

# Vested Interests and Resistance to Technology Adoption <sup>†</sup>

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## *Abstract*

Employed technologies differ vastly across countries. Within countries many technologies that would obviously improve firms' efficiency are not adopted. This paper explains these observations by emphasizing that a new technology positively affects workers by lowering prices and increasing their real income, but also negatively by costs of getting acquainted with the new technology. If the costs of adoption for workers exceed the benefits, they will aim at keeping the old technology in place. We formalise the trade-off in a simple OLG model with majority voting. Age groups that lose from adopting resist. Successful resistance blocks adoption and hence lowers growth. Finally, we analyse the effects of tougher competition. Provided that consumption and leisure are relatively good substitutes, tougher competition mitigates resistance and thus favours economic growth as it increases the share of the rent associated with the new technology that is being captured by the workers.

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## *Abstract*

Employed technologies differ vastly across countries. Within countries many technologies that would obviously improve firms' efficiency are not adopted. This paper explains these observations by emphasizing that a revolutionary new technology positively affects workers by lowering prices and increasing their real income, but also negatively by costs of getting acquainted with the new technology. If the costs of adoption for workers exceed the benefits, they will aim at keeping the old technology in place. We formalize the trade-off in a simple OLG model with majority voting. Age groups that lose from adopting resist. Successful resistance blocks adoption and hence lowers growth. Finally, we analyse the effects of tougher competition. Provided that consumption and leisure are relatively good substitutes, tougher competition mitigates resistance and thus favours economic growth as it increases the share of the rent associated with the new technology that is being captured by the workers.

## **1. Introduction**

Do firms in the same industry apply the same and best-practice technology? Do all countries use the same technology? The answers to these questions are obvious: Technologies employed by different firms and in different countries differ tremendously, even in modern times with the huge advances in travel and communication technology. "Germans have been shocked by the weak technical standards in Britain" is not a quote from decades or centuries ago, but actually from 1998.<sup>1</sup> Such differences in technology are hard to understand by relying on the standard view on technology that treats technology as a public good that is accessible to everybody at no cost. The question becomes urgent why not everybody is employing best-practice technologies, even though these technologies are known and yield, by standard means of calculation, a

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<sup>1</sup> *The Economist*, 5<sup>th</sup> December 1998. About German BMW assessing productivity in the British Rover factories.

positive net present value. In, for example, the field of environmental economics, much attention has been paid to this seemingly paradoxical evidence that firms do not employ those environmentally friendly technologies that, according to standard calculations, yield positive net present values. This paradox is often referred to as the 'energy efficiency paradox' and has given rise to an extensive literature trying to resolve it.<sup>2</sup>

Several explanations have been explored. Firstly, technology could be localized, meaning that the technology is available but useless with the given production technique.<sup>3</sup> This perspective explains why a seemingly better technology may actually not be superior in specific circumstances. Such a perspective might shed light on cross-country differences between widely different countries, but does not explain why in seemingly similar countries best-practice technologies are not implemented. Secondly, asymmetric information resulting in capital market imperfections, or information costs resulting in bounded rational behaviour might explain seemingly sub-optimal behaviour. Thirdly, uncertainty with respect to future pay-offs may prevent firms from investing given that the investments are often to a large extent irreversible (for example, Dixit and Pindyck, 1994).

The perspective we take in this paper is one in which we argue that adoption of a major new technology is costly. Jovanovic (1995) argues, for example, that adoption costs outweigh invention costs roughly a factor 20 or 30 to 1. Also, evidence that diffusion lags for new technologies are long suggests that sizeable adoption costs are at work. Opposite to common approaches (for example, Parente 1995, Parente and Prescott, 1994), we focus on the costs that workers have to bear. Alongside firms' installation and instruction costs, workers have to learn to use the new technology. An example is a training program for a new technology that will be offered to employees during normal leisure hours instead of during working time. In the latter case, training

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<sup>2</sup> See for example Howarth and Andersson (1993), Jaffe and Stavins (1994) and Sutherland (1991).

<sup>3</sup> Localized technological progress (Atkinson and Stiglitz, 1996, Stiglitz, 1987, and Antonelli, 1995) or appropriate technology as Basu and Weil (1996) call it, provides a potential micro-economic foundation for the specificity of knowledge. The basic idea of localized learning is simple: learning-by-doing or innovation does not shift the *total* isoquant inward, but only the part that is actually used (hence where the initial technology choice was optimal given the factor prices). So with different factor endowments a poor country is unable to acquire total factor productivity levels of a rich country, as the technology requires the factor endowments of rich countries.

hours effectively reduce production time so that firms bear the costs in terms of foregone production. In the former case it is the employee who has less leisure time left. Hence, the distribution of the adoption costs among different groups of workers, as well as among firms on the one hand and workers on the other is relevant. In this paper, we focus on these distributional issues.

