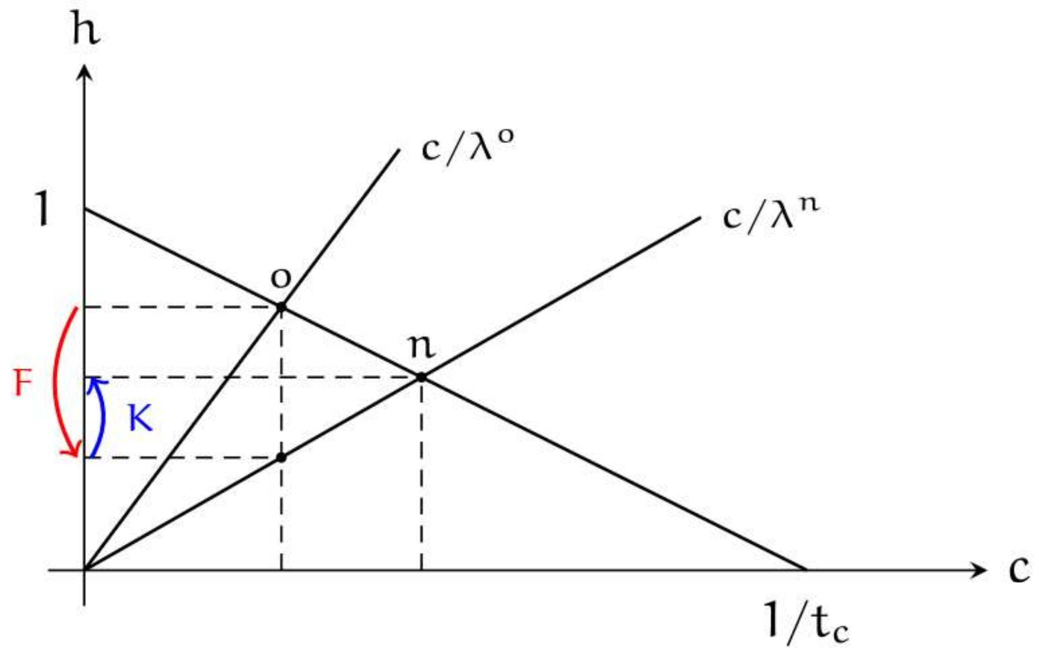

Figure 2: Labour-displacement effect (F) and compensation effect (K) of a productivity-enhancing innovation.

coefficient. Such a qualitative change in consumption behaviour would cause the time constraint to pivot outwards around its intercept with the h-axis. As a result, both consumption and employment would increase for a given level of labour productivity.

However, due to the problem of satiation, new products are perhaps a more important cause of structural shifts in consumption. Before we turn to the problem of product innovations, we incorporate growth into our model, which we then use to assess the labour-productivity effect of different types of profitable new methods of production.

3.2 Growth

Assume, that production and population grow at rate g. The quantity system can be written as

$$Y_1 = (1+g) * (a_1 Y_1 + a_2 Y_2),$$

$$Y_2 = C.$$

Gross production of good 1 per unit of the consumption good 2 therefore is given by

$$Y_1^2 = \frac{(1+g)a_2}{1-(1+g)a_1}.$$

The vertically *hyper-integrated* labour productivity now is given by

$$\lambda(g) = \frac{1}{l_2 + l_1 * Y_1^2} = \frac{1-(1+g)a_1}{(1+g)a_2 l_1 + [1-(1+g)a_1]l_2}.$$

The reciprocal value of it is the vertically *hyper-integrated* labour coefficient. It denotes the amount of direct and indirect labour required to produce one unit of good 2, to replace the means of production, and, additionally, to produce the amount of means necessary to expand production at rate g.

Consumption per head of population and employment per head of population then are given by

$$c^* = \frac{\lambda(g)}{1 + t_c * \lambda(g)}$$

$$h^* = \frac{1}{1 + t_c * \lambda(g)}$$

Our result is this: The higher the growth rate, the lower the vertically hyper-integrated labour productivity ($\lambda'(g) < 0$), because more labour is required to produce the additional means needed for growth. Hence, for a given production technique, a higher growth rate reduces consumption and increases employment per head of population. More growth could thus help to re-absorb labour displaced by technical change. To this end, however, the growth rate would have to increase permanently.

Notice, that our argument crucially rests on the assumption that production and population are growing at the same rate. In fact, if production is growing at rate g while population is growing at a different rate, say n, the time constraint of a fully commercialised and fully utilised closed economy is violated, unless the consumption-time coefficient adjusts accordingly. For example, $g > n$ would require a continuous shift towards activities which economize on consumption time.

3.3 Better methods, less employment?

Above, we have shown that technical change displaces labour, i.e. causes a fall in employment per head of population, if the vertically hyper-integrated productivity of labour increases. We here explore the question of whether every profitable innovation displaces labour or not. In order to isolate the employment effect, we assume a constant growth rate g (equal to n) and a constant profit rate, r.

