Endogenous Technical Change and

Skill Biases in Employment Opportunities

by

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Abstract.

In this paper we present a model that addresses the issue of the uneven distribution of employment opportunities over low- and high-skilled workers in a context of skill-biased endogenous technical change. In our model, technical change consists in part of product innovation. There is also process innovation to the extent that new products can be produced in two different ways, either using high-skilled workers, or using low-skilled workers after adapting the production process of a new product. The model combines elements from Krugman’s (1979) North-South framework, Vernon’s (1966) life-cycle hypothesis and Aghion and Howitt’s (1992) work on creative destruction. We show that from a growth point of view, lowering the relative wages for low-skilled workers does indeed reduce unemployment in the short run, as expected, but it also lowers growth. This is reminiscent of Kleinknecht’s (1998) contention that moderate wage growth makes for slow technical change.

Keywords: Product innovation, life-cycle theory, skill-biases, endogenous technical change, business stealing, creative destruction.

JEL-codes : J21, J29

1. Introduction

Since Romer (1986), so called "New Growth Economics" has flourished. Many have contributed to the debate on how to explain (differences in) long run economic growth. This debate has been summarised in a number of excellent overview articles (Jones (1997), Aghion and Howitt (1998), Barro and Sala-I-Martin (1995)). We refer to them for further details and discussion. For our purposes, we like to stress that most of the literature in this field aims at explaining the *rate* of growth, and technological change is generally accepted as the main driving force.

More recently, however, economists have been confronted with new and equally challenging "stylised facts" that seem to be related to economic growth but that do not fit the aforementioned "new growth" models. We refer to the well-documented and rather dramatic shift in labour demand towards more skilled workers (f.i. OECD (1996)). This shift in demand causes declining relative (or even absolute) real wages for low skilled workers and/or high unemployment rates for the low skilled. Despite interesting differences between countries, it is a well-documented fact that the employment shares of low skilled workers have dropped throughout the OECD in the recent past. There is a growing consensus that this shift in demand is due to structural changes in production technology. Alternative explanations, such as a supply induced substitution away from low skilled workers or a trade- or final goods demand induced sectoral shift towards skill intensive industries seem to be difficult to establish empirically. [1]

But if this is the case, technological change must be studied, not only from the economic growth perspective, but also as a potential source of skill bias. This puts the emphasis on the *direction* or nature of technological change. New growth theory, despite its focus on the *rate* of growth, can serve as a useful starting point. From Aghion and Howitt (1992,1998) and Romer (1990) we borrow the idea that the source of growth is technological change through the expansion of the range of available products (Aghion and Howitt (1992,1998)) or intermediates (Romer (1990)). These innovations require the allocation of R&D resources to the generation of new products and production processes. The incentives for such efforts come from monopoly rents in product markets that are protected by patents.

In order to create the link to the direction of technological change, we invoke insights from the literature on product life cycles. This literature follows Vernon (1966) in assuming

1. With this statement we do not want to imply that biased technical change has been established empirically but the evidence available seems to point in that direction. See for an overview Sanders and ter Weel (2000).

that products and processes (often embodied in machines or intermediates) have a life cycle with certain more or less general characteristics. Hirsch (1965) was the first who linked skills and skill requirements to the cycle phase of a product or production process. In the early phases of the cycle the product is in flux. There is no dominant design, production runs are short and knowledge about the product and the corresponding production process accumulates relatively rapidly. The need for high engineering and managerial skills is evident, and there is little or no use for low-skilled labour at this stage. In the established phase of the product, however, we have specialised capital equipment and long stable production runs that allow the employment of cheaper low skilled workers.

We borrow some of the main elements of product cycle theory and introduce them into a model of a **closed** economy that consists of two production sectors, one producing new and one producing established goods, and an R&D sector that develops new products and established production processes. We chose the formal structure of the Krugman (1979) model of North-South trade, where we interpret the South as a sector producing established products in the same country. Relative profitability in the sectors drives the allocation of R&D resources over the generation of new products and established processes. Furthermore, as in Aghion and Howitt (1992), arbitrage in the labour market for high skilled labour determines the allocation of high skilled workers over R&D and the production of the available new products. We deviate from Krugman (1979) in one important respect. We endogenise not only the rate of introduction of new products, but also the rate of maturation of these products. In Krugman (1979) this “imitation rate” was an exogenous parameter. As such, this model builds on and extends the model we presented in van Zon, Sanders and Muysken (1998).

In the present model, we assume that there are intrinsic asymmetries between the employment opportunities of low and high-skilled workers. As in Hirsch’s (1965) life-cycle theory, low-skilled workers produce goods and services using established production techniques, while high-skilled workers are used in the initial stages of a products life cycle. Hence, we essentially assume that new products are high-skill intensive, whereas established products are low-skill intensive. For reasons of simplicity, we even assume that established products are generated using low-skilled labour only, whereas new products need to be produced using high-skilled labour only. Moreover, we disregard other factors of production. As in Krugman (1979), we assume that production technologies are linear, while the demand for goods is described using a CES utility function in which all the goods enter in a symmetric way. Hence, all goods contribute to utility in the same way. Therefore, the only reason why there may be differences in the demand for individual goods is that prices of these goods may be different. Differences in prices in turn are the result of differences in marginal costs, which are related to differences in technology.

The set up of this paper is as follows. In section 2 we present the outlines of the model and in section 3 we further analyse the dynamics of the model. In section 4, we present the outcomes of some simulation experiments that we have conducted in order to illustrate the working of the model. Section 5 contains some concluding remarks.

2. The Model

The demand for goods

The demand for goods is derived using a CES utility function. This results in a downward sloping relation between the volume of consumption of a certain good and its price. In short:

$$U = \int_{i \in S_n} c_i^{\alpha} di + \int_{j \in S_e} c_j^{\alpha} dj \qquad (1)$$

where U is total consumer utility, c_i is the level of consumption of good i, and S_n and S_e are the sets of the indices of 'new' and 'established' products, respectively. $\sigma = 1/(1-\alpha)$ is the elasticity of substitution between different goods.

Let p_i be the price of good i, then the composition of the utility maximising consumption basket is implicitly given by equation (2) which is one of the first order conditions of this utility maximisation problem:

$$\alpha c_i^{\alpha-1} = \lambda p_i \qquad (2)$$

where λ is the Lagrange multiplier associated with the budget constraint. Post-multiplying (2) by c_i and then summing over i yields for the value of λ:

$$1/\lambda = (1/\alpha)(B/U) \qquad (3)$$

where B is the available nominal consumer budget. Equation (3) implies that the inverse of λ is proportional to the cost of one util. Setting the cost of one util equal to 1 is then equivalent to setting $\lambda = \alpha$. By choosing the cost of a util to be the numeraire, it follows from (2) that the demand for each good is given by:

$$c_i = p_i^{-\sigma} \qquad (4)$$

The supply of goods

Every good is produced by a single producer. That producer must first buy the right to produce the good in question from the R&D sector that generates blueprints for new products. The demand schedule given by (4) serves as a constraint for the monopolist to set his profit maximising price, which is then given by the Amoroso-Robinson condition:

$$p_i = m_i / \alpha \qquad (5)$$

where m_i is the marginal production cost of good i. In that case, profits at time t from producing good c_i are given by:

$$\Pi_i = (1-\alpha) p_i c_i = (1-\alpha) p_i^{1-\sigma} = (1-\alpha)(m_i/\alpha)^{1-\sigma} \qquad (6)$$

where we have used equations (4) and (5). Note that equation (6) links profits to marginal costs only.

Labour Supply and Demand

We assume that low skilled and high-skilled workers supply their labour in-elastically. Equilibrium wages by skill can then be obtained by assuming that labour suply by skill matches labour demand by skill.

Let μ_e and μ_n be constant parameters that describe the productivity of labour in new and established industries. Then we can obtain aggregate demand for low-skilled workers from (4) and (5):

$$l = n_e (w_e / \alpha)^{-\sigma} \mu_e^{1-\sigma} \quad (7)$$

where w_e is the wage rate of low-skilled workers in the established industries. w_n is the wage rate of high-skilled workers in the new industries. n_e and n_n are the number of established and new products, respectively. n_e enters (7) because all sectoral production functions are assumed to be identical within the groups of established and new industries. The only difference between both industries is that the established industries use low-skilled labour, whereas the new industries have to use high-skilled labour, and so compete with future consumption possibilities because the R&D sectors use high-skilled labour too. The demand for high-skilled workers in the new products industry is similarly defined.

Wages

Substituting the exogenous supply of low-skilled labour $\bar{l}$ into (7), we can obtain the equilibrium low-skilled wage rate:

$$w_e = (\bar{l} / n_e)^{-1/\sigma} \alpha \mu_e^{1-1/\sigma} \quad (8)$$

Similarly, for the industries that produce new products we get:

$$w_n = ((\bar{h} - r) / n_n)^{-1/\sigma} \alpha \mu_n^{1-1/\sigma} \quad (9)$$

where r is the total number of high-skilled research workers, and $\bar{h}$ is the total supply of high-skilled labour, while $s = \bar{h} - r$ denotes the number of high-skilled workers employed in the sector that produces new products. Combining (8) and (9), relative wages are given by:

$$w_n / w_e = ((\bar{h} - r)/\bar{l})^{-1/\sigma} (n_e / n_n)^{-1/\sigma} (\mu_n / \mu_e)^{1-1/\sigma} \quad (10)$$

It should be noted from equation (10) that relative wages are influenced by changes in the number of new and established products.[2] An increase in the number of new products, ceteris paribus will increase the competition for high-skilled labour and hence drive up

[2] We will introduce technical change shortly by allowing the number of new and established products to vary.

relative high-skilled wages. We also see that an increase in the relative supply of a specific skill type will lower its relative wage.

Profits

Equations (8) and (9) can be used to show how profits are affected by technological change, -i.e. changes in the number of new products or changes in the number of established products. For a typical industry we would have for profits Π from equation (6):

$$\Pi_i^x = (1-\alpha)(w_x / \alpha)^{1-\sigma} \mu_x^{\sigma-1} \qquad (11)$$

for $x=n,e$. Equation (11) shows that profits would be eroded over time by increases in wage rates, at least when $\sigma \geq 1$. The latter is a necessary condition in order not to have prices fall below marginal costs, which is satisfied by assumption. From equations (8) and (9) on the other hand, we observe that wages in the established industries and the 'new' industries would rise with the number of goods produced by those industries. Hence, we may observe an interesting interplay between the different types of technical change in the model. An increase in the number of new products will raise the wage rate of high-skilled labour. This decreases the future profits to be earned from generating new products. This would shift technical change in favour of process R&D. The latter would increase the number of established products relative to the number of new products. This in turn would increase low-skilled wages and hence decrease the profit stream on established products somewhat, thus raising the incentive to engage in product R&D again, and so on. The next section will formalise this process.

The R&D sectors

Equations (11), (8) and (9) can actually be used to derive the value of both types of blueprints to a producer. By assuming that blueprints can be bought in an auction, the value of a blueprint to the producer is also the price of the blueprint and therefore also the value to the research sector.[3] Combining Aghion and Howitt (1998) and van Zon c.s. (1998), we assume that this provides the incentive to a competitive research sector to hire high-skilled labour and

[3] An alternative is to assume R&D is an inhouse activity such that all costs and benefits are fully incorporated.

to try and find a new product or a new process. In a competitive R&D sector arbitrage ensures that the value of the marginal blueprint is equated to the marginal cost of producing that new blueprint, -e.g. the opportunity cost of using the high skilled worker in producing new products or blueprints of the other type. Since we assume labour to be completely mobile, we know that in order to have a stable allocation of high skilled labour, the marginal benefits and costs must be equal in both research sectors. Moreover, they must also be equal to the wage rate in the new goods sector.

In the research sector that generates new products, we assume the existence of an intertemporal externality, as in Romer (1990): research into new products becomes more productive the more cumulative knowledge exists about new products. With respect to research into new processes we assume a positive external spill-over from the introduction of new goods that can be turned into established ones. However, this type of research is subject to diminishing returns in the sense that once all products are established, none are left to transform. More specifically, we assume that it becomes increasingly difficult to transform the marginal new product as the remaining stock of new products goes to 0. Defining $z=n_e/n_n$, the above can be summarised by:

$$\frac{dn}{dt} = \kappa_n n r_n \qquad \Rightarrow \ \hat{n} = \kappa_n r_n \tag{12.A}$$

$$\frac{dn_e}{dt} = \kappa_e n_n r_e \qquad \Rightarrow \ \hat{n}_e = \kappa_e r_e / z \tag{12.B}$$

$$\frac{dn_n}{dt} = \frac{dn}{dt} - \frac{dn_e}{dt} \qquad \Rightarrow \ \hat{n}_n = (1+z)\hat{n} - z\hat{n}_e \tag{12.C}$$

where r_n and r_n refer to the number of research workers engaged in generating new or established products, respectively, and where $\hat{x} = (dx/dt)/x$.