The story this paper tells is simple. First, the net benefits from adopting a revolutionary new technology may be unevenly distributed among workers when workers are heterogeneous. The heterogeneity is captured by differences with respect to age. Older workers could be more hesitant to a new technology since they have to go through a costly learning process, whereas they are not able to reap the full benefits from working with the new technology. Young workers are more willing to accept a new technology since they can recover the cost of training more easily, simply because their remaining lifetime is longer. Second, the share that workers get of the rent that is associated with improving the technology will generally differ from the share that the firm gets. This difference may depend on, for example, the competitiveness of the industry in which firms are operating (an idea that is also present in Aghion and Howitt, 1998, and Prescott, 1998). Once a majority of the workers calculates that the net benefits of the new technology are negative, they will block the new technology by a majority vote over the allowance for the new technology. We thereby explicitly recognize that a firm is a collection of individuals, which cannot be modelled as an entity with a single mind. Although we model the decision to adopt a technology by voting, one might as well think of it as a decision influenced by resistance activities. In the most general interpretation, these activities include threats of worker disobedience, threats of consumer boycotts, loss of political sympathy, etc.

The idea that new technologies or innovations are met with resistance is not new. As Machiavelli (1961, p. 51) pointed out, “There is nothing more difficult to arrange, more doubtful of success, and more dangerous to carry through, than to initiate a new order of things. ... Men are generally incredulous, never really trusting new things unless they have tested them by experience.” In a similar spirit, Schumpeter argued that “... in the case of something new being attempted, the environment resists while it looks on with – at least – benevolent neutrality at repetition of familiar acts. Resistance

may consist in simple disapproval – of machine-made products, for instance – in prevention – *prohibition* of the use of new machinery – aggression – smashing new machinery.” (1939, p. 100, italics added). Though in our formal analysis the focus is on voting over prohibition, the broader interpretation should be kept in mind when evaluating the results.

The basic conclusion we arrive at in this paper is that new technologies that carry a substantial cost, that is necessarily borne by workers, are unlikely to be adopted. Moreover, in anti-competitive environments it is more likely that a new technology is resisted as the share of the rent associated with the new technology that accrues to workers is relatively small, making them more hesitant towards adoption.

The analysis adds to the literature on population ageing by emphasizing the relation between age distribution and technology adoption: economic growth may be reduced in an ageing society as the willingness to adopt new technologies is decreasing in remaining lifetime. Hence, the paper provides a complementary perspective on problems related to the age distribution of the population - besides issues in relation with savings and pensions.

The analysis in this paper proceeds as follows. The next section discusses historical and anecdotal evidence on resistance to technological change. Section 3 presents the model we develop to analyse the adoption of technology and discusses the most important assumptions. The basic framework is as simple as possible. Hence initially we abstain from issues related to entry and exit of firms, endogenous supply of labour, and endogenous costs of learning to use the new technology. These assumptions will be discussed and relaxed later on. The trade-offs different generations face and the way in which the generational composition of the economy affects the likeliness of a technology being blocked by workers is discussed in section 4. Attention will also be paid to endogenizing learning costs. Section 5 evaluates the impact of competition policy. Having discussed the basic model, we turn to some extensions in sections 6 and 7. In particular, section 6 analyses the model under free entry (and thus an endogenously determined number of firms). In section 7 we study the robustness of the characteristics of the model by allowing for a more general utility function. Section 8 concludes and discusses some potential extensions of the simple framework developed

in this paper.

## **2. Resistance to technology**

This section argues by means of anecdotal and descriptive historical evidence, that resistance to technology is a potentially powerful explanation for the lack of implementation of “best-practice” technologies. A convenient framework for the analysis of resistance to technological change distinguishes three separate but related layers. First, as technological progress can be viewed as a positive-sum game, it is not immediately obvious that resistance should arise at all. For resistance to arise there should be losers alongside the winners.<sup>4</sup> Hence, the first layer explores the underlying incentives for resistance activities. The second layer explores the action of resistance, hence whether the incentive for resistance fulminates in, for example, violence, regulations or unionism. The third layer consists of the consequences of the actions taken, namely the dynamic and static inefficiencies that arise due to effective resistance.