Innovations are new methods of production which are able to pay extra profits. The price system of the old long-period position, identified by superscript 'o', is given by

$$p_1^o = (1+r)p_1^o * a_1^o + w^o * l_1^o,$$

$$1 = (1+r)p_1^o * a_2^o + w^o * l_2^o,$$

where r denotes the profit rate, w the real wage rate and p_1 the relative price of the capital good. A new method in the capital good industry is able to pay extra profits, if

$$p_1^o > (1+r)p_1^o * a_1^n + w^o * l_1^n,$$

where a_1^n denotes the capital coefficient and l_1^n denotes the labour coefficient of the new method. A new method in the consumption good industry is able to pay extra profits, if

$$1 > (1+r)p_1^o * a_2^n + w^o * l_2^n,$$

where a_2^n denotes the capital coefficient and l_2^n denotes the labour coefficient of the new method. Put differently, an innovation is able to pay extra profits, if the real wage rate in the new long-period position, w^n, is higher than the real wage rate in the old one, w^o, given the rate of profit (Kurz, 2008).

Above we have shown that employment per head of population increases, if the vertically hyper-integrated labour productivity in the new long period position, $\lambda^n(g)$, is lower than the productivity in the old long period position, $\lambda^o(g)$.

Profitable innovations, which increase employment thus satisfy two conditions:

$$w^n(r) > w^o(r)$$

$$\lambda^n(g) < \lambda^o(g)$$

Since the consumption good is taken as a numéraire, the wage-profit curve $w(r)$ and the consumption-growth curve $\lambda(g)$ for each technique have the same functional form. It follows that if $g = r$, the two inequalities are mutually exclusive, meaning that every profitable innovation displaces labour.

But if $g \neq r$, there are profitable new methods, which increase employment per head of population: For $g < r$, an innovation is 'labour-friendly', if two conditions are met: (1) the two techniques have a switch-point at $r = r^*$, at which the slope of the new wage-profit curve is smaller than the slope of the old wage-profit curve; (2) the ratio g/r is small enough such that $g < r^* < r$ (see Figure 3).

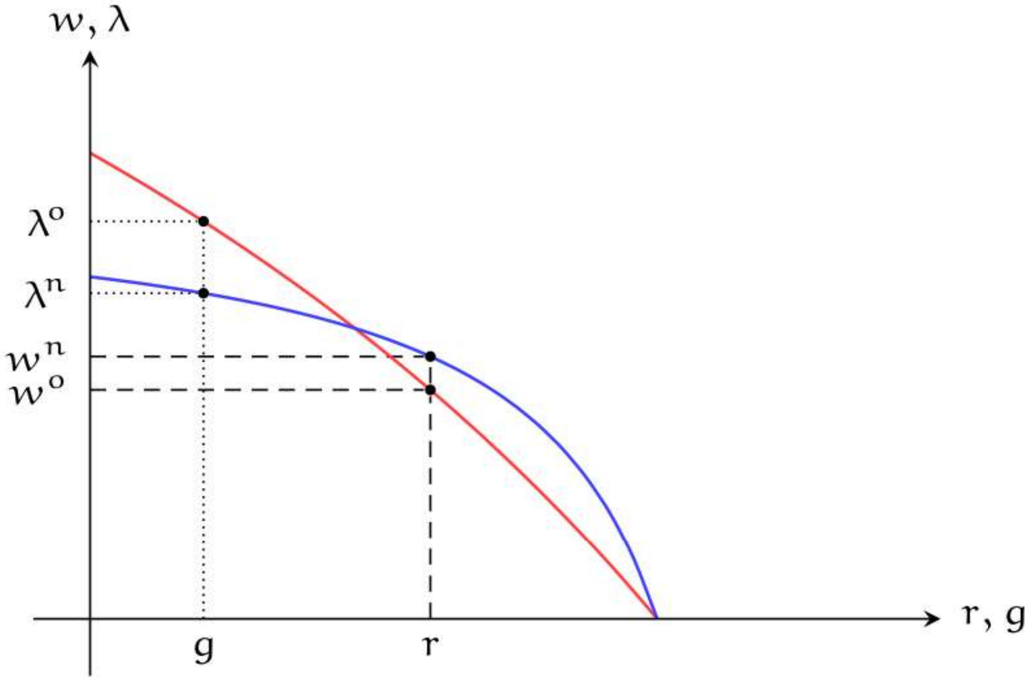

Figure 3: A new technique which is profitable at the given rate of profit (r) and labour-friendly for the given rate of growth (g).

We have shown that for a given rate of growth and a given rate of profit there exist 'labour-friendly' innovations. In order to shed some light on their properties, we look at the following categories of innovations: (1) the introduction of a new method of production, either in the consumption good industry or in the capital good industry aka *local improvements*; (2) the introduction of a new intermediate product aka *more roundabout production techniques*; (3) the elimination of existing intermediate products aka *disintermediation*; and (4) the adoption of new basic capital goods aka *radical transformation*.

Innovation in the consumption good industry

A new production method for the consumption good has been successfully developed. This method use l_2^n units of labour and a_2^n units of the existing capital good as inputs per unit of output.

The pure process innovation is profitable, if

$$l_2^n < \underbrace{l_2^o + \frac{(1+r)*a_2^o*l_1^o}{1-(1+r)*a_1^o}}_{d_A} - \underbrace{\frac{(1+r)*l_1^o}{1-(1+r)*a_1^o}}_{k_A} * a_2^n.$$

Its absorption into the economy increases employment, if

$$l_2^n > \underbrace{l_2^o + \frac{(1+g)*a_2^o*l_1^o}{1-(1+g)*a_1^o}}_{d_B} - \underbrace{\frac{(1+g)*l_1^o}{1-(1+g)*a_1^o}}_{k_B} * a_2^n.$$

Clearly, if $g = r$, then $d_B = d_A$ and $k_B = k_A$. The boundary lines of the two inequalities therefore are identical and the above two inequalities are mutually exclusive. Put differently, if $g = r$ all profitable innovations in the consumption good industry displace labour.