Assuming that the probability of any new product becoming established is independent of the product under consideration, it follows that each new product and each new production process has a certain probability per unit of time of becoming an established product. This probability is given by the ratio of the number of newly established products (i.e. dn_e/dt) relative to the number of not yet established products (i.e. n_n). As in Aghion and Howitt (1998), we assume that the probability of a new product being replaced by an established one can be accounted for in the present value of the corresponding expected profit stream in the effective rate of discount:

$$V^x = \Pi^x / (\rho + \delta_x) \qquad (13)$$

where $x=n,e$. In equation (13), ρ is the nominal rate of discount, while δ_x is the additional discount on the expected present value of a blueprint due to creative destruction and wage induced profit erosion. The wage changes are in turn induced by the growth of the number of new and established products, as was noted in equations (8) and (9).

3. Solving the Model

The Steady State Solution

It is instructive to see what happens to wages and technical change in a steady state growth situation before turning to the full dynamics of the model. The steady state requires the constancy of the ratio $z=n_e/n_n$. This ratio would remain constant only if the rates of growth of the number of new and established products are equal to the growth rate of total products. The equality of these rates in the steady state defines a relation between z and this common steady state rate of growth of the various classes of products. However, the free mobility of high-skilled labour between the new industries and the research sector then defines both the allocation of high-skilled workers between those sectors as well as the common wage rate in those sectors. In this paragraph we will first simply assume that there is a steady state, and see what happens. Later on we will show that the model actually converges to this steady state.

Let the steady state value of z be denoted by $\bar{z}$. Then it follows directly from equations (12.A)-(12.C) that:

$$\hat{n} = \hat{n}_e = \hat{n}_n \quad \Rightarrow \quad \bar{z} = \frac{r_e}{r_n} \frac{\kappa_e}{\kappa_n} \qquad (14)$$

Equation (14) describes the relation between the steady state value of the distribution of all products over new ones and established ones, and the input of research workers in both uses of those workers. For a given allocation of research workers, the ratio of established products to new products will be larger, the higher is the ratio of the R&D productivity parameter κ_e / κ_n.

Following Romer (1990) and Aghion and Howitt (1998), we can define the allocation of labour between the final output of new products and both research sectors in terms of the free mobility of labour that requires wages earned by high-skilled workers in those sectors to be the same. We obtain the following arbitrage equation:

$$\frac{dn}{dt}\frac{\Pi^n}{\rho+\delta_n}/r_n = \frac{dn^e}{dt}\frac{\Pi^e}{\rho+\delta_e}/r_e = w_n = ((\bar{h}-r)/n_n)^{-1/\sigma}\alpha\,\mu_n^{1-1/\sigma} \qquad (15)$$

The right hand-side of (15) is the same as equation (9). The left most part of (15) is the present value of total expected profits per researcher from the marginal blueprints in the research sector that generates new products. The middle part of (15) refers to the present value of total expected profits per researcher in the other research sector. In order to obtain the distribution of high-skilled labour over its various uses, we need to fill in the various δ 's in equation (15).

Profit Erosion through Rising Wage Costs and Business Stealing

As stated above, profits are eroded over time by growing wage rates. From equations (8) and (9) it is easily seen that for a constant size and skill-composition of the labour force, as well as a constant allocation of high-skilled and low-skilled workers (which would be the case in the steady state) we have:

$$\hat{w}_x = \hat{n}_x / \sigma \qquad (16)$$

for *x*=*n*,*e*. From equation (11) it follows that the growth of profits due to technical change induced changes in wages would be equal to $1-\sigma$ times the growth in wages as given by equation (16). Obviously, for $\sigma \geq 1$the growth in profits would be non-positive for a positive griwth in wages. In addition to this, the profits in the new products sector are also eroded due to new products becoming established. The proportional rate at which this happens is given by $(dn_e/dt)/n_n = z\hat{n}_e$, as stated above. Using this information and equations (12.A)-(12.C) and (16) we can now define:

$$\delta^n = \alpha(1+z)\kappa_n r_n + (1-\alpha)\kappa_e r_e \tag{17.A}$$

$$\delta^e = \alpha\kappa_e r_e / z \tag{17.B}$$

Equation (17.A) shows that the rate of profit erosion in the new products sector depends positively on the number of research workers in the other research sector. However, it also depends positively on the number of research workers employed in the research sector that generates new products. The latter is due to the fact that more new products makes high-skilled workers scarcer, which tends to increase wage costs in the R&D sectors. The former effect is in part a business-stealing effect as in Aghion and Howitt (1992, 1998). This business stealing effect does not appear in equation (17.B), because there is nobody here to 'steal' the production of established goods. However, one can envisage the introduction of a foreign sector in this model set-up that could account for the occurrence of an international business stealing effect at this exact spot in the model.[4]

A Graphical Solution

Unfortunately, the model has become non-linear in its variables, which makes it hard to solve analytically. However, we can develop an intuition of the way the model works by condensing the model to two links between two variables in two-dimensional space. We can then see how the graphs of these relations would be affected by changes in the model parameters but also by out of steady state situations.

The procedure to generate the links mentioned above, consists of using the arbitrage condition given by (15), and substituting for wages using (8)-(9), and for the rates of profit erosion using (17.A) and (17.B). We can then solve r_e and r_n in terms of $s = \bar{h} - r$ and z, the latter not necessarily being the equilibrium value of z as given by (14). Then, using $s = \bar{h} - r$,

[4] This would increase the correspondence of the model with the original Krugman North-South model again. Note that with the introduction of a South in this context, there are some interesting extensions of the model to consider. If, for instance, the absorption capacity of established technologies would in part depend on the level of education of a population, then the South could try to induce growth by increasing educational efforts. This would tend to lower low-skilled wages in the North, while raising low-skilled wages in the South. However, the overall growth effect would be ambiguous, because the increased profitability of generating established products due to the decrease in relative low-skilled wages in the North, would in part be counteracted by the international business stealing effect. Moreover, even if there would be an immediate gain for the North in switching R&D

we could solve s as a function of s and z, through $r_e=r_e(s, z)$ and $r_n=r_n(s, z)$ and hence obtain s as a function of z only. This would give us r_e and r_n as a function of z. Then, using (14), the steady state value of z could in principle be obtained in function of the system parameters only. Following this procedure, we show that this system leads to a stable equilibrium by combining an analytical and a graphical analysis. More in particular, we want to show that the growth rate of z depends negatively on z itself: it becomes negative for large values of z, while it is positive for small values of z. In addition to this, we show the parameter restrictions that are necessary to ensure the existence of such a stable equilibrium situation. In order to do this, we first need to relate the growth rates of n_e and n_n to z (and s). This is easily done by using equations (12.A-12.C) and the labour market arbitrage equations in (15).

The relation between s and r_e that describes a labour market equilibrium between the 'established products' R&D sector and the final output sector for new products can be obtained by equating the middle part of (15) with its right hand side. The relation between s and r_n that describes a labour market flow equilibrium between the 'new products' R&D sector and the final output sector, can be obtained by equating the left hand side of (15) with its right hand side. We can turn this relation into an equivalent one between r_e and s and z again, by using the high-skilled full-employment condition $r_e + r_n + s = \bar{h}$, and obtain equations (18.A)- (18.C), where (18.B) and (18.C) are equivalent:

$$r_e = z^{1-\alpha}(s(1-\alpha)\kappa_e(\mu_e\bar{l}/(s\mu_n))^{\alpha} - z^{\alpha}\alpha\rho)/(\alpha^2\kappa_e) \tag{18.A}$$

$$r_n = \frac{s(1-\alpha)(\alpha\kappa_e + (1+z)\kappa_n) - \alpha(\bar{h}(1-\alpha)\kappa_e + \rho)}{\alpha((\alpha-1)\kappa_e + (1+z)\alpha\kappa_n)} \tag{18.B}$$

$$r_e = \frac{-s(1+z)(1-\alpha+\alpha^2)\kappa_n + \alpha(\bar{h}(1+z)\alpha\kappa_n + \rho)}{\alpha((\alpha-1)\kappa_e + (1+z)\alpha\kappa_n)} \tag{18.C}$$

Since (18.A) and (18.C) can be represented by a graph in the same plane, we can see what would happen to the equilibrium values of r_e, r_n and s for a given value of z when we would change some of the parameters of the system. Equations (18.A) and (18.C) are depicted in Figure 1 below.

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efforts to established products, in the long term this would necessarily lower growth performance, since new products are the ultimate source of long term growth in income/utility.

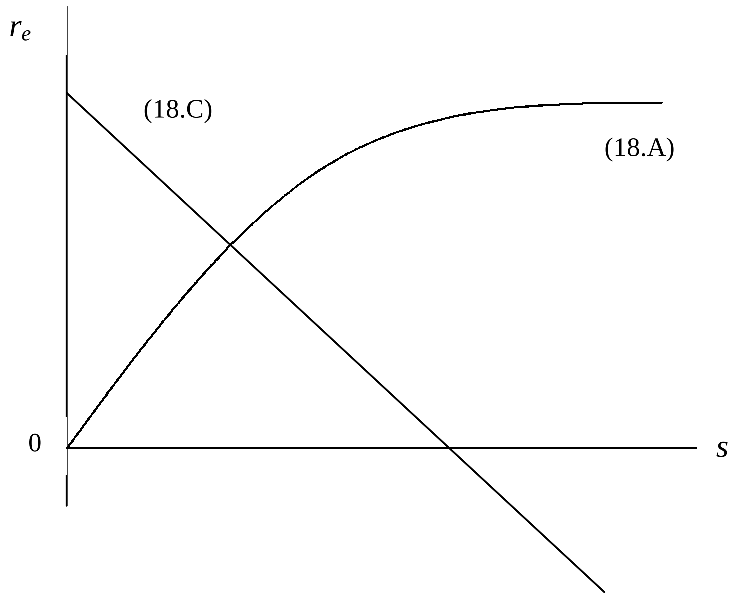


Figure 1 Labour Market Equilibrium

Changes in the system parameters would shift the graphs, and hence lead to other points of intersection of the graphs, if there are any. At any point of intersection of both graphs, all labour market arbitrage opportunities would be exhausted. [5]

As can be seen in Figure 1, equation (18.A) is a concave function in *s*. For rises in the parameters $\kappa_e, \kappa_n, \rho, \bar{h}, \bar{l}$, the graph of equation (18.A) would shift +,0,-,0,+ respectively[6], while the graph of equation (18.C) would show the corresponding shifts -,+,+,+,-. This has the following effects on the equilibrium values of r_e and s (where an ambiguous effect is denoted by a question mark, while a rising equilibrium value is given by an upward pointing arrow, and a falling equilibrium value is given by a downward pointing arrow): ($\kappa_e \uparrow \Rightarrow r_e\, ?, s \downarrow$), ($\kappa_n \uparrow \Rightarrow r_e \uparrow, s \uparrow$), ($\rho \uparrow \Rightarrow r_e\, ?, s \uparrow$), ($\bar{h} \uparrow \Rightarrow r_e \uparrow, s \uparrow$), ($\bar{l} \uparrow \Rightarrow r_e\, ?, s \downarrow$).[7]

There are three ambiguous results, i.e. the first, third and fifth case. The first and the fifth case are the most interesting, since one would expect at first sight that an increase in the productivity of the 'established products' R&D sector or an increase in the profitability of producing established goods would change the allocation of research workers in favour of the 'established products' R&D sector. But that would have the effect of decreasing the number of new blueprints that can be used by the established products R&D sector, thus providing a

[5] However, that does not imply that in such a point of intersection *z* itself will not change. We will come back to this later.
[6] + denotes an upward shift, 0 no shift and – a downward shift.
[7] See Annex A for more details.

negative productivity shock as well. The third case is ambiguous because whether or not a reallocation between research sectors takes place depends on the size of the profit erosion parameters δ_e and δ_n in comparison with the value of the discount rate itself. However, both types of blueprints will become less valuable for sure, hence the unambiguous rise in *s*, whereas the reallocation of high-skilled labour between both R&D sectors depends on the specific model parameters. The fifth case is ambiguous, because a rise in $\bar{l}$ would increase profits on established products, thus increasing the incentive to engage in process R&D. But, as in the first case, this also reduces the number of new blueprints that can be assimilated.

Stability Issues

The analysis above assumed a given value of *z*. However, *z* changes if the allocation of high-skilled workers between the R&D sectors changes. Again, we can use a graphical analysis to show what happens to z assuming that the labour market is continuously in equilibrium. In Annex B to this paper we provide the analytical details. Here we simply state that we have strong analytical reasons to believe that we are dealing with a stable equilibrium situation. Moreover, this is corroborated in the numerical experiments we have conducted (see section 4). In the next section we show the outcomes of some illustrative model simulations in order to get a more complete intuition of the properties of the model.

4. Some Illustrative Model Simulations

The Base Run

Table 1: Base Run Parameter Settings

Exogenous Variables		**Parameters**	
		α	0.5
$\bar{h}$	1.5	ρ	0.1
$\bar{l}$	1.0	μ_n	1.5
		μ_e	1.0
		κ_n	0.1
		κ_e	0.075

In this section, we present the results of several simulation experiments we ran with the model. For the base run, we chose the parameters of the model with no particular actual situation in mind. The parameters and exogenous variables used for the base run are listed in Table 1. The exogenous variables $\bar{h}$ and $\bar{l}$ are set at 1.5 and 1 respectively to reflect the fact that in most western countries the labour force consists predominantly of skilled labour. The labour productivity parameters μ_n and μ_e were chosen such that the resulting labour shares in R&D are closer to observed shares and normalised to 1 for the established sector. κ_n and κ_e are also assumed to be slightly different in order to improve the readability of the figures. These values have little impact on the overall picture. α and ρ were chosen arbitrarily at 0.5 and 10% respectively. As the figures in this section will show, the model will reach a steady state equilibrium for the values of the endogenous variables listed in Table 2.