Section 2.1 explores, by means of analysing descriptive (historical) material, mostly the second perspective, that is, what type of resistance will lead to non-adoption of technology. Section 2.2 discusses theoretical approaches to the economics of technology resistance. This is a literature that deals rather implicit with the actual resistance activity and focuses on the incentives and resulting inefficiencies.

### *2.1 Resistance*

The failure to adopt new technologies may derive from various sources. The first and historically very relevant obstacle to the adoption of new technology is violence and effort to get political acclaim for the request to stick to the status quo in production technology. A difference in the extent and success of resistance to technology is one of

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<sup>4</sup> Though obvious, the necessity of distinguishing between groups that tend to lose and groups that tend to win from technological progress immediately reveals that a symmetric, homogeneous-agent framework is insufficient for our purpose.

the, admittedly many, pieces of the puzzle of why the Industrial Revolution occurred in Britain and not on the Continent. A piece, moreover, that is “barely...explored” and “dimly understood” (Mokyr, 1990, p. 255, 266). The Industrial Revolution brought gains to consumers and a few innovators, while the costs were mostly borne by skilled artisans. On the Continent “the old urban guilds became a fetter on technological progress” (p. 258) and workers rioted against spinning machines imported from Britain.<sup>5</sup> The guilds resisted less by outright violence and riots, but more through a vast body of regulations and restrictions. Though resistance was eventually blown over, it retarded the introduction of new technologies on the Continent substantially. A potential explanation for less successful resistance in Britain is the fact that the ruling class had most of its assets in real estate and agriculture; assets whose value was not threatened to be reduced by technological progress. Hence, the British ruling class had no interest in granting workers’ claims for resistance (Mokyr, 1990).<sup>6</sup>

Second, obstacles to the adoption of new technologies may be unions that, by acting in favour of their members, resist labour saving projects. Examples are found in the textile industry in India (Wolcott, 1994) where workers had less incentive to adapt and more ability to resist to the introduction of labour saving technologies. Another example is the United States coal mining industry where strong unions were able to resist technological breakthroughs until they were pressed to give up their resistance due to the availability of cheap oil (Prescott, 1998).

A third, currently most pressing, source of the failures to adopt best-practice technologies derives from regulations and laws that formally prevent technological improvements. Their importance is well established in Baily (1993) and Baily and Gersbach (1995). Baily studies productivity differences in *service* industries<sup>7</sup> operating in Europe, the United States and Japan, and evaluates the role of certain types of

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<sup>5</sup> Mokyr warns not to *identify* machine breaking, commonly observed early in the Industrial Revolution, with resistance to technology. More often this was simply a sign of a labour dispute, as machines were a vulnerable target.

<sup>6</sup> Actually, in Britain destruction of machinery was made a felony punishable by death.

<sup>7</sup> Four major industries are examined: airlines, retail banking, telecommunications, and general merchandise retailing.

regulation and the intensity of competition as a potential explanation for observed productivity differentials. The general lesson to be drawn is that incomplete convergence in service industry's productivity is due to regulatory barriers and lack of competition, causing slack and inhibiting productivity growth. Such barriers could be created by special interest groups, trying to protect their economic interests. A case study of banking stresses the idea that available innovations may not be adopted without the threat of competition. Competition in the banking industry is limited by the regulated structure of this sector, resulting from the fact that most countries considered financial stability as more important than economic (competitive) efficiency. In the United States, however, the regulatory environment has encouraged competition. Overall productivity varies widely in the countries studied. Germany's overall productivity level in banking is about 68% of that in the United States. This productivity gap is due to the failure to exploit economies of scale and scope in German banks with their many small branches, and their less effective use of information technology. Part of the emerging productivity differential between German and United States banks is due to the fact that far fewer transactions per person passed through ATMs in Germany than in the United States, so that German banks need more labour input to dispense cash to their customers. The fact that new technologies such as ATMs were earlier adopted in the United States reflects that competition in the United States banking industry is more intense, forcing banks to cut operation costs and streamline their operations.