In contrast, if $g < r$, then $d_B < d_A$ and $k_B < k_A$. The two boundary lines then intersect at the point $(a_2^o|l_2^o)$. Therefore, profitable innovations exist which decrease the vertically hyper-integrated labour productivity at the given rate of growth and thereby increase employment per head of population.

For $g < r$, moreover, *all* labour-friendly innovations exhibit a larger labour coefficient and a smaller capital coefficient than the displaced method. Figure 4 illustrates this point. Here, the boundary lines of the above two conditions are drawn for a given old technique, a given profit rate and a given growth rate. Profitable new methods lie in the shaded region and those that are profitable and labour-friendly lie in the dotted region.

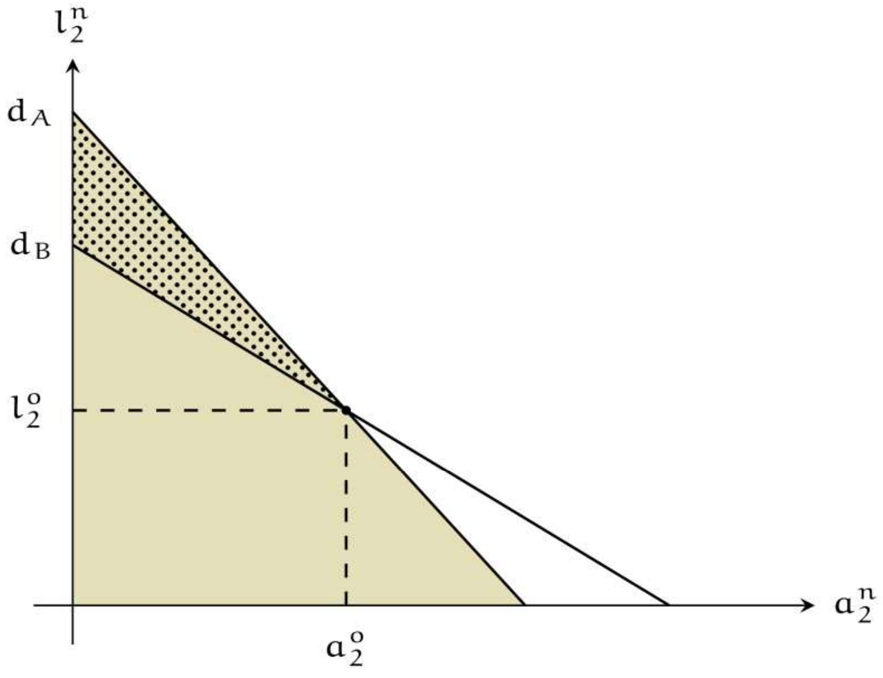

Figure 4: Labour-friendly innovations in the consumption good industry are capital-saving and labour-using if $g < r$.

Innovation in the capital good industry

A new production method for the capital good has been successfully developed. This method takes l_1^n units of labour and a_1^n units of the existing capital good as inputs per unit of output.[2]

The innovation is profitable, if

$$l_1^n < \underbrace{\frac{l_1^o}{1-(1+r)*a_1^o}}_{d_A} - \underbrace{\frac{(1+r)*l_1^o}{1-(1+r)*a_1^o}}_{k_A} * a_1^n.$$

Its absorption into the economy increases employment, if

$$l_1^n > \underbrace{\frac{l_1^o}{1-(1+g)*a_1^o}}_{d_B} - \underbrace{\frac{(1+g)*l_1^o}{1-(1+g)*a_1^o}}_{k_B} * a_1^n.$$

Again, if $g = r$, then $d_B = d_A$ and $k_B = k_A$, such that every profitable innovation displaces labour. If $g < r$, then $d_B < d_A$ and $k_B < k_A$ and the two boundary lines intersect at the point $(a_1^o | l_1^o)$. Therefore, there are profitable innovations which are labour-friendly. Also in the capital goods industry, profitable innovations which are labour-friendly exhibit a larger labour coefficient and a smaller capital coefficient than the method they replace.

In sum, all labour-friendly *local improvements* in one of the two industries are capital-saving, but labour-using.

A new intermediate product

A more roundabout production method for the consumption good has been successfully developed. It takes a new intermediate product (commodity 3) as an input, which in turn is produced by means of the existing capital good. The dimension of the system increases from two to three through the diffusion of the 'product-cum-process' innovation.