Table 2: Base Run Results

WE/WN	0.4262
Z	0.2706
GN=GNE=GNN	0.0362
δ_n	0.0279
δ_e	0.0181
GWSPWE=GWSPWN	0.0179
RE	0.1308
RN	0.3624
S	1.0068

In the table above, WE/WN is the relative wage rate of low-skilled workers vis a vis that of high skilled workers. GN, GNE and GNN correspond to the proportional growth rates of n, n_e and n_n, respectively. RN and RE are the number of research workers in the 'new products' R&D sector and in the 'established products' R&D sector, respectively. S is the number of high-skilled workers in the final output industry producing new products and Z is the ratio of the number of established products and the number of new products. WSPWN and WSPWE are the wage sums of workers producing established products and new products, respectively. GWSPWE and GWSPWN are the corresponding growth rates.

About one third of the high skilled labour available is allocated towards R&D and the relative wage for unskilled workers is roughly half that of high skilled workers. As one would expect, the profits in the new goods sector are discounted at a much higher rate than those in the established goods sector due to the business stealing effect. Finally the economy grows at about 3.6 % in steady state.

We have performed seven experiments in the model, which will be discussed in some detail below. Table 3 gives a summary of the experiments we considered. In all experiments the shock was administered in period 200 and reversed in period 250. It turned out that the system had stabilised well before that period in all experiments, so the reversal usually shows an opposite development to the original steady state.

Table 3: Experiments

Experiment	**Description**	**Parameter**	**Shock**
X1	Labour Supply Shocks	$\bar{l}$	+10%
X2		$\bar{h}$	+10%
X3	R&D Productivity Shocks.	κ_n	+10%
X4		κ_e	+10%
X5	Labour Productivity Shocks	μ_e	+10%
X6		μ_n	+10%
X7	Wage Leadership	ψ	-10%

Experiments 1 and 2: Labour Supply Shocks

In the first set of experiments, we consider the impact of a 10% change in the availability of low and high skilled labour, respectively. One would expect the increase in $\bar{l}$ to cause a drop in the relative wages of low skilled workers. Figure 2 shows this initial drop. However, after the shock relative wages go up again. This is caused by the initial improvement in profitability in the established sector, as in shown in Figure 6, that causes a reallocation of R&D labour, see Figure 7. This causes the R&D sector to generate more established products and the rate of growth of NE goes up, as can be verified in Figure 3. This in turn causes the rate of profit erosion on established products to rise, shown in Figure 4, and relative wages rise again. After some 20 periods, the system is back in equilibrium and the allocation of R&D workers is back to what it was, implying that all growth rates returned to their original steady state levels. The relative wage remains below its initial level, however. The increased relative supply of low skilled labour is absorbed entirely due to the reduction in their relative wages. Reversing the experiment returns us to the original situation. Since this is the case for most experiments, we will not mention this again.

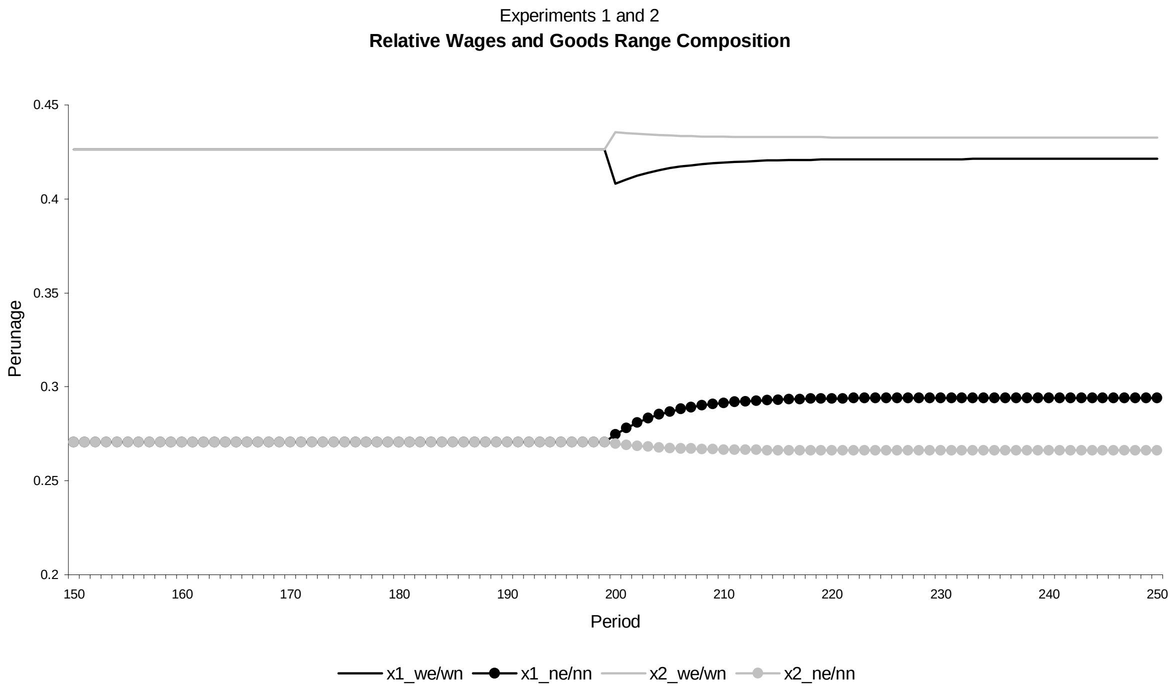


Figure 2

If the supply of high skilled workers is increased, the impact is far more permanent. Initially the wages of high skilled workers fall, as was to be expected. This time, however, we have both a reallocation within R&D and an increase in total R&D labour, causing all growth rates to rise, but also the rates of profit erosion. Due to the knowledge spillover effect, the output of both the RN and RE workers goes up, causing overall growth to increase. Relative wages are permanently lower for high skilled workers, but as can be verified in Figure 5 the growth rate of wages is higher for both labour types.