International productivity differentials in *manufacturing* are studied in Baily and Gersbach (1995). The major part of the observed productivity differences is caused by the way functions and tasks are organized, and the fact that some companies require less labour and material input by new designs of their products.<sup>8</sup> The question then arises why companies fail to exploit best-practice technologies. An illustrative example is that German breweries are simply forbidden to adopt better technologies that are used

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<sup>8</sup> Nine industries (automobiles, automotive parts, metalworking, steel, computers, consumer electronics, food, beer, soap, and detergent) in three countries (Germany, Japan, and the U.S.) are studied. Baily and Gersbach find that physical capital and embodied technology can account for part of the productivity-differential. The major part of productivity differences, however, is to be found elsewhere (in technology and/or organization).



in the United States and Japan. Baily and Gersbach suggest that exposure to the most efficient producers through global competition will speed up the adoption of new technology and promote efficiency.

Besides all mechanisms driven by some explicit loss, one might argue that “In every society, there are stabilizing forces that protect the status quo. Some of these forces protect entrenched vested interests that might incur losses if innovations were introduced, others are simply don’t-rock-the-boat kinds of forces. Technological creativity needs to overcome these forces” (Mokyr, 1990, p. 12). How strong and pervasive these pressures can be, exerted in the old days by for example guilds, has been nicely illustrated by Olson (1982) in his book on *The Rise and Decline of Nations*. In his description of the operation of the caste groups in India, he argues that these groups controlled lines of business, kept crafts mysteries or secrets, used boycotts and strikes and were organized with a strong emphasis on obedience to the rules of the caste ruling out competition.

Despite overwhelming evidence of the relevance of resistance activities, more formal analysis is scarce. A sketch of the available contributions will be discussed in the next section.

## *2.2 Related theoretical literature*

As mentioned earlier, the theoretical literature on technology adoption mainly focuses on the adoption costs for firms. One important exception is Helpman and Rangel (1998). They focus on the short-run response to an arrival of a General Purpose Technology (further GPT), and answer the central question under what conditions the arrival of a GPT causes a decrease in aggregate productivity. At the heart of the analysis is a (continuous) overlapping-generations framework. Two basic effects are distinguished, namely (i) an adoption effect and (ii) an entry effect. The adoption effect results from the fact that the introduction of a new technology makes old experience worthless, implying a temporary drop in productivity for those who adopt. In addition there is an entry effect, which may be positive or negative. It is positive in case the new

technology requires less schooling and results in students leaving school earlier than expected (the case of technology-skill substitutability). It is negative in case the new technology requires additional schooling and results in more people going to school instead of producing (the case of technology-skill complementarity). The general conclusion is that the arrival of a new GPT can trigger off a temporary slowdown in growth. This is the more likely, the higher the required educational level to operate the new technology, the more experience is lost upon adoption of the new technology and the faster experience is generated when using the new technology (making adoption more attractive).<sup>9</sup>

Adoption when technology arrives in a continuous stream, opposite to the once-and-for-all nature of technological change in Helpman and Rangel (1998), is analysed by Chari and Hopenhayn (1991). In a two-generation OLG economy they show that vintage-specific human capital of the old, accumulated through learning-by-doing when unskilled and young, leads to slow adoption of new technology if newborn unskilled are highly complementary with human capital of the old.<sup>10</sup> Jovanovic and Nyarko (1996) show in a similar vein that in a one-agent model, even bounded learning-by-doing might be detrimental to growth. Abundance of expertise with a specific vintage that is non-transferable to a new vintage (specific human capital) locks the agent in.

Complementary to our work is Caselli (1999) who analyses adoption of technology in a model with heterogeneous agents. The heterogeneity is reflected in the cost of learning to work with the next generation technology. Where we stress the heterogeneity on the benefit side (lifetime benefits depend on age), Caselli emphasizes the cost side by pointing at differences in ability.

A theoretical contribution that is closely related to ours is Holmes and Schmitz (1994, further H&S). They focus on the effects of trade on technology adoption.

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<sup>9</sup> Some unattractive features of the model are that it is not a general-equilibrium model and that the old and the new technology can co-exist.

<sup>10</sup> Krusell and Ríos-Rull (1996) introduce a dynamic political process in the Chari and Hopenhayn (1991) model and analyse stagnation and growth equilibria. Our one-shot voting approach simplifies on the political process compared to Krusell and Ríos-Rull's dynamic voting process (where the current policies' consequences for future political equilibria are taken into account). We, however, extend their discussion by focussing on the general equilibrium effects of competition on regime switches from stagnation to growth.