The quantity system of the new long-period position, identified by superscript 'n', can be written as

$$Y_1^n = (1+g)(a_1 Y_1^n + a_3^n Y_3^n),$$

$$Y_3^n = (1+g) a_{23}^n Y_2^n,$$

[2] For consistency, we confine our analysis to cases where $g < (1 - a_1^n)/a_1^n$.

$$Y_2^n = C^n.$$

Levels of gross production of good 1 and good 3 per unit of good 2 are given by

$$Y_1^{2\,n} = \frac{(1+g)^2 a_3^n a_{23}^n}{1-(1+g)a_1},$$

$$Y_3^{2\,n} = (1+g)a_{23}^n.$$

The vertically hyper-integrated labour productivity thus is given by

$$\lambda^n(g) = \frac{1}{l_2^n + l_3^n * Y_3^{2\,n} + l_1 * Y_1^{2\,n}}.$$

The price system of the new long-period position is given by

$$p_1^n = (1+r)p_1^n * a_1^o + w^n * l_1^o,$$

$$1 = (1+r)p_3^n * a_{23}^n * +w^n * l_2^n,$$

$$p_3^n = (1+r)p_1^n * a_3^n + w^n * l_3^n,$$

from which the new wage-profit curve can be derived. In the case of an intermediate product, both its production process and its use must be able to pay extra profits. Again, this is so only if $w^n(r) > w^o(r)$, since only then there is a price range $(\underline{p}_3\,,\overline{p}_3)$, for which the new intermediate product can be both profitably produced and profitably processed at the old wage rate w^o and the old relative price p_1^o.

Our results are:

(i) If $g = r$, the two boundary lines are identical, implying that every new intermediate product displaces labour.

(ii) If $g < r$, however, there are more roundabout methods of production, which are profitable and labour-friendly. In our example, the old and the new technique exhibit the same maximum rate of profit, R, and have in the range $0 \leq r < R$ not more than two switch-points (Bharadwaj 1970, 416-417). In the case of two switch-points, the slope of the new wage-profit curve in one of the two is necessarily smaller than the slope of the old wage-profit curve.

Elimination of an intermediate product

A *less* roundabout production method for the consumption product has been successfully developed. Contrary to the existing method, the new method takes the basic good (good 1) instead of the intermediate product (good 3) as an input. In our example, the 'disintermediation' reduces the dimension of the system, from three to two.

The innovation is profitable, if

$$l_2^n < \underbrace{\left(l_2^o + (1+r)a_{23}^o l_3^o + \frac{(1+r)^2 a_3^o a_{23}^o l_1^o}{1-(1+r)a_1^o}\right)}_{d_A} - \underbrace{\frac{(1+r)l_1^o}{1-(1+r)a_1^o}}_{k_A} a_2^n$$

The diffusion of the new method increases employment, if

$$l_2^n > \underbrace{\left(l_2^o + (1+g)a_{23}^o l_3^o + \frac{(1+g)^2 a_3^o a_{23}^o l_1^o}{1-(1+g)a_1^o}\right)}_{d_B} - \underbrace{\frac{(1+g)l_1^o}{1-(1+g)a_1^o}}_{k_B} a_2^n$$

Again, if $g = r$, then $d_B = d_A$ and $k_B = k_A$, such that profitable forms of disintermediation displace labour. However, if $g < r$, then $d_B < d_A$ and $k_B < k_A$ implying that the two boundary lines intersect in the first quadrant. Therefore, there are less roundabout production methods which are labour-friendly.

Radical transformation

So far, we have discussed innovations through which only one existing method is replaced. We now discuss an innovation that replaces both existing methods: A new basic capital good (good 3) has been successfully developed and supersedes the old capital good (good 1). Initially, the new capital good is produced by means of the old one, but later on it enters into its own production. At the same time, a new method is adopted in the consumption good industry, which uses the new capital good instead of the old one as an input. Through what may be considered a *radical transformation* of production, the dimension of the system increases initially, from two to three, and decreases as soon as the old capital good becomes obsolete.

The price system in the new long-period position can be written as

$$p_3^n = (1+r)p_3^n * a_3^n + w^n * l_3^n,$$

$$1 = (1+r)p_3^n * a_{23}^n + w^n * l_2^n.$$

Again, if $g = r$, the two boundary lines are identical, implying that every new basic capital good displaces labour. However, if $g < r$, there are new capital goods which are both profitable and labour-friendly. We illustrate this by means of an extreme case, in which the production of the new capital good is almost fully automated, i.e. l_3^n is almost zero (see Figure 5). Through its diffusion indirect labour disappears almost completely. Nevertheless, employment increases, if the corresponding production method in the consumption good industry requires sufficiently more direct labour compared to the old method.[3]