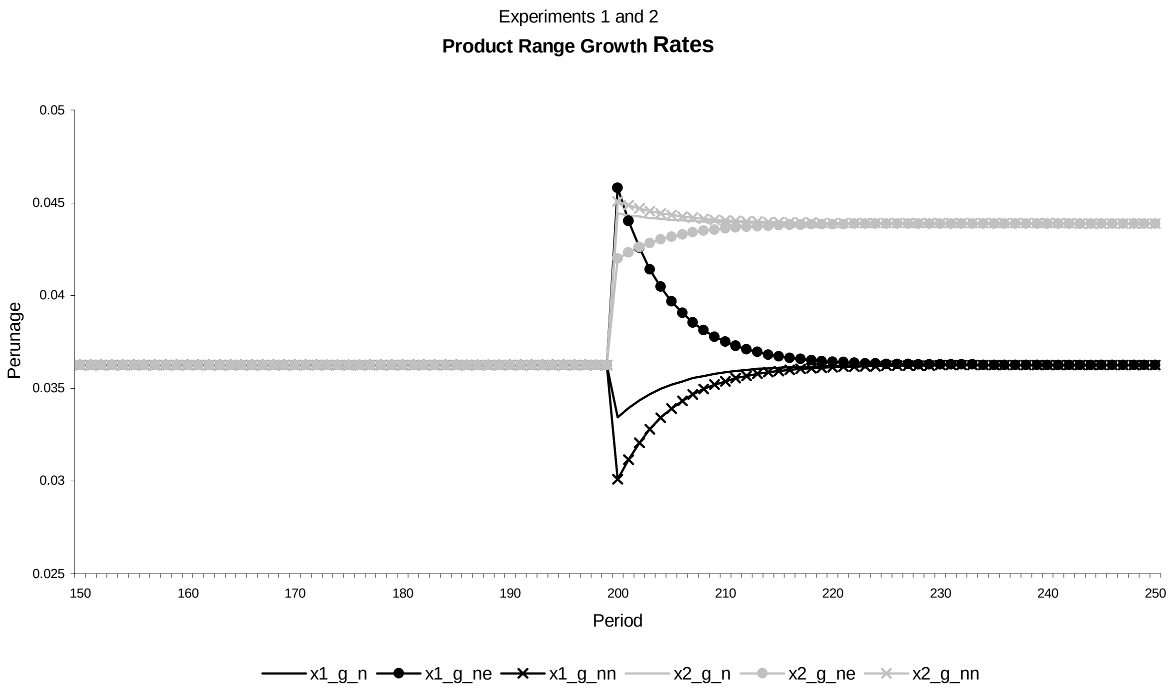


Figure 3

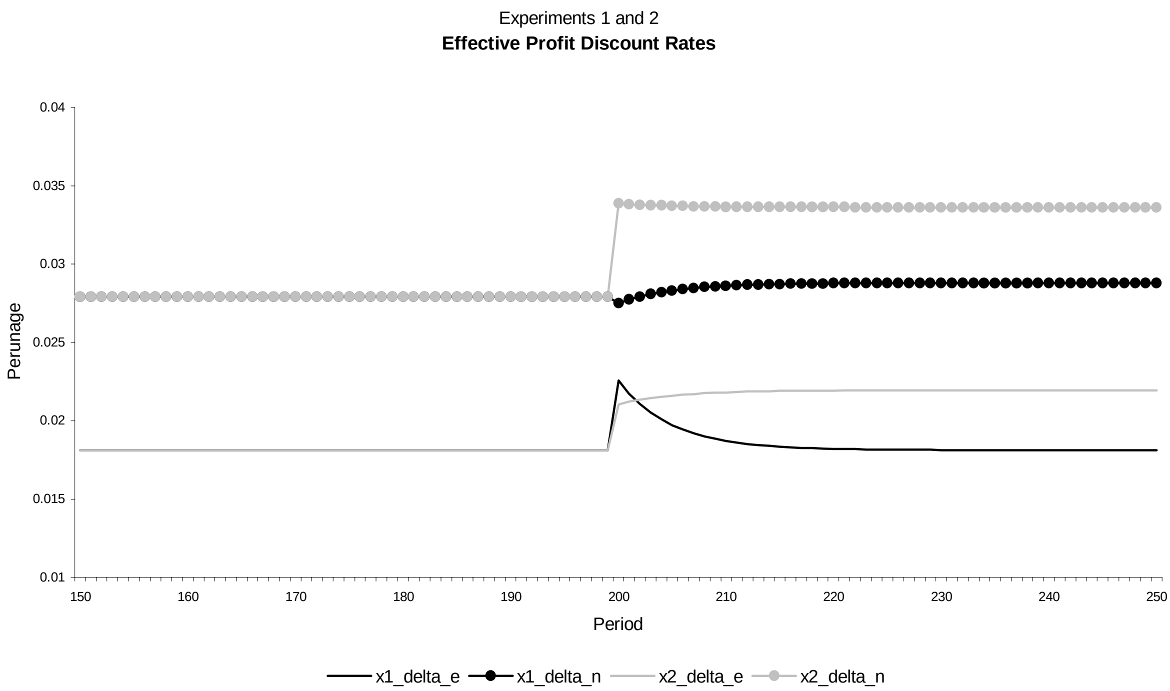


Figure 4

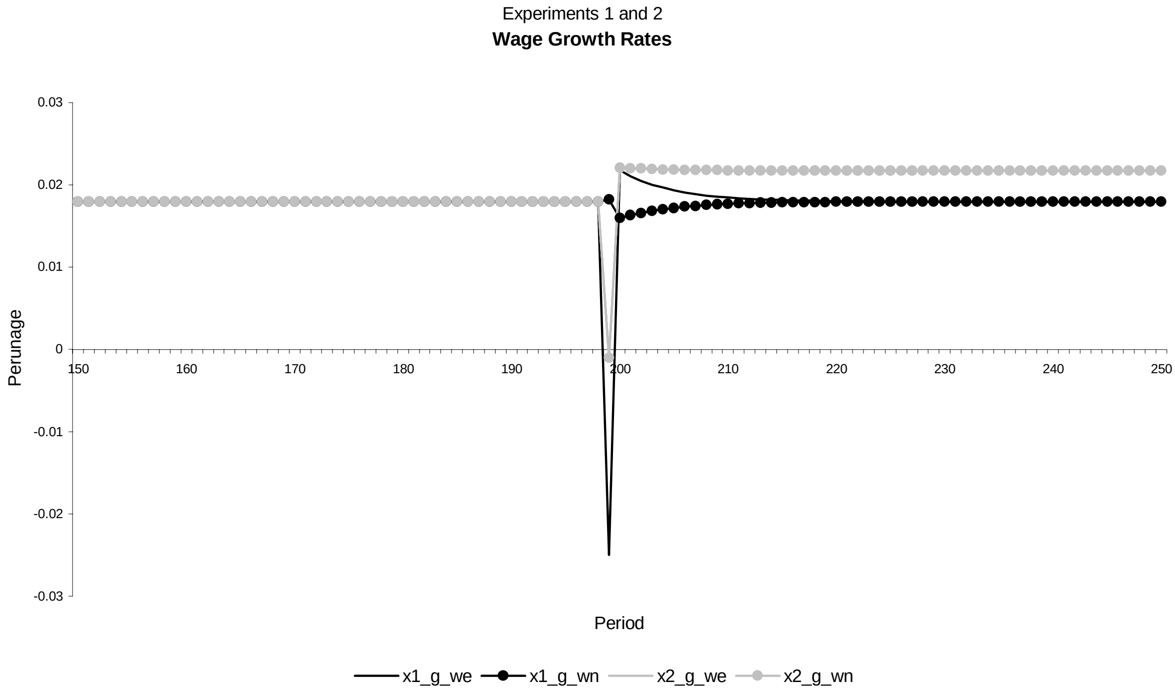


Figure 5

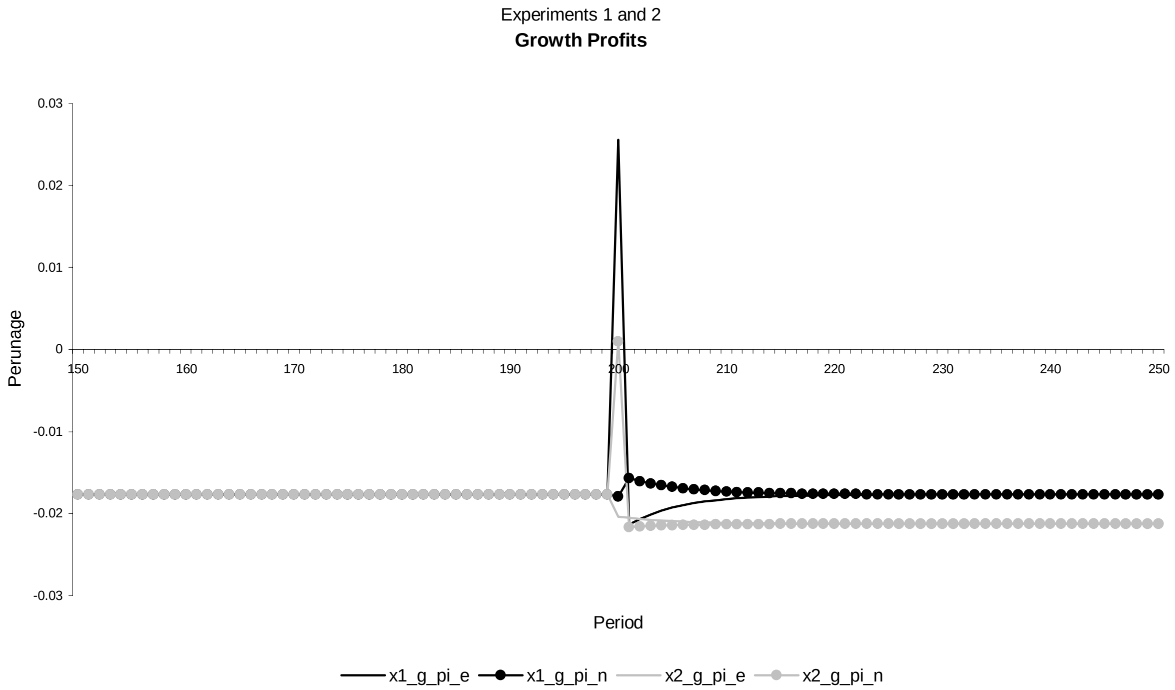


Figure 6

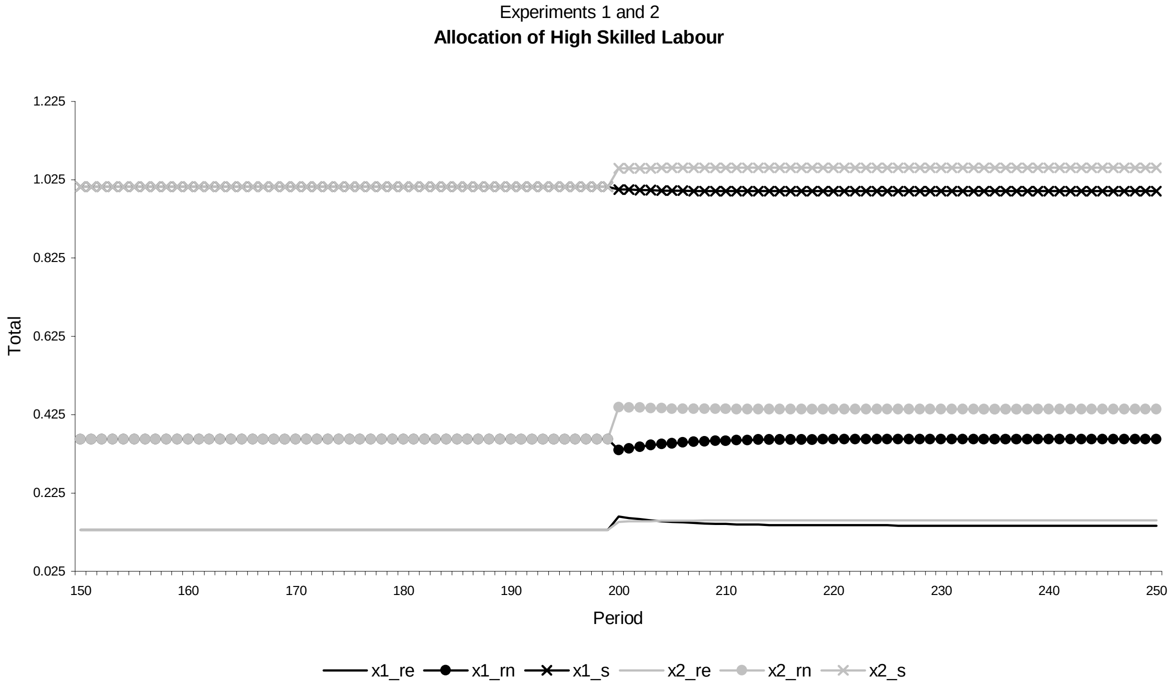


Figure 7

Experiment 3 and 4: R&D Productivity Shocks

A shock in the productivity of the R&D process can be interpreted as the arrival of some new general-purpose technology that makes developing new products relatively easier. Or alternatively as an increase in the efficiency due to better communications that allow for knowledge spill over to occur more frequently and effectively. The difference being that the former is likely to fade out over a period of time whereas the latter is likely to be permanent. Whatever the cause, we have analysed the impact of a 10% increase in either κ_n or κ_e and the results are presented in Figures 8 to 13.

When we increase κ_n we would expect the growth rate of NN to go up, and that of NE to go down due to immediate reallocation of R&D workers. Also high skilled workers are drawn out of production into R&D, increasing the overall growth rate. This can be seen in Figure 9. Then, as the high skilled workers become relatively scarce, their wages start drifting up, and R&D labour is re-allocated towards production, although the net effect remains positive. In addition, the spillover effects of expanding NN relative to NE start to make themselves felt, and a reallocation of R&D workers occurs. As can be verified in Figure 11, wages grow faster in the new steady state and hence profits are eroded faster too (see Figure 12).