Workers are modelled as being skilled in that they have a technology-specific advantage in one sector of the economy. As this relative advantage is to be lost if adoption takes place, skilled workers might opt for resistance to a new technology. Blocking technology is modelled as a legal ban on consumption of goods produced with the newly available technology or on the use of the newly available technology. In a closed economy these two are identical. The cost of blocking a technology by skilled workers, by means of resistance, is weighted against the real income gain.<sup>11</sup> The main conclusion is that tradeability of goods acts as an important disciplinary device, as non-adoption, to keep specific rents, is ineffective because the rents will be competed away by foreign firms who will adopt (by assumption).

Our paper differs in several important ways from H&S. Firstly, we introduce heterogeneity by age whereas H&S distinguish workers who have or don't have technology specific skills. This allows us to study the relation between age structure and technology adoption. Secondly, our paper differs from H&S with regard to competition. We have imperfect competition, whereas H&S have perfect competition. Furthermore, competition, in our paper is (also) a domestic concept, whereas H&S only consider changes from autarky to free trade.

### **3. A simple framework**

We study the adoption decision of a new technology in a simple overlapping generations model. Consider an economy with a large number of individuals. At time

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<sup>11</sup> Erecting a barrier increases the price of the manufacturing good relative to the no-barrier case, so that real income is decreased. However, skilled workers' income might increase if a barrier is erected. If skilled workers are relatively scarce, a barrier causes the price of the manufacturing good to be relatively high, as it is determined by the marginal rate of transformation of unskilled workers between the two goods (who in both activities are equally productive). In that case a skilled worker's marginal product is higher with a barrier. If skilled workers are relatively abundant, their income equals that of unskilled workers as they both produce the non-manufacturing good, in which skilled workers have no advantage.

$t$ , a generation is born of size  $P_t$ . At each point in time, there are three overlapping generations alive, the young, the middle-aged and the old. Total population size at time  $t$  is thus equal to  $P_t + P_{t-1} + P_{t-2}$ .<sup>12</sup> All generations work and are equally productive. Households are endowed with one unit of time, which they can use for working, leisure or education (see below). Total leisure time ( $v$ ) is thus equal to  $1 - l - s$ , where  $l$  is labour time and  $s$  is schooling time. Consumers derive utility from the consumption of a homogeneous good, a composite of differentiated products and leisure. Besides the workers, the economy is inhabited with  $N$  holders of ideas.<sup>13</sup> The possession of an idea enables them to produce a differentiated good. They make profits which they spend on consumption (based on the same homothetic utility function that applies to all other consumers).

The present discounted utility ( $u_t$ ) of an individual born at date  $t$  is given by

$$u_t = \sum_{\tau=0}^2 \delta^\tau \left[ c_{t+\tau,t}^\alpha + \zeta v_{t+\tau,t}^\alpha \right]^{1/\alpha}, \quad (1)$$

where  $\delta < 1$  is the discount factor and  $\zeta$  is the relative preference for leisure. In case two subscripts are added the former denotes time whereas the latter denotes date born. Hence,  $c_{t+\tau,t}$  is utility derived from consuming a bundle of goods at time  $t+\tau$  by an individual born at time  $t$  and  $v_{t+\tau,t}$  is leisure time consumed at time  $t+\tau$  by an individual born at time  $t$ . The elasticity of substitution between consumption and leisure is  $1/(1-\alpha)$ . For the time being we assume that consumption and leisure are perfect substitutes, *i.e.*  $\alpha \rightarrow 1$ . The instantaneous utility function then becomes linear in its arguments. The more general case when  $\alpha < 1$  is studied in section 7. For the moment, we assume that labour

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<sup>12</sup> In what follows, we assume, without loss of generality, that population growth is absent. This implies that  $P_t = P$  at all points in time. In the remainder, we will normalize  $P$  at one-third for presentational convenience.

<sup>13</sup> We abstain from a discussion of inheritance of patents or ideas. The number of idea owners is small compared to the total population and therefore irrelevant for the decision whether or not a new technology will be adopted (which is assumed to be the outcome of a vote among the consumers; see section 4). However, the number of idea owners (and thus the number of varieties of the high-tech good produced in the economy) is assumed to be sufficiently large so that we can assume that firms compete monopolistically (for different modes of competition we refer to Van de Klundert and Smulders, 1997). Moreover, for simplicity, we assume that idea owners do not supply labour on the labour market.