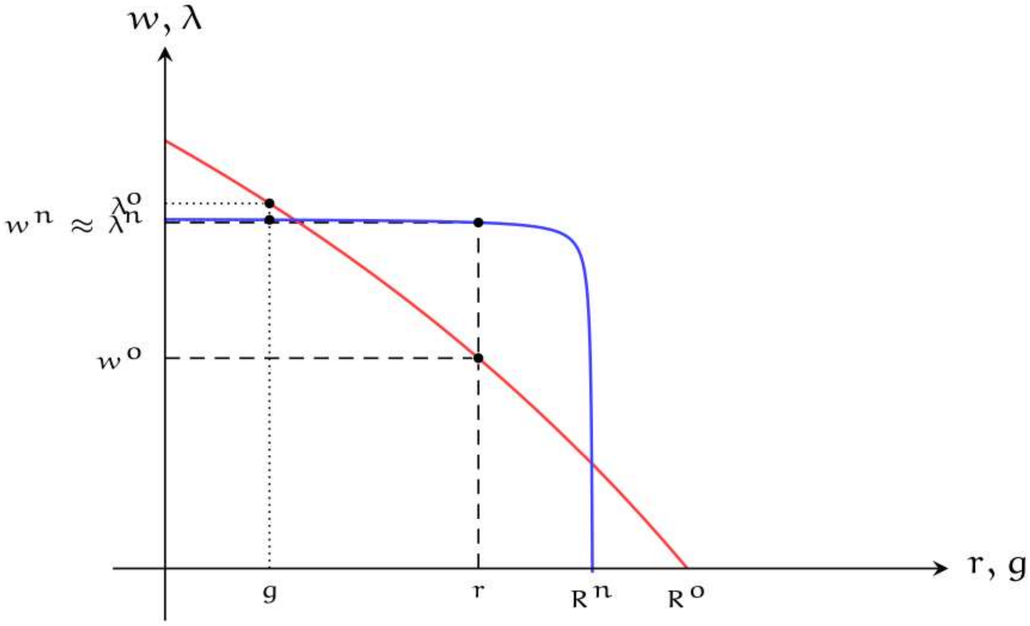

Figure 5: A labour-friendly new technique with an almost fully automated capital good.

Further results and questions

In summary, different forms of technical change have different effects on employment. For example, purely labour-saving technical change, through which the wage-profit curve pivots outwards around its intercept with the r-axis, reduces employment in the model at hand. However, there is no reason to presume that profitable innovations always displace labour. As shown above, under certain circumstances even almost fully automated new capital goods can increase employment.

[3] If the production of the new capital good is fully automated ($l_3^n = 0$), the price system of the new long-period position is given by

$$p_3^n = (1+r)p_3^n * a_3^n,$$
$$1 = (1+r)p_3^n * a_{23}^n + w^n * l_2^n.$$

In this case, the profit rate increases or decreases towards the new level, given by $r^n = R^n = (1 - a_3^n)/a_3^n$, while the new real wage rate is undetermined.

Labour-friendly innovations increase employment and decrease consumption per head of population. The profitability of an innovation depends on the rate of profit, its 'labour-friendliness' on the rate of growth. The smaller the ratio g/r, the greater the share of profitable innovations which are labour-friendly. Hence, labour-friendly innovations are 'more likely' to occur in stagnating economies, where g is almost zero and r is greater than zero.[4]

If $g < r$, the diffusion of labour-friendly innovations causes a fall in the capital intensity (per unit of labour employed), given by the ratio $k = (\lambda - w)/(r - g)$. If $w^n > w^o$ and $\lambda^n < \lambda^o$, it follows that

$$\frac{\lambda^n - w^n}{r - g} < \frac{\lambda^o - w^o}{r - g}.$$

Moreover, because $w^n > w^o$ and $k^n < k^o$, labour-friendly innovations may diminish real income per capita, y:

$$w^n > w^o$$

$$y^n - rk^n > y^o - rk^o$$

$$y^n > y^o + r * \underbrace{(k^n - k^o)}_{<0}.$$

3.4 New Products, more Employment?

Above it has been shown that the introduction and adoption of a new product by consumers increases employment per head of population only if the labour requirement for corresponding new activities is higher than for displaced activities. Here, we discuss this condition in greater detail by means of a simple typology of new products. In addition, we illustrate the labour displacement and compensation effects involved when product innovations shift consumption time towards new activities.

We will confine ourselves to cases, where the new product is a 'pure' consumption product and hence does not alter the production technique of existing goods. Additionally, it is assumed that the new product enables a single new consumption activity and that this new activity replaces the existing activity completely. These two assumptions simplify our analysis without affecting conclusions reached.

[4] Note that this result does not depend on the relative factor price ratio r/w.

Complementary, substitutive or both

We distinguish between three types of new products: (1) absolute substitutes, (2) relative substitutes, and (3) relative complements.

Table 6 provides a definition for each type of product innovation in terms of the rates of consumption, the b's, of the new activity, identified by superscript 'n'. The subscript refers to goods and the superscript refers to activities: The new product (good 3) is called an absolute substitute, if the new activity does not use the existing product (good 2) as an input. It is called a relative substitute, if the rate at which the existing product is consumed in the new activity is relatively smaller ($b_2^n < b_2^o$). And it is called a relative complement, if the rate at which the existing product is consumed in the new activity is equal or larger than in the old activity ($b_2^n \geq b_2^o$).

	Rates of consumption	
	'Old' Product 2	'New' Product 3
Old consumption activity	b_2^o	0
Absolute Substitute	0	b_3
Relative Substitute	$b_2^n < b_2^o$	b_3
Relative Complement	$b_2^n \geq b_2^o$	b_3

The new product increases employment per head of population, if the new activity consumes a bundle of goods per unit of time, which embodies more labour, directly and indirectly. We may express this condition either in terms of rates of consumption, the b's, or in terms of consumption-time coefficients, the t's:

$$h^n > h^o \Leftrightarrow \frac{b_2^n}{\lambda_2} + \frac{b_3^n}{\lambda_3} > \frac{b_2^o}{\lambda_2} \Leftrightarrow \frac{1}{t_2^n * \lambda_2} + \frac{1}{t_3^n * \lambda_3} > \frac{1}{t_2^o * \lambda_2} \tag{3}$$

where h^n (h^o) denotes employment per head of population in the new (old) long period position.