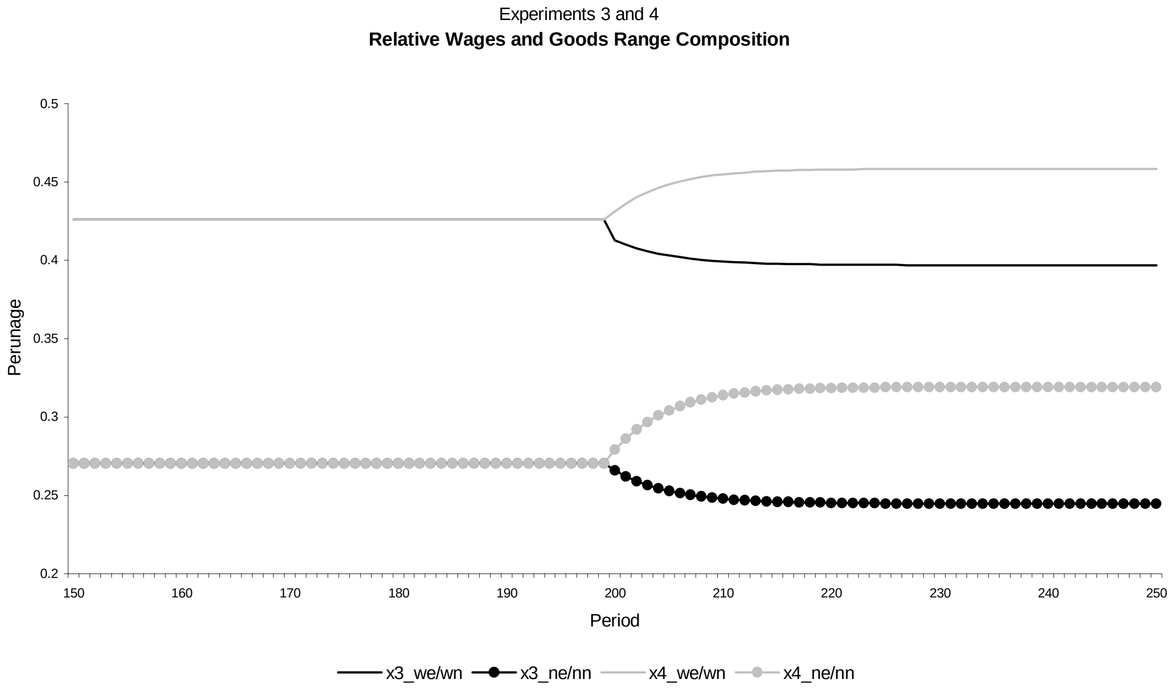


Figure 8

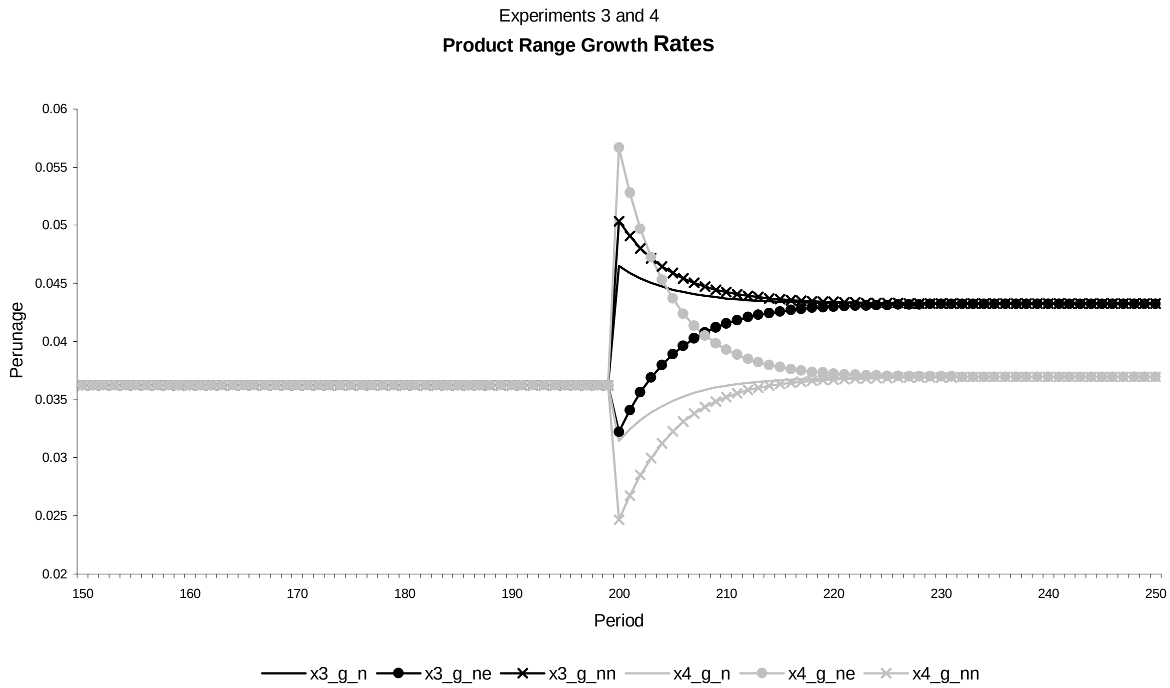


Figure 9

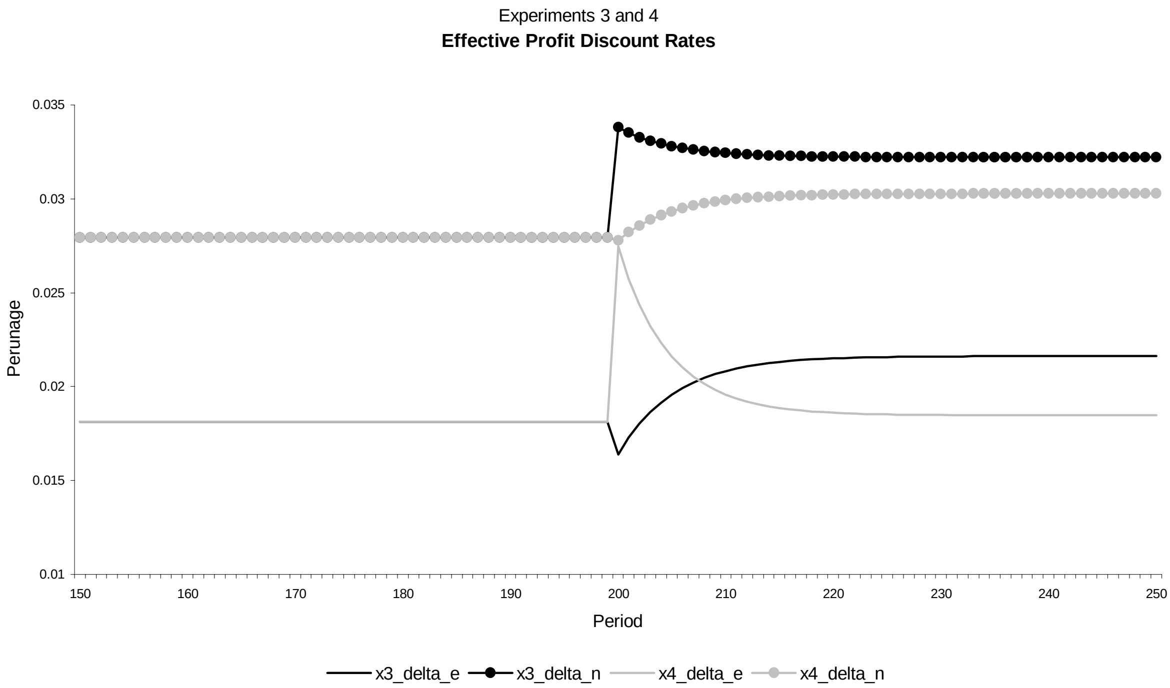


Figure 10

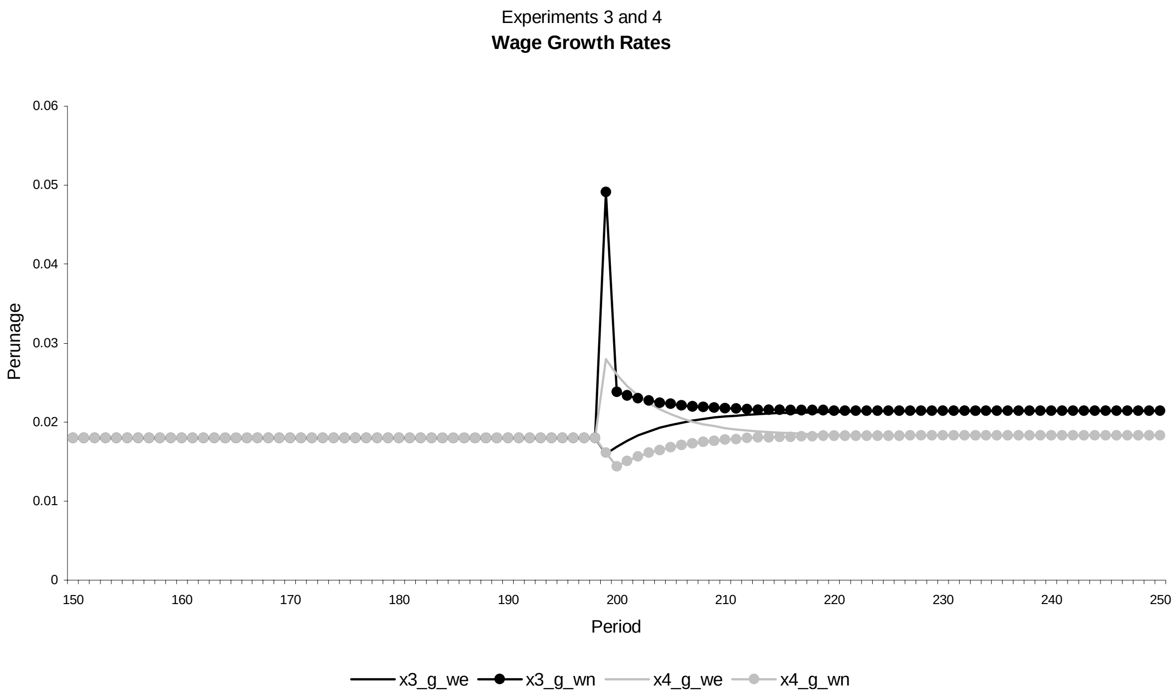


Figure 11

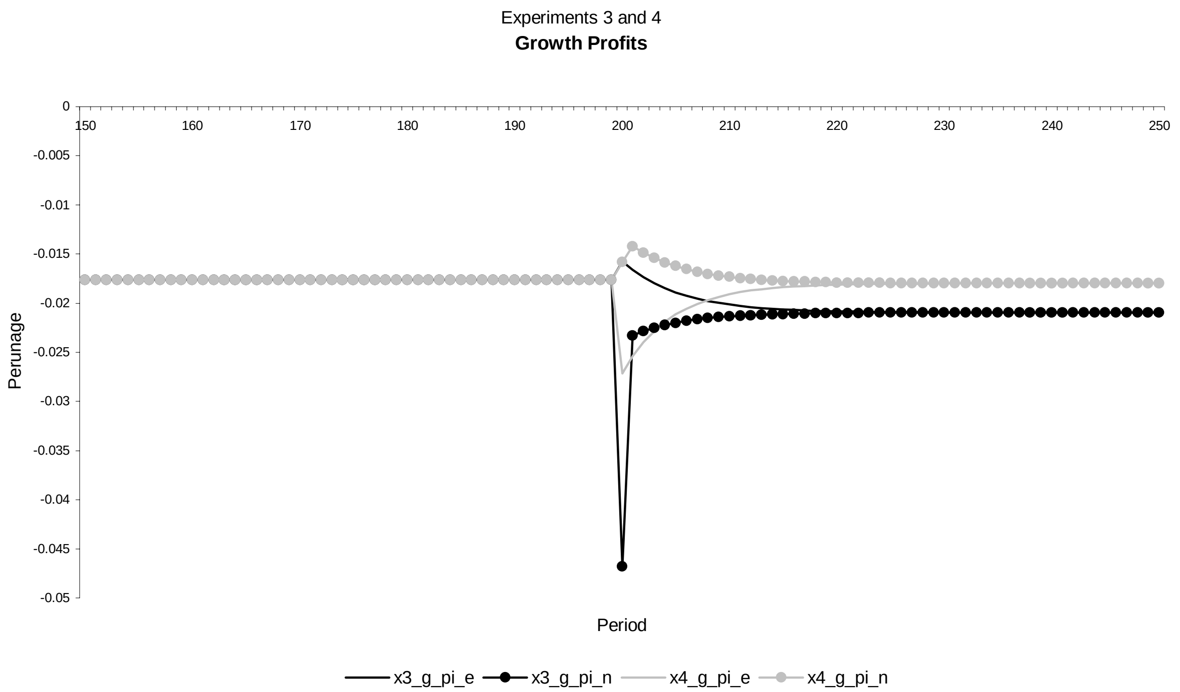


Figure 12

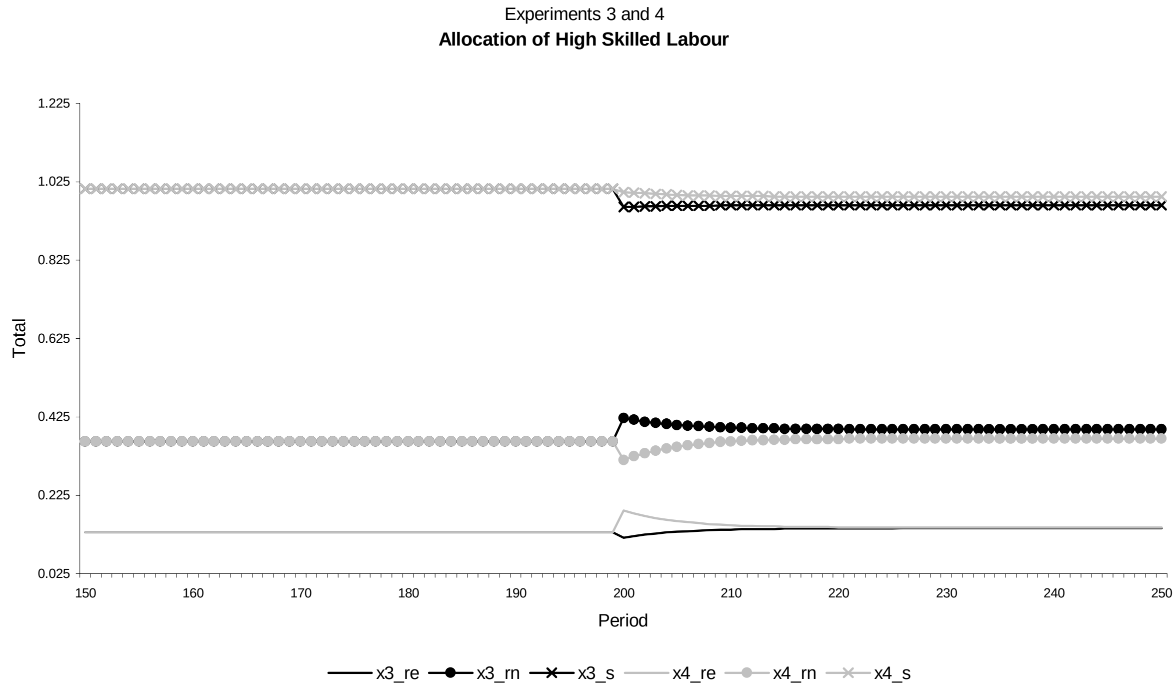


Figure 13

In the case where we increased κ_e by 10%, we can observe some striking differences. First of all, the absence of spillovers and the actual diminishing returns one encounters when increasing NE relative to NN, cause the effects on the allocation of resources in the R&D

sector to be marginal. The impact on relative wages is a level effect that takes some time to arise but once it is achieved wage growth and profit erosion fall to their initial levels. Moreover, the overall growth rate of N also falls back to its initial level. The reason is that the increase in the productivity of generating established products is all but counterbalanced by the negative effect on productivity that arises when NN is squeezed.

Experiments 5 and 6: Labour Productivity Shocks

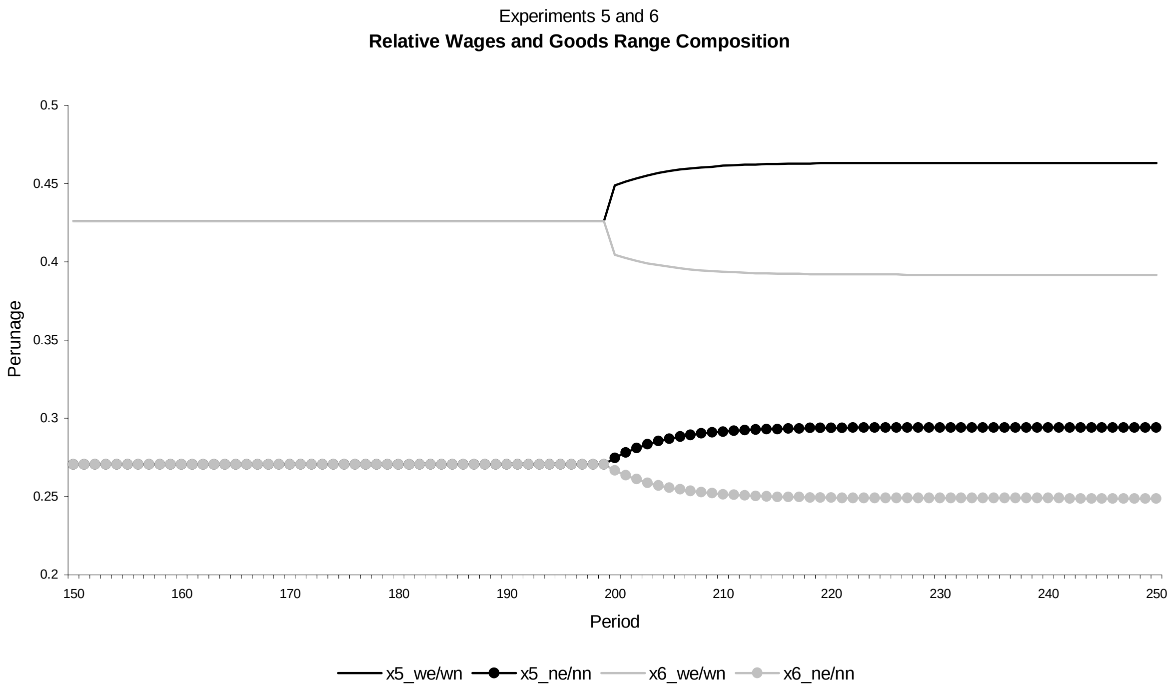


Figure 14

The labour productivity shock experiments are done to check for the impact of sector specific factor augmenting technical change. This experiment has essentially the same impact as increasing the availability of labour to one of the production sectors. The difference when comparing experiments 5 and 6 to experiments 1 and 2 is that now the shocks are exactly opposite. This is because the impact on the R&D sector is now marginal. A 10% increase in productivity is quite something else to the R&D sector than a 10% increase in their potential labour force. The level effects on wages and profits are larger but we return to almost the initial steady state situation after a few periods. There are no surprises in Figures 14 to 20 worth further mentioning.