supply ( $l$ ) is perfectly inelastic and equal to  $\bar{l}$  (this assumption is relaxed in Appendix D). The bundle of goods that is consumed consists out of a numeraire good ( $y$ ) and a composite of high-tech goods (labelled  $x$ )<sup>14</sup> which consists of  $N$  varieties of a quality differentiated high-tech good (which are indexed  $i=1, \dots, N$ ). The instantaneous sub-utility function of an individual consumer with regard to the composite consumption good is specified in Cobb-Douglas format:

$$c = x^\theta y^{1-\theta} . \quad (2)$$

This homothetic utility function applies to individuals from all three generations alive who spend their wage income and to the idea owners who spend their profits. The composite  $x$  is defined as<sup>15</sup>

$$x = N^\sigma \left[ \frac{1}{N} \sum_{i=1}^N \check{x}_i^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}} , \quad (3)$$

where  $\check{x}$  is the individually consumed amount of the high-tech good of variety  $i$ ,  $\sigma$  represents the taste for variety, and  $\epsilon$  measures the elasticity of substitution between any pair of differentiated high-tech goods. The numeraire good  $Y$  is produced according to a simple linear technology<sup>16</sup>

$$Y = L_Y , \quad (4)$$

where  $L_Y$  is the amount of labour employed to produce the numeraire good. Labour productivity in this sector is, without loss of generality, taken to be equal to one. Each

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<sup>14</sup> Where it leads to no confusion, we drop indices. Lower cases variables pertain to individually consumed volumes (to be distinguished from macroeconomic volumes which are indicated with capitals).

<sup>15</sup> A discussion of this aggregation function is beyond the scope of this paper. We refer to De Groot and Nahuis (1998).

<sup>16</sup> In equilibrium, it holds that all individual demands of consumers from the three generations alive and the idea owners sum up to total macroeconomic supply of the numeraire good ( $Y$ ).

individual firm in the high-tech sector produces according to the following technology<sup>17</sup>

$$X_i = h_i L_{X_i}^\mu, \quad (5)$$

where  $X_i$  denotes the produced volume of the high-tech good of variety  $i$ ,  $L_{X_i}$  is skilled labour employed in the  $i$ -th intermediate firm,  $h_i$  is its labour productivity, and  $\mu$  indicates a scale effect. The labour market clears so

$$L_{Y_t} + \sum_{i=1}^N L_{X_{it}} = L_t = \sum_{\tau=0}^2 P_{t-\tau} l_{t-\tau}, \quad (6)$$

where  $L_t$  is total labour supply across all generations (in time units). Due to our normalization, we have  $L_t = 3P\bar{l} = \bar{l}$ , which will further be denoted as  $L$ . Note that since workers from different age groups are perfect substitutes, we can simply add them up.

With a given number of idea holders the condition for labour market clearing completes the description of the model. Implicitly, a perfect entry barrier is present in the economy such that the number of firms/ideas is fixed. The sensitivity of our results for this assumption is checked in Section 6. In solving the model, however, we will proceed under the assumption of blocked entry.

We can now straightforwardly solve the model for a given labour productivity and a given number of firms by solving (i) the two-step consumer optimization problem yielding the division of income over the goods available to the consumers and (ii) the profit-maximization problem for producers of the goods (see Appendix A.1 for a detailed description of the model solution). This results in an allocation of labour that looks like

$$L_{X_i} = \frac{\theta\mu(\varepsilon-1)L/N}{(1-\theta)\varepsilon + \theta\mu(\varepsilon-1)} \quad \text{and} \quad L_Y = \frac{(1-\theta)\varepsilon L}{(1-\theta)\varepsilon + \theta\mu(\varepsilon-1)}. \quad (7)$$

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<sup>17</sup> Again, all individual demands of the three generations alive and the idea owners sum up to total supply of the high-tech good ( $X$ ).

So the size of firms in the high-tech sector will be larger the larger the supply of labour ( $L$ ) in time units, the smaller the number of producers ( $N$ ), the more weight consumers attach to the consumption of high-tech goods ( $\theta$ ), the smaller the distortion due to mark-up pricing (*i.e.*, when  $\varepsilon$  is increased), and the more important economies of scale ( $\mu$ ).