Absolute substitutes

For *labour-friendly* absolute substitutes, condition (3) reduces to

$$h^n > h^o \Leftrightarrow \frac{\lambda_2}{\lambda_3} > \frac{b_2^o}{b_3^n}.$$

Our results are:

(i) A new absolute substitute, which makes the existing product obsolete, can have a positive effect, a negative effect or no effect on employment. It has a positive effect, if consumption time per unit of labour is smaller for the new product than for the existing product:

$$h^n > h^o \iff t_3^n * \lambda_3 < t_2^o * \lambda_2$$

(ii) Figure 6 classifies absolute substitutes by their consumption-time coefficient and their labour productivity, relative to the existing product. Labour-friendly new absolute substitutes lie within the coloured region, which consists of the three areas A, B and C: If the new product (good 3) is time-saving ($t_3 < t_2$) and exhibits the lower productivity ($\lambda_3 < \lambda_2$), it is clearly labour-friendly. But also a substitute with a higher labour productivity increase employment, if it is sufficiently time-saving (area B). Instead, if the new good is time-intensive ($t_3 > t_2$), thus, in a certain sense output-saving, its diffusion increases employment only if its labour productivity is sufficiently small (area C).

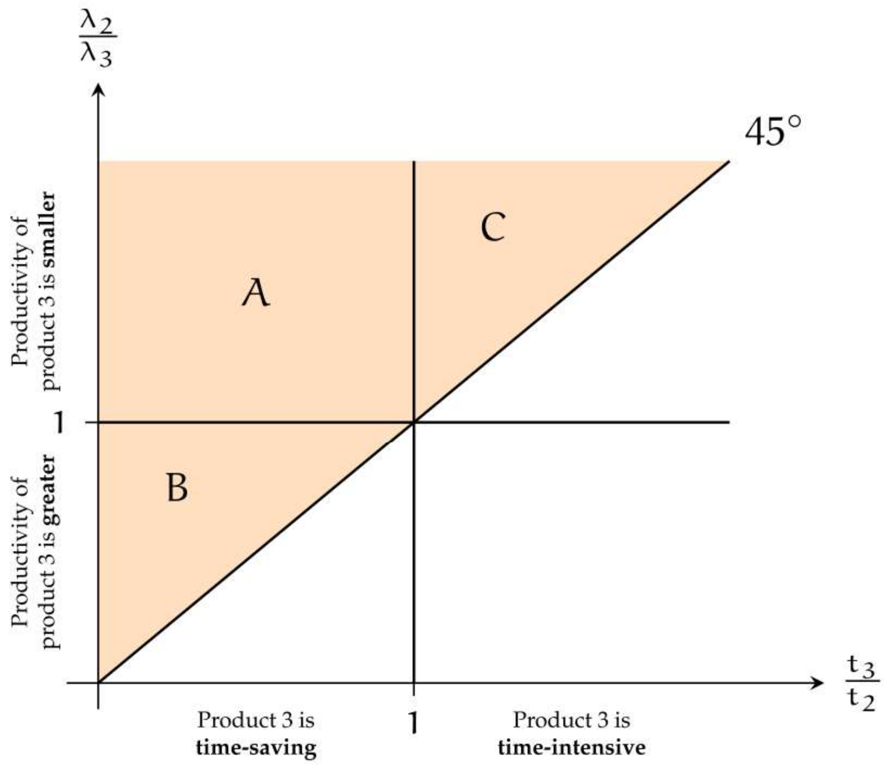

Figure 6: Absolute substitutes located in the coloured region increase employment per head of population.

(iii) The two vertically hyper-integrated labour productivities depend not only on the methods of production, but also on the rate of growth. Provided that $l_3/a_3 \neq l_2/a_2$, a change in the growth rate also changes the ratio of productivities. Therefore, it may be the case that for the lower growth rate the new product lies below the 45-degree line, but for the higher growth rate it lies above this line.

(iv) It is a well-established fact in diffusion theory that the diffusion of new products takes some time (see e.g. Rogers 2003); moreover, diffusion requires that the production of the new products grows faster than the production of the old product. Because of the growth differential of the two subsystems along the traverse, the ratio of labour productivities, λ_2/λ_3, is larger than compared to a steady state, where growth is uniform. Employment can therefore be expected to grow (or fall) non-monotonously, with ups and downs and with transient gains at the beginning. For example, if the long-term employment effect of the new product is zero (it locates on the 45-degree line of Figure 6), employment increases initially and then falls back to its former level. Or, if the long-term employment effect is negative (the new product lies in the region below the 45-degree line), employment may, in some circumstances, increase initially and decrease to the new, lower level at a later stage, when the old industry has disappeared and the new industry has lost momentum.

Relative Substitutes and complements

For *labour-friendly* relative substitutes and complements, condition (3) can be re-written as

$$h^n > h^o \Leftrightarrow \frac{\lambda_2}{\lambda_3} > \frac{b_2^o - b_2^n}{b_3^n}.$$

Our results are:

(i) Since $b_2^n \geq b_2^o$ for relative complements, the fraction on the right-hand side of the inequality is negative (or zero). Therefore, every new complement increases employment.

(ii) Since $b_2^n < b_2^o$ for relative substitutes, the fraction on the right-hand side of the inequality is positive. A new relative substitute therefore can have a positive effect, a negative effect or no effect on employment.

(iii) In contrast to absolute substitutes, relative substitutes increase employment per head even in some of the cases where the new product exhibits both a higher labour productivity and is more time-intense; graphically, the boundary line in Figure 6 is flatter for relative substitutes than for absolute substitutes.