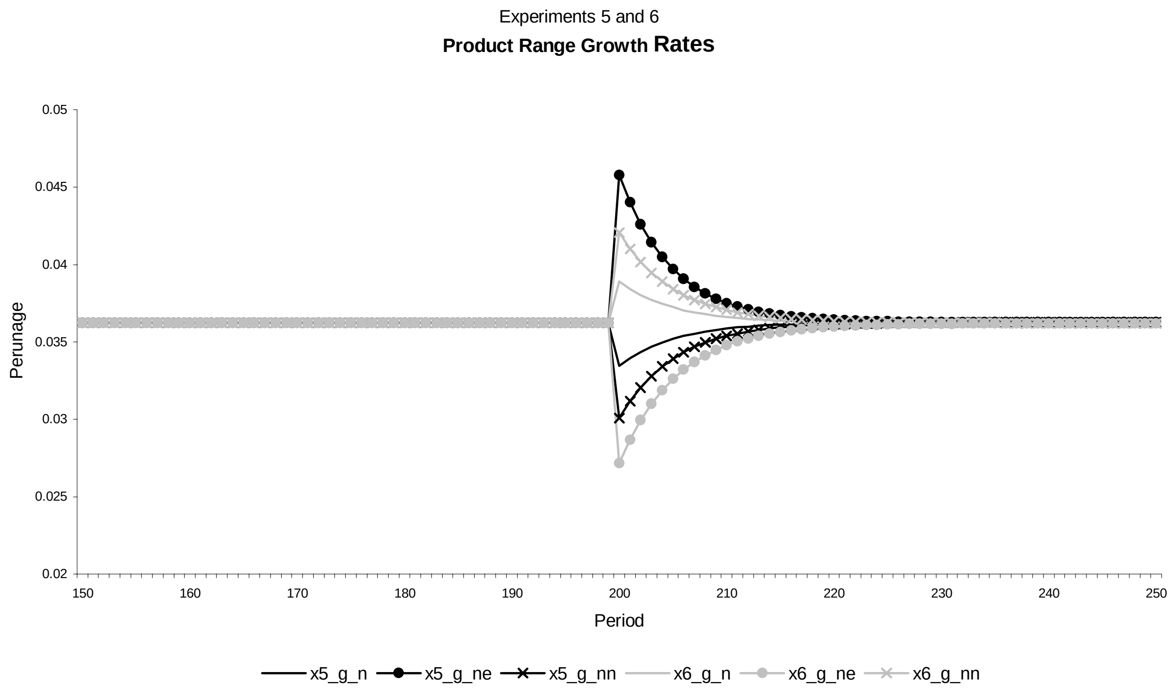


Figure 15

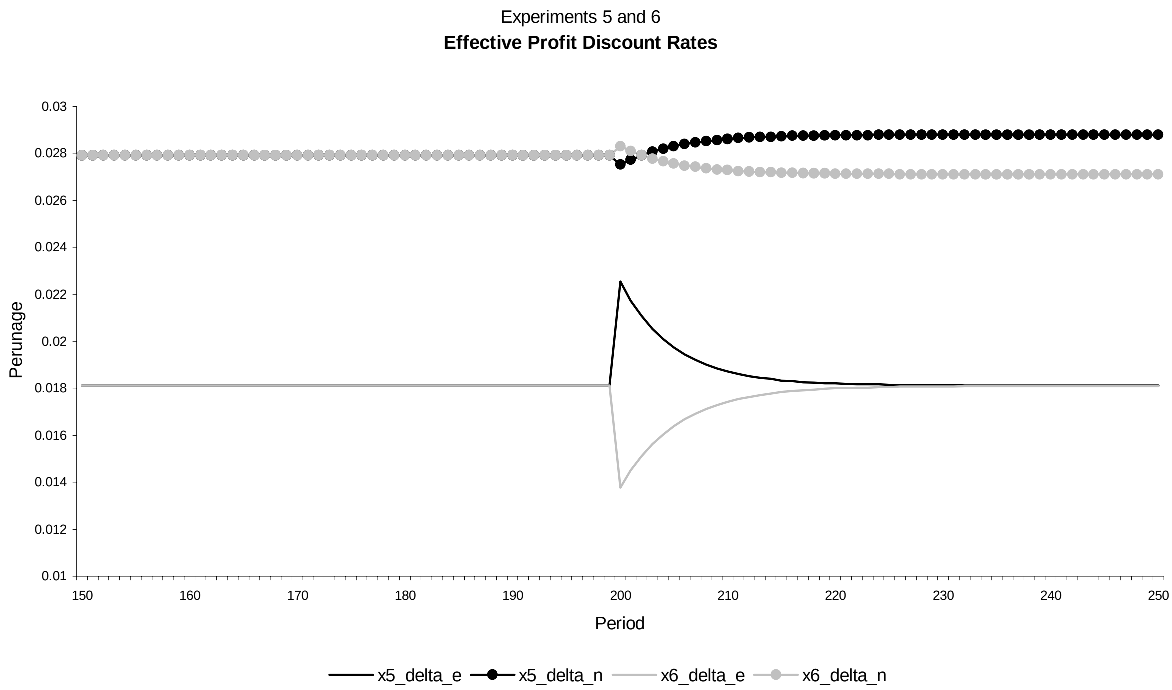


Figure 16

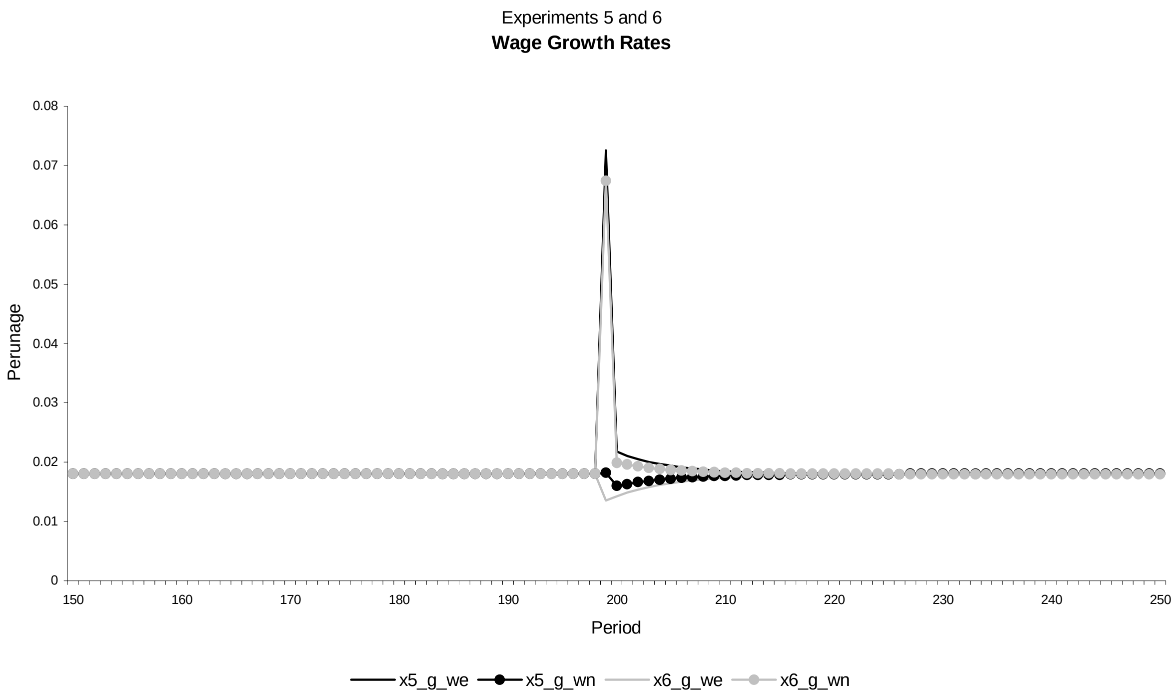


Figure 17

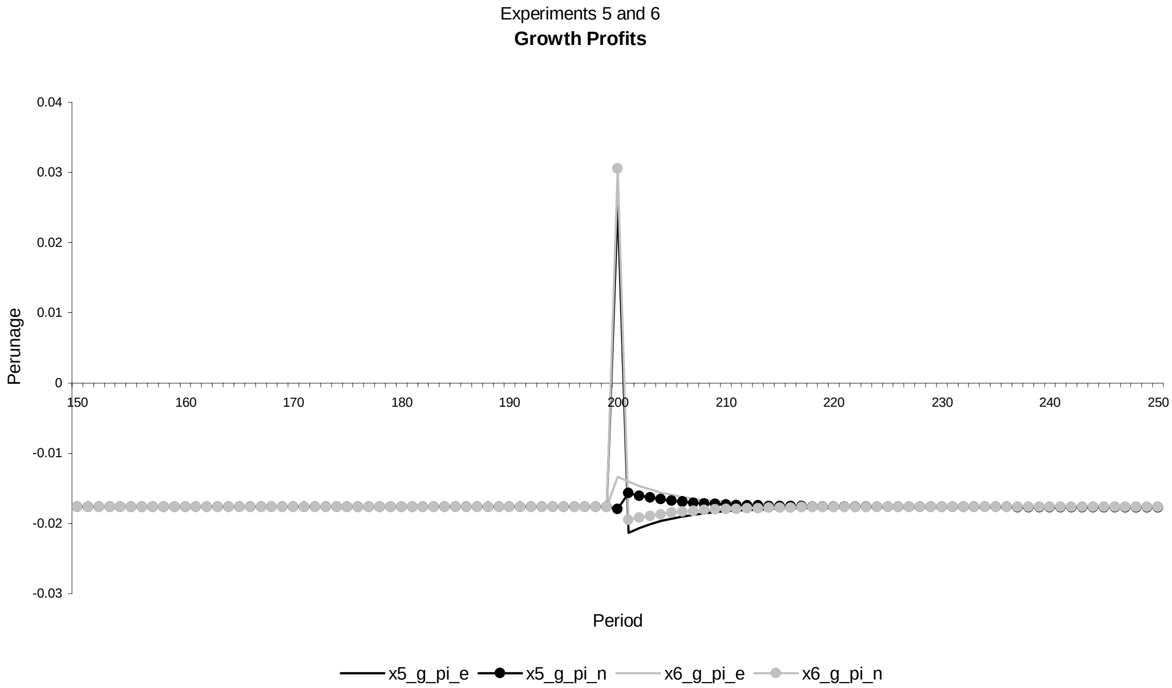


Figure 18

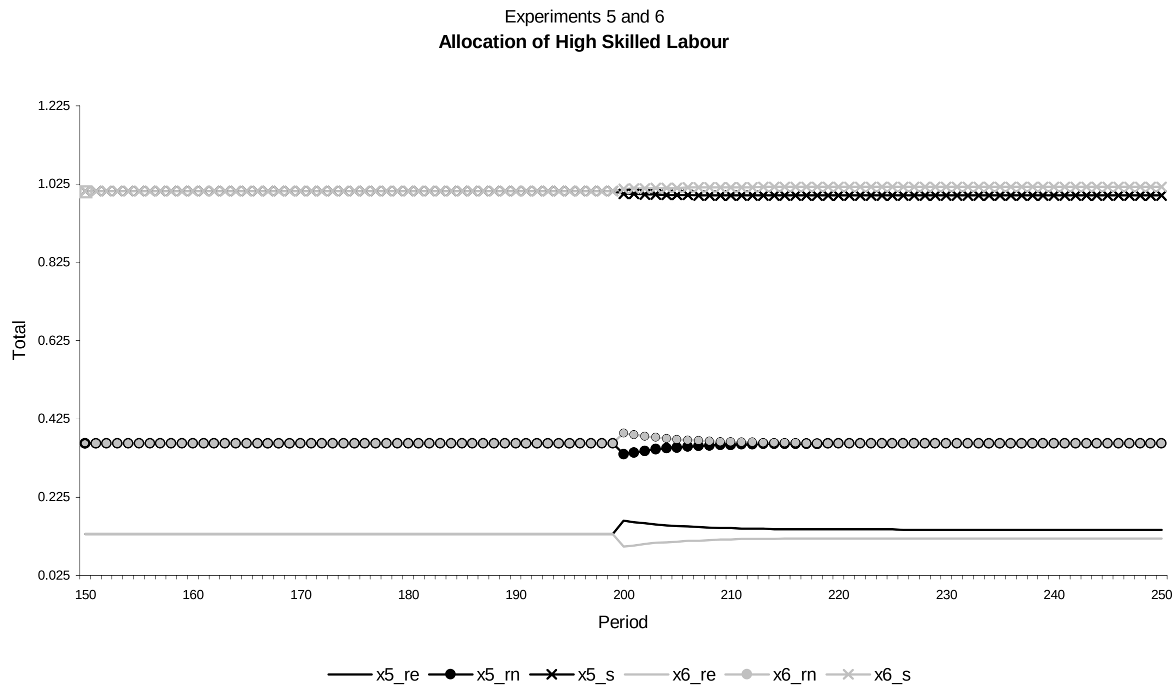


Figure 19

Experiment 7: Wage Leadership

In this experiment, we wanted to see how the model would behave if we would introduce a restriction on the relative wage. One can think of a legal minimum wage set as a percentage of the high skilled wage or some more elaborate bargaining schemes in which relative wages matter as in Muysken, Sanders and van Zon (1999). In this experiment we set the minimum wage in the low skilled market equal to a geometrically weighted average of leading sector wages (weight 10%) and the follower sector market-clearing wage (90%) from period 200 upto 250. As such, an increase in high skilled wages by 10% would cause the low skilled wage to go up by 1%. Of course, in such a framework there is also unemployment of the low skilled workers.