#### 4. The decision whether or not to adopt a newly arrived technology

Having established the equilibrium solution of the model, we can now discuss how consumers will react to the invention of a new technology. Suppose that at time  $t_1$  a new, better technology becomes available to produce the quality differentiated high-tech goods. When this technology is adopted, each worker has to incur a cost in terms of foregone leisure time equal to  $s=\bar{s}$  at time  $t=t_1$ . We assume, for simplicity, that the technology can fully be employed in period  $t_1+1$  and is  $\gamma$  times as effective as the old technology ( $\gamma>1$ ). Upon effectively being used, the old technology is immediately and fully replaced by the new technology. Two remarks are in place. First, we make the assumption that the old experience the cost of adjustment even when they stand to lose from the adoption of the new technology. This assumption can be justified by the simple fact that change is disliked (in Appendix D we relax assumption).<sup>18</sup> Secondly, we assume that income transfers between generations and between the holders of ideas and workers (other than wage payments) are impossible. This is due to a hold-up problem present in the model. Neither people from the current young generation nor the possessors of ideas can credibly commit to transfer money since they have no incentive to do so once the investment has been made (under the absence of perfect contractibility).<sup>19</sup>

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<sup>18</sup> In appendix D we endogenize labour supply. In the presence of economies of scale the old generation dislikes adoption even if there are no direct learning costs for the generation involved.

<sup>19</sup> This implies that the adoption decision is in some cases not Pareto-efficient. The economy as such is not efficient due to distortionary pricing in the monopolistically competitive sector.

Let us now characterize the costs and benefits of adoption for each age group.<sup>20</sup> We are allowed to ignore the generation that enters the labour market the period after the adoption decision is taken for two reasons. First, we think of that generation as those currently enrolled in primary and secondary education hence their education will be adjusted to the new dominant technology. This means that there is no *additional* cost of adoption and change for them because they are well-prepared for the new technology. Second, that generation has, in general, no suffrage and hence does not affect the outcomes of voting.

We denote the net change in utility that results from adoption at time  $t_1$  for an individual borne at  $t_1 - \tau$  by  $F_{t_1, t_1 - \tau}$ . So for the currently old, we get

$$F_{t_1, t_1 - 2} = \left[ c_{t_1, t_1 - 2}^A - c_{t_1, t_1 - 2}^{NA} \right] - \zeta \bar{s} , \quad (8)$$

where the indices  $A$  and  $NA$  refer to situations with and without adoption, respectively. In order to determine the value of this  $F$ -function, we need to establish the consumption index  $c$ . As shown in Appendix A.2, this value can be derived as

$$c = \bar{l} \left( \frac{\theta(\varepsilon - 1)\mu h L_X^{\mu - 1}}{\varepsilon N^{1 - \sigma}} \right)^\theta (1 - \theta)^{1 - \theta} . \quad (9)$$

Since the new technology only becomes effective after one period and  $L_X$  is constant (see equation (7)), the consumption index is not changed when adoption takes place and hence  $F_{t_1, t_1 - 2} = -\zeta \bar{s}$ . So the currently old lose from adoption. Once the new technology becomes effective, they have passed away. Nevertheless, they have to incur the cost of foregone leisure. As a consequence, the currently old will be against the adoption of a new technology.

For the other two age groups, the returns from adoption are not necessarily negative. On the one hand they gain due to the fact that the new technology enlarges their (future) consumption basket. This follows from the fact that  $\partial c / \partial h > 0$  (see

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<sup>20</sup> Whether the possessors of ideas are in favour of adoption depends on two factors, namely (i) the effect on their nominal income (the profit  $\pi$ ), and (ii) the purchasing power of the profit.



equation (9)). On the other hand, however, both groups lose as some leisure time has to be foregone. Without adoption an individual has  $1-\bar{l}$  units of leisure, while with adoption individuals only enjoy  $1-\bar{l}-\bar{s}$  time units of leisure. These costs are more likely to exceed the benefits for the middle-aged than for the young since the former can only benefit from the enlarged consumption possibilities for one period. This shows up in the  $F$ -functions for the young and medium aged, that respectively look like

$$F_{t_1,t_1} = [c_{t_1,t_1}^A - c_{t_1,t_1}^{NA}] - \zeta\bar{s} + \delta[c_{t_1+1,t_1}^A - c_{t_1+1,t_1}^{NA}] + \delta^2[c_{t_1+2,t_1}^A - c_{t_1+2,t_1}^{NA}] , \quad (10)$$

and

$$F_{t_1,t_1-1} = [c_{t_1,t_1-1}^A - c_{t_1,t_1-1}^{NA}] - \zeta\bar{s} + \delta[c_{t_1+1,t_1-1}^A - c_{t_1+1,t_1-1}^{NA}] . \quad (11)$$