In sum, structural changes in consumption can be expected to affect employment: (1) Even though new activities displace existing ones completely, existing products become obsolete only in the case of absolute substitutes. (2) Only for relative complements is the net employment effect always positive. For relative and absolute substitutes, the net employment effect can be positive, negative or zero, depending on the consumption-time coefficients and labour productivities of old and new subsystems.

Labour displacement and compensation via new products

We now turn our attention to the composition of the net employment effect in order to shed some light on the labour displacement and compensation effects triggered by product innovations. In doing so, we again compare two long-period positions for a given and constant growth rate g (equal to n). We will confine our analysis to two cases: new relative substitutes and complements.

In the new long-period position, one capital good (good 1), the existing 'old' consumption product (good 2) and the 'new' consumption product (good 3). All three goods are produced by means of the capital good and one quality of labour. The quantity system can be written as:

$$Y_1 = (1+g)(a_1 Y_1 + a_2 Y_2 + a_3 Y_3),$$

$$Y_2 = C_2,$$

$$Y_3 = C_3.$$

Gross production of good 1 per unit of good 2 is given by

$$Y_1^2 = \frac{(1+g)a_2}{1-(1+g)a_1},$$

and gross production of good 1 per unit of good 3 is given by

$$Y_1^3 = \frac{(1+g)a_3}{1-(1+g)a_1}.$$

Total gross production of good 1 for C_2 units of good 2 and C_3 units of good 3 is given by

$$Y_1 = C_2 * Y_1^2 + C_3 * Y_1^3,$$

and total employment L is given by

$$L = L_2 + L_3 = C_2(l_2 + l_1 * Y_1^2) + C_3(l_3 + l_1 * Y_1^3).$$

Here, L_i denotes employment of subsystem $i = 2{,}3$, i.e. the amount of labour necessary to produce C_i units of good i, to replace the means of production, and, additionally, to produce the amount of means necessary to expand production at rate g. The terms in brackets are known as the vertically hyper-integrated labour coefficients, their reciprocal values as the corresponding vertically hyper-integrated labour productivities.

Consumption of good 2 and good 3 per head of population are given by

$$c_2 = \frac{C_2}{N} = \frac{C_2}{L_2} * \frac{L_2}{N} = \frac{1}{l_2 + l_1 * Y_1^2} * h_2 = \lambda_2 * h_2,$$

$$c_3 = \frac{C_3}{N} = \frac{C_3}{L_3} * \frac{L_3}{N} = \frac{1}{l_3 + l_1 * Y_1^3} * h_3 = \lambda_3 * h_3,$$

where λ_i denotes the labour productivity and $h_i = L_i/N$ denotes work hours per head of population in subsystem i. Total employment per head of population is then given by $h = h_2 + h_3$.

The time constraint for the old long-period position is given by

$$1 = h^o + t_2^o * c_2^o,$$

whereas the time constraint for the new long-period position is given by

$$1 = h^n + t_2^n * c_2^n,$$

where $h^n = h_2^n + h_3^n$, $h_3^n = c_3^n/\lambda_3$ and $c_3^n = c_2^n * b_3^n/b_2^n$, implying that

$$h^n = \underbrace{\left(\frac{1}{\lambda_2} + \frac{t_2^n}{t_3^n} * \frac{1}{\lambda_3}\right)}_{k} * c_2^n.$$

The following two figures illustrate the shifts of the time constraint and of the productivity line due to new relative substitutes and new relative complements. In the two figures, consumption of the 'old' product per head of population, c_2, is depicted on the horizontal axis and employment per head of population, h, is depicted on the vertical axis; point 'o' describes the situation in the old long-period position and point 'n' describes the situation in the new long-period position.

Results:

(i) For relative *substitutes*, $b_2^n < b_2^o$ and $t_2^n > t_2^o$. As a result, the new time constraint decreases faster than the old one, while the new 'productivity line', $h^n = k * c_2^n$, is relatively steeper (see Figure 7). The two shifts together imply that consumption of the 'old' product per head, c_2, drops. Consequently, employment in the old subsystem drops. This displacement effect, however, is compensated by new jobs in the new subsystem which produces the new product. The net effect can be positive, negative ore zero: If the slope of the new productivity is greater than slope of the dashed line in Figure 7, the net employment effect is positive. If, however, the slope of the new productivity is relatively smaller, the net employment effect is negative.

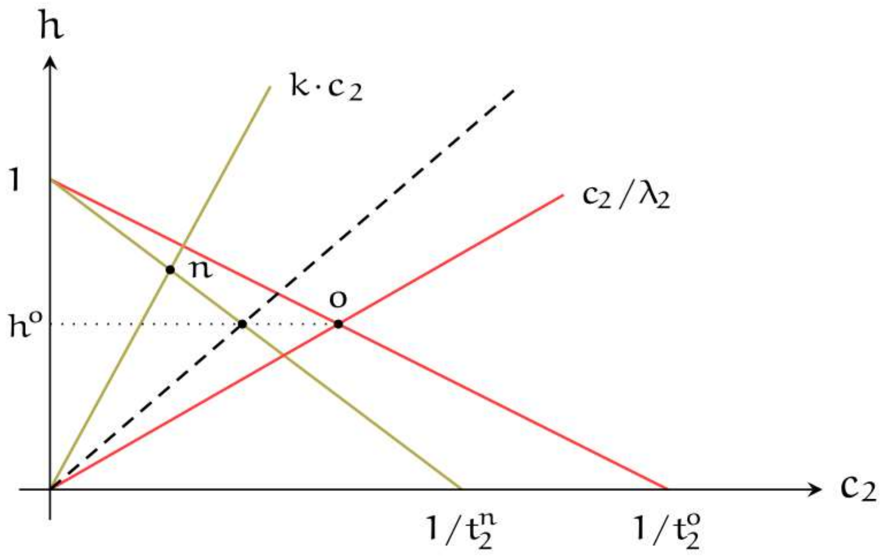

Figure 7: Effects of a new relative substitute on employment and consumption of the old product per head.