The simulation shows that this policy results in permanently higher relative wages for the low skilled and a smooth transition to a new steady state composition of the goods spectrum (Figure 20). Overall growth increases initially as the reduction in profitability in the established sector causes R&D firms to reallocate towards new goods invention, which has a positive spillover effect on the generation of established products (Figure 21).

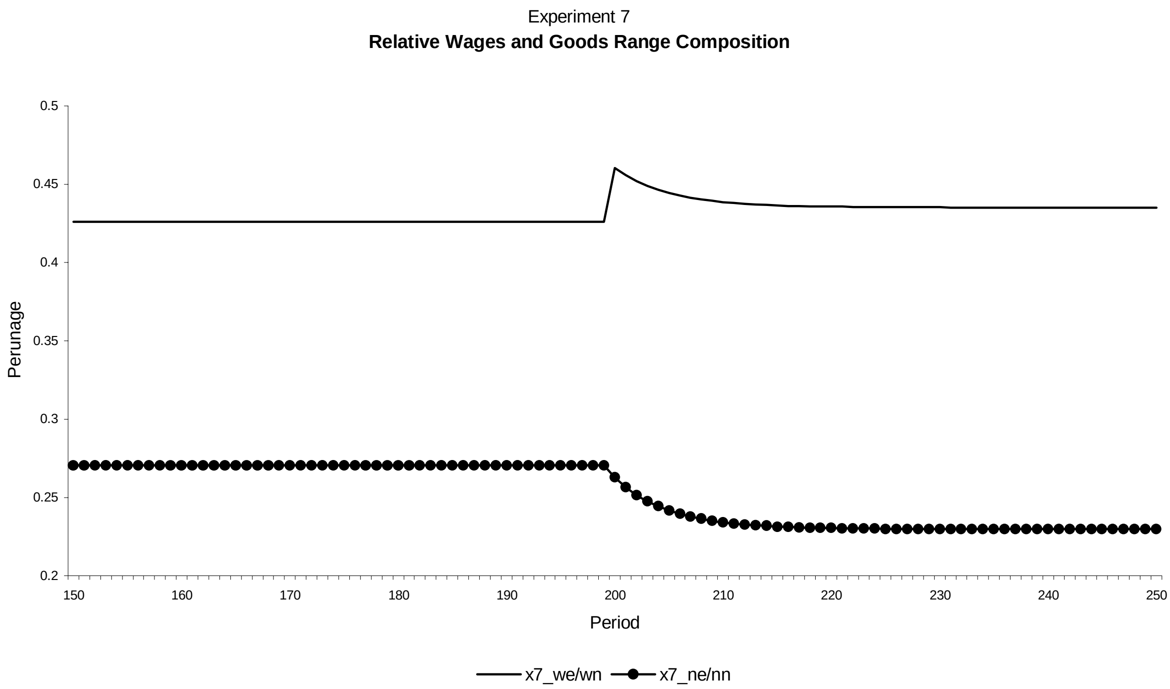


Figure 20

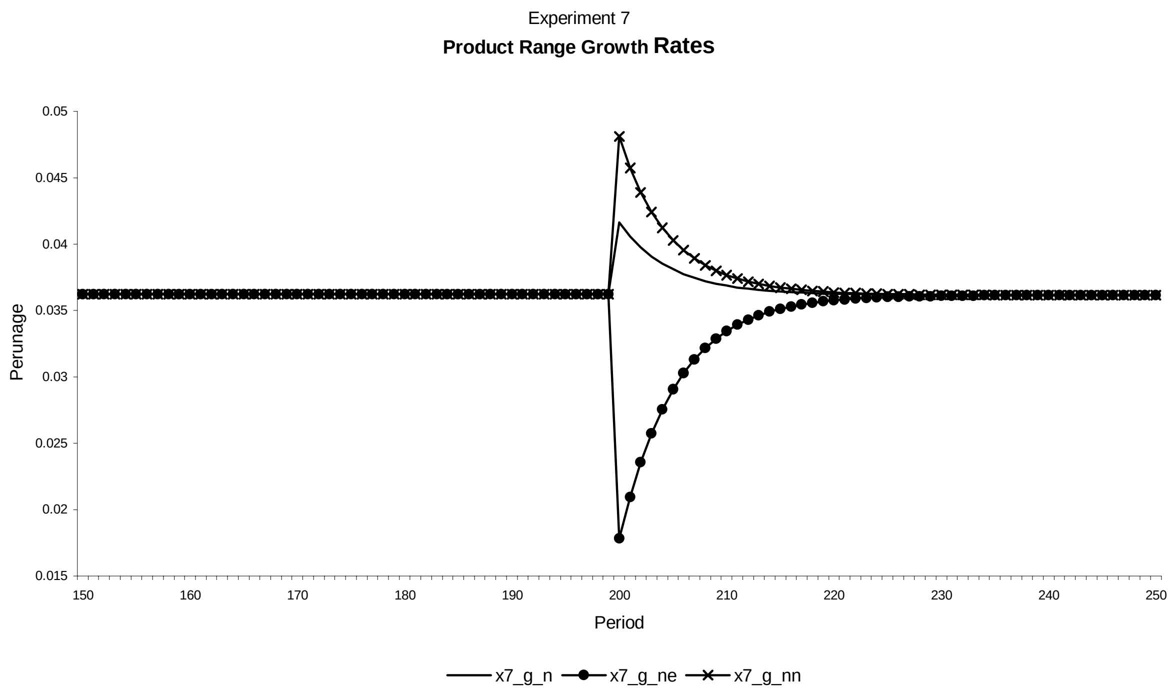


Figure 21

This is in line with Kleinknecht (1998), who argues that wage moderation as an employment policy may be self-defeating in the long run because of the negative impact this may have on innovative activity. However, in our model, this growth effect fades away in about 30 periods. Wages eventually grow at the same rate after a level increase in the initial period, hence all workers earn more after the experiment (Figure 23). There is a major drawback to this type of policy, however. The unemployment rate among low skilled workers will jump to about 15% initially and stabilise only after some 20 years at a level of about 16%. In our model, these people are without income and are thus definitely worse off. For the economy as a whole, however, their exit might be beneficial in terms of growth of the economy. The high skilled benefit from the wage link due to higher wages. The low skilled who are actually employed will also benefit.

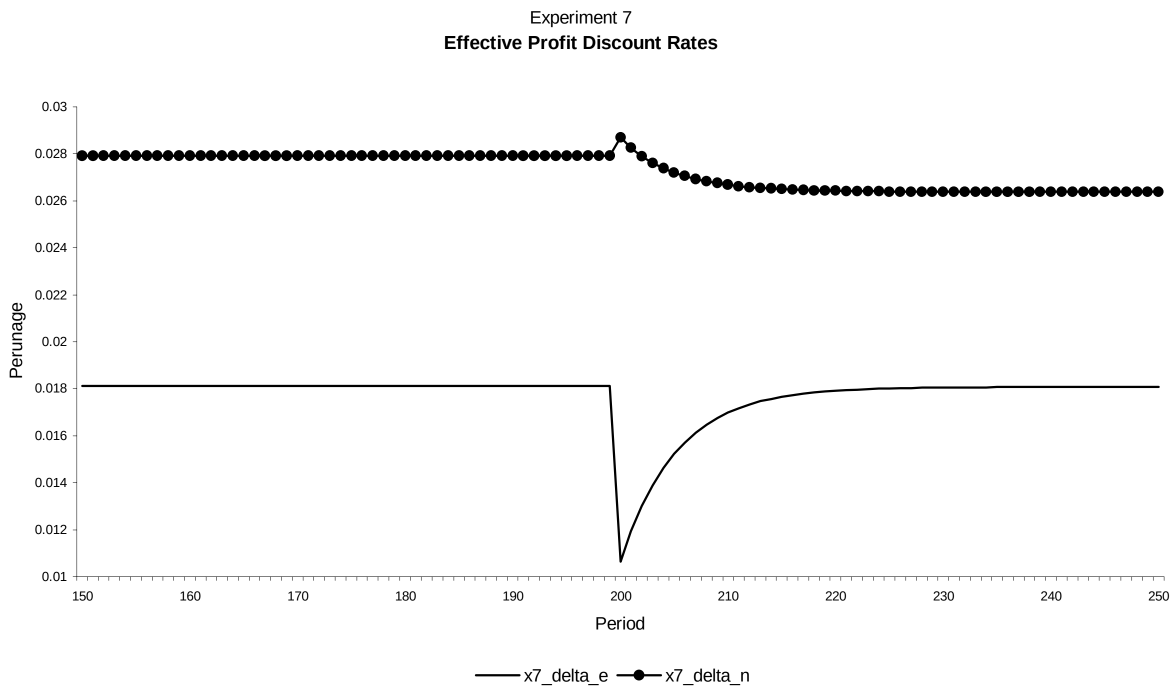


Figure 22

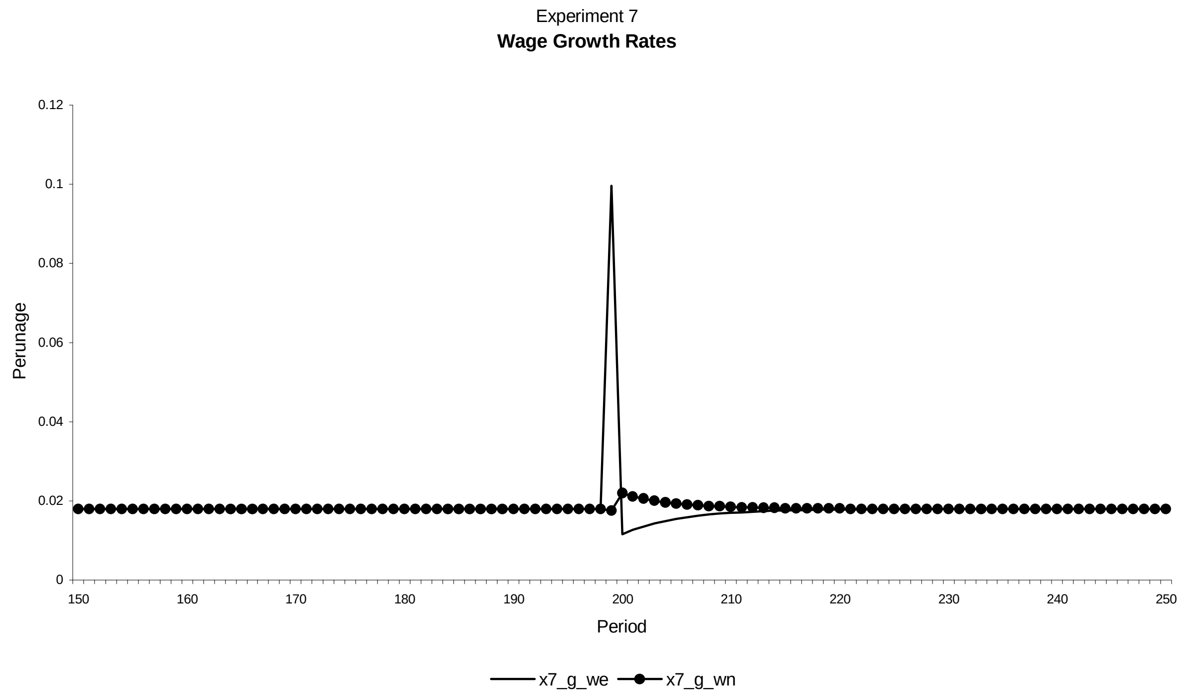


Figure 23

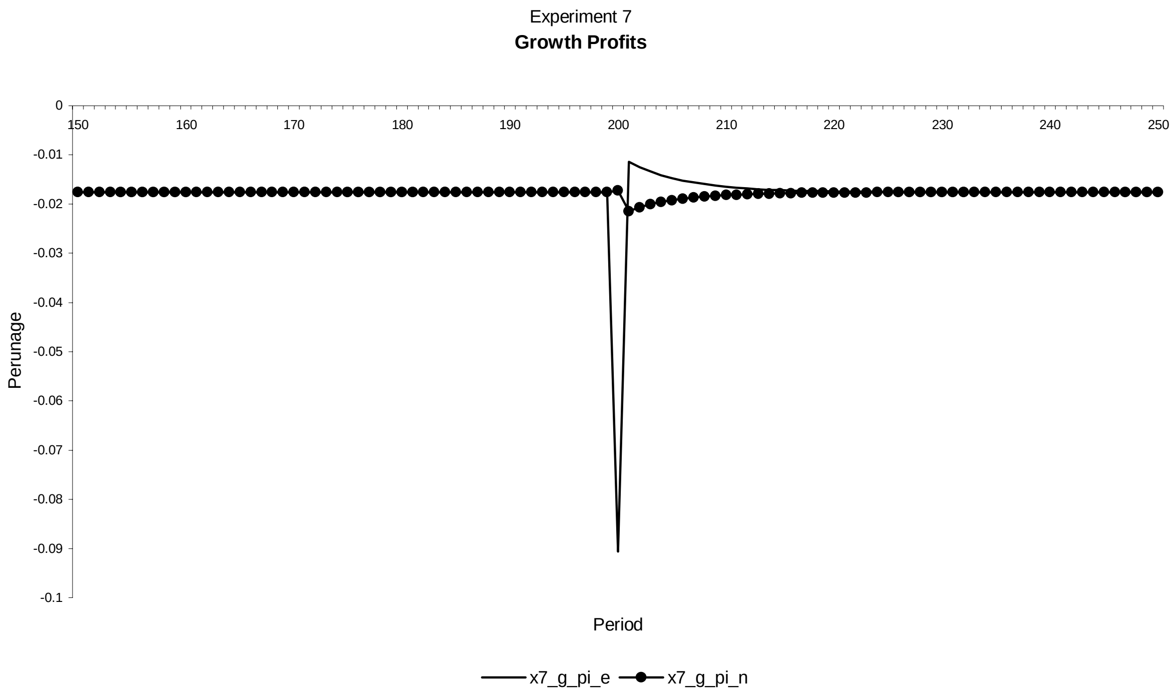


Figure 24

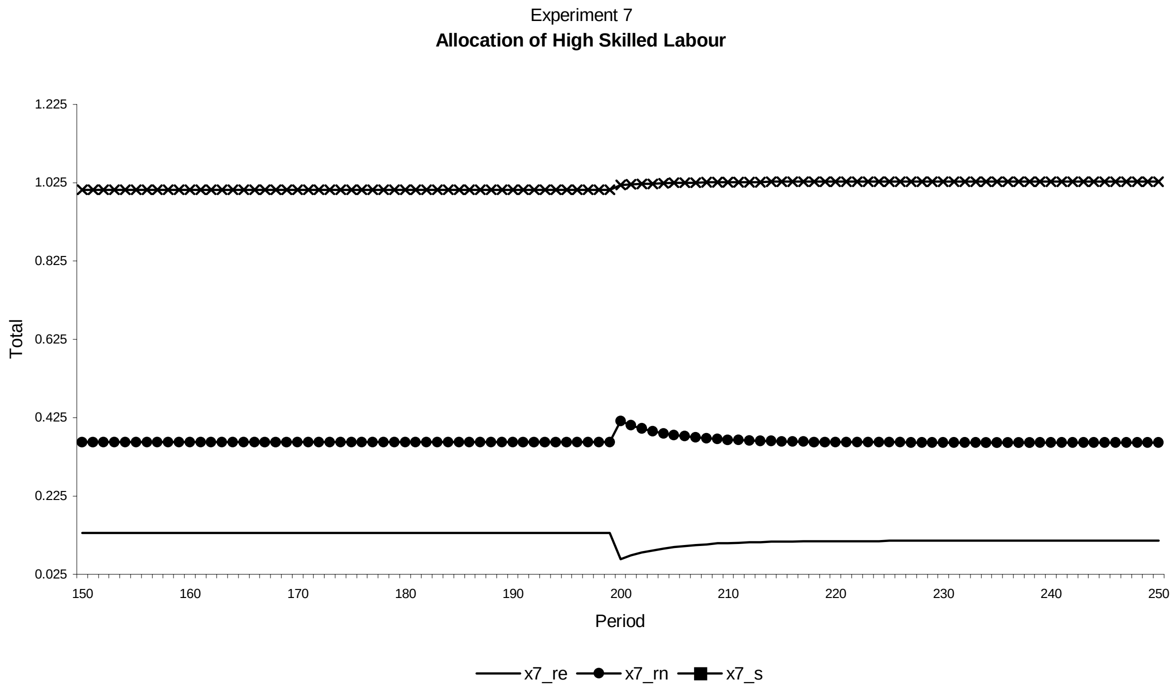


Figure 25

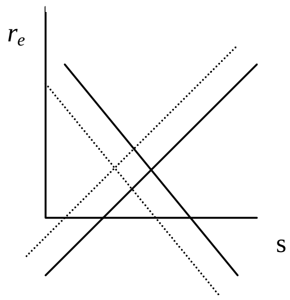
5. Concluding Remarks

In this paper we have presented a model that addresses the issue of the uneven distribution of employment opportunities over low- and high-skilled workers in a context of skill-biased endogenous technical change. In our model, technical change consists in part of product innovation. There is also process innovation to the extent that new products can be produced in two different ways, either using high-skilled workers, or using low-skilled workers after adapting the production process of a new product. The model combines elements from Krugman's (1979) North-South framework, Vernon's (1966) life-cycle hypothesis and Aghion and Howitt's (1992) work on creative destruction. Because it is difficult to describe the working of the model in analytical terms only, we have run some illustrative model simulations using fake data. We have experimented with changes in labour market supplies, productivity shocks, but also with wage leadership. To some extent, productivity shocks can be compared to labour market supply shocks in terms of their impact on the supply of labour (measured in efficiency units) relative to demand. However, there are also differences, in that productivity shocks may reduce real production costs more than an equivalent labour supply shock would do through the induced pressure on wages. We have also performed a wage leadership experiment, where the development over time of low-skilled wages is linked only partially to that of high-skilled wages. The result is that part of the gap between high-skilled and low-skilled wages is bridged at the expense of the occurrence of unemployment for the low-skilled. However, the experiments also show that raising the relative wages for the low-skilled also raises growth. This is reminiscent of Kleinknecht's (1998) contention that moderate wage growth makes for slow technical change.

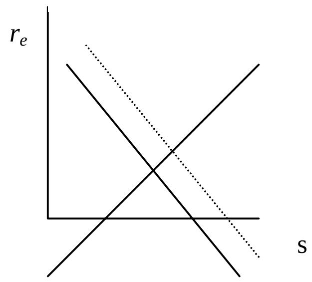
Annex A. Sensitivity Analysis.

In this annex we illustrate how the equilibrium allocation of high-skilled labour changes for varying values of the system parameters. We reproduce Figure 1 and indicate how equations (18.A) and (18.C) will shift in the r_e,s –space. (18.A) is represented by the upward sloping line, while the downward sloping line represents (18.C). The new curves are the dotted ones.

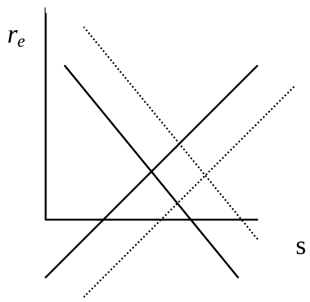
$\kappa_e \uparrow \Rightarrow r_e\,?, s \downarrow$



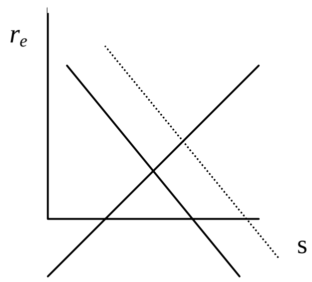
$\kappa_n \uparrow \Rightarrow r_e \uparrow, s \uparrow$



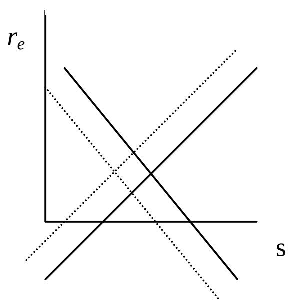
$\rho \uparrow \Rightarrow r_e\,?, s \uparrow$



$\bar{h} \uparrow \Rightarrow r_e \uparrow, s \uparrow$



$\bar{l} \uparrow \Rightarrow r_e\,?, s \downarrow$



Annex B. Stability Issues

As stated in the main text, we can use equations (18.A) and (18.B) and write the growth rates of n_e and n_n as given in (12.A-12.C) in terms of s and z. Introducing the notation y=1+z, and setting $\rho = 0$ for simplicity, we have:

$$\hat{n}_e = \frac{y(\overline{h}\alpha^2 - s(1-\alpha+\alpha^2))\kappa_e\kappa_n}{y^2\alpha^2\kappa_n - y((1-\alpha)\alpha\kappa_e + \alpha^2\kappa_n)) + (1-\alpha)\alpha\kappa_e} \tag{19.A}$$

$$\hat{n}_n = \frac{y^2(1-\alpha)s\kappa_n^2 + y\kappa_e\kappa_n(s-\alpha\overline{h})}{y\alpha^2\kappa_n - (1-\alpha)\alpha\kappa_e} \tag{19.B}$$

Note that we only have to know the behaviour of (19.A) and (19.B) for y>=1, since that implies that z>=0. For y=1, the denominator of (19.A) is equal to zero. Moreover, the parameter constraint $\frac{\kappa_n}{\kappa_e} >= \frac{1-\alpha}{\alpha}$ ensures that the derivative of the denominator of (19.A) with respect to y in y=1 is positive. Since the denominator is a quadratic function in y that reaches a minimum for y<=1, it follows that the denominator of (19.A) is positive for all relevant values of y>=1. This implies that for $s >= \frac{\alpha^2\overline{h}}{1-\alpha+\alpha^2}$, $\hat{n}_e$ is a negatively sloped but positive function of y.[8]

With regard to $\hat{n}_n$ we can follow a similar approach. First note that the denominator will be positive for all values of $y >= \frac{(1-\alpha)\kappa_e}{\alpha\kappa_n}$. Since we require y>=1 anyway, this is not a binding constraint on y. The numerator is again a quadratic function in y that has a minimum extreme value. It has two roots, namely y=0 and $y = \frac{(s-\overline{h}\alpha)\kappa_e}{s(\alpha-1)\kappa_n}$. If we would require the latter root to be smaller than 1, $\hat{n}_n$ becomes a rising function of y for y>=1. But this requires that $s >= \frac{\alpha\kappa_e\overline{h}}{\kappa_e + (1-\alpha)\kappa_n}$. By substituting the constraint $\frac{\kappa_n}{\kappa_e} >= \frac{1-\alpha}{\alpha}$ in the previous result,

[8] For α=1/2, as we have assumed it to be the case, it follows that this requires s to be larger than one third of total high-skilled labour supply, which does not seem to be a very binding constraint in practice.

we obtain an even stronger constraint on *s*, namely $s >= \frac{\alpha^2 \overline{h}}{1-\alpha+\alpha^2}$. But we already accepted this constraint in order to have $\hat{n}_e$ as a negatively sloped function of *y* (see above). Given these parameter constraints, this implies that $\hat{z} = \hat{n}_e - \hat{n}_n$ is a negatively sloped function of *z* with a point of intersection with the horizontal axis at a positive value of *z*. This is depicted in Figure B.1, where the dotted downward sloping line represents $\hat{z} = \hat{n}_e - \hat{n}_n$. It intersects the horizontal axis for a value of *z* implicitly given by equation (14).

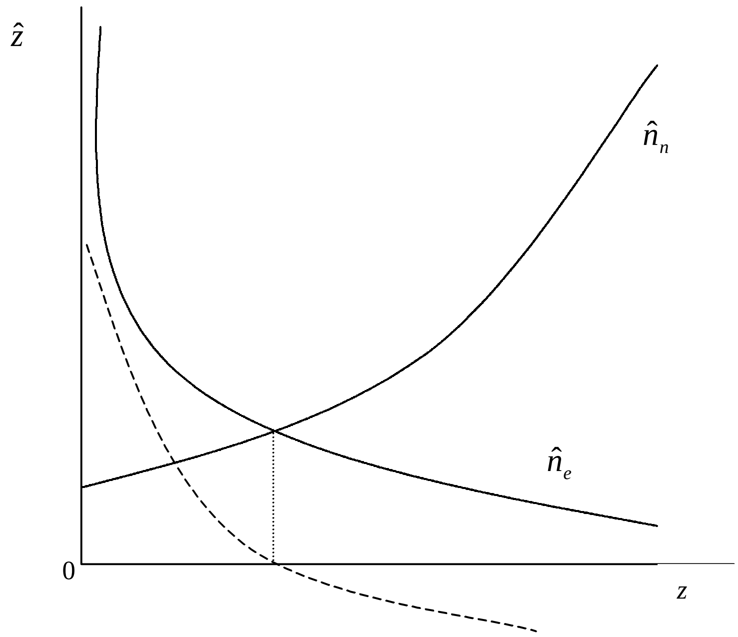


Figure B.1

It should be noted here that equations (19.A) and (19.B) still depend on *s*. It is possible to obtain the derivative of *s* with respect to *z* by implicit differentiation of the full employment constraint for high-skilled labour after substitution of (18.A) and (18.B). However, the sign of $\frac{ds}{dz}$ is unclear. Nonetheless, from equations (19.A) and (19.B) it is clear that a rise in *s* would shift both solid curves in Figure 2 in an upward direction. But in case of $\hat{n}_e$, the shift is largest for small values of *z*, while in case of $\hat{n}_n$ the shift is largest for large values of *z*. This has the effect that a change in *s* will primarily change the slope of $\hat{z} = \hat{n}_e - \hat{n}_n$ and less so the equilibrium value of *z*.

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