(ii) For relative *complements* $b_2^n \geq b_2^o$ and $t_2^n \leq t_2^o$. Therefore, the new time constraint has a relatively greater slope than the old one. The new 'productivity line' again is relatively steeper. The two shifts together imply that the net employment effect is always positive, while

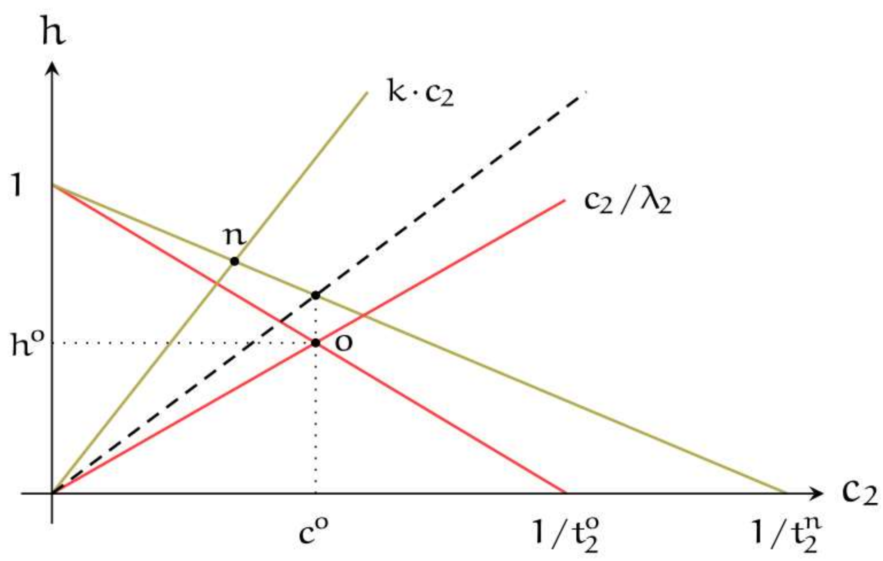

Figure 8: Effects of a new relative complement on employment and consumption of the old product per head.

consumption of the 'old' product per head, c_2, may increase, decrease or remain unchanged. As is indicated in Figure 8, c_2 remains unchanged for the dashed productivity line. If, as exemplified, the productivity line has a relatively greater slope, the 'old' consumption good industry shrinks. In contrast, if its slope is relatively smaller, the rise of the new industry entails a rise of the 'old' one.

4 Summary and outlook

In this paper we have studied the implications of the consumption-time problem for the long-term employment effect of innovations. In addition, we have shed some light on the labour displacement effect and the various compensation effects involved for different types of new methods and new consumption products.

The three most important results are:

(1) Because available time is fixed, new consumption activities enabled by new products displace existing activities. As a consequence, the diffusion of a new product and of corresponding new activities creates new jobs in new industries, but in the majority of cases it also destroys existing jobs by reducing demand for existing products. The net employment effect can therefore be positive, negative or zero, depending on the labour productivities and the consumption-time coefficients of involved products.

(2) New, profitable production methods displace labour only if their absorption into the system increases the vertically hyper-integrated labour productivity. Whether a profitable innovation raises labour productivity or not, depends on the form of technical change, the rate of profit and the rate of growth.

(3) The labour displaced by productivity-enhancing technical change with respect to existing goods cannot be expected to be fully compensated via *more consumption* or via *more growth*. This is so simply because of the time constraint. In fact, in the model at hand, only shifts towards more intensive activities via *new products* can achieve a full compensation of displaced labour.

Relaxing certain assumptions of our model opens the way for several extensions:

(1) We focused on per-capita quantities and have implicitly assumed a representative agent. It is safe to say that the roles of differences in incomes, lifestyles and consumption behaviours

only become visible in a model with heterogeneous agents. Certain forms of innovations then can be expected to have different impacts on different agents.

(2) We assumed a closed economy. Incorporating trade into the model would allow us to tackle the implications of the consumption-time problem for the gains from trade.

(3) In a model with fixed capital, durable consumption products and different types of labour or occupations, some additional forms of 'technical change' can be discussed.

(4) Unpaid work, or 'household labour', can be incorporated into the model by treating consumption products as inputs into the production of *Z commodities* (Becker 1965) aka *definite end products* (Linder 1970) by households. In such a framework it could be discussed, to what extent innovations which reduce or replace unpaid work can generate compensation effects.

(5) It was assumed above, that consumption and capital goods no longer exist after their use or that they can be disposed of without cost or time effort. By introducing costly and time-consuming processes of disposal, environmental aspects of consumption can be considered in the model.

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