From these two equations, it is evident that a sufficient condition for the young to be in favour of adoption is that the middle-aged are in favour of adoption ( $F_{t_1,t_1} > F_{t_1,t_1-1}$ ). Hence, under a system of majority voting the critical question that we need to address is whether the middle-aged are in favour or against adoption since the middle-aged have the decisive vote. Using equation (9), we can derive that  $c_{t_1}^A = c_{t_1}^{NA}$  and  $c_{t_1+1}^A = \gamma^\theta c_{t_1}^{NA}$ , where  $\gamma > 1$  is the measure of the increase in productivity ( $\gamma \equiv h^A/h$ ). The middle-aged are thus in favour of adoption provided that

$$F_{t_1,t_1-1} = \delta(\gamma^\theta - 1)c_{t_1+1,t_1-1}^{NA} - \zeta\bar{s} > 0 \quad (12)$$

So adoption is preferable if the discounted benefit from accepting the new technology exceeds the associated cost in terms of foregone leisure.

We will now proceed by characterizing the increase in  $h$  that is required to make the group of middle-aged people just indifferent between adopting the new technology and proceeding with the old one. This critical increase will be labelled  $\gamma^*$ . Since  $\partial F/\partial \gamma > 0$  we know that there is exactly one value  $\gamma^* > 1$  for which middle-aged consumers are indifferent, *i.e.*  $F=0$ . Combining equations (9) and (12), the critical value of  $\gamma$  is easily derived as (see Appendix A.2)

$$\gamma^* = \left[ 1 + \frac{\zeta \bar{s} (\epsilon N^{1-\sigma})^\theta}{\delta \bar{l} (\theta (\epsilon - 1) \mu h L_X^{\mu-1})^\theta (1-\theta)^{1-\theta}} \right]^{1/\theta}, \quad (13)$$

where  $L_X$  is determined by equation (7). Obviously, the required productivity gain to leave middle-aged workers indifferent is increasing in the time loss ( $\bar{s}$ ).  $\gamma^*$  is decreasing in  $\delta$ , as a loss today is more easily compensated tomorrow, if tomorrow is valuable.

The costs of adjustment ( $s$ ) have so far been simply modelled as being independent of the size of the productivity increase ( $\gamma$ ). More realistically, we might model the cost of adoption as consisting of an exogenous part, and a part that is related to the size of the increase in productivity:

$$s = \bar{s} + a(\gamma^b - 1). \quad (14)$$

The parameter  $a > 0$  reflects the idea that adoption becomes more costly if the increase in productivity becomes larger, while  $b > 1$  captures the idea that costs of adoption increase more than proportionally with the increase in productivity. The solution of the model can now conveniently be represented in a graphical manner as is done in Figure 1. The vertical axis in the graph depicts gross benefits of adopting the new technology for the middle-aged consumers (*i.e.*, the increase in utility associated with the higher productivity, the light dashed line), costs of adopting the new technology (the heavily dashed curve), and the net benefit (the solid line). The new technology will be adopted, provided that the net benefit is positive.

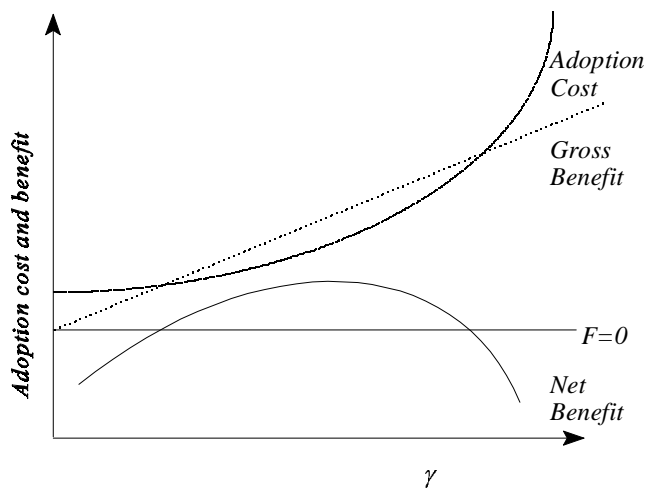


Figure 1 Endogenous adoption costs

The figure reveals that adoption will occur provided that (i) the increase in productivity is sufficiently large in order to enable the consumers to ‘recover’ their loss in utility associated with the costs of adoption, and (ii) the increase in productivity is not too large in order to prevent the adoption costs to dominate the gross benefits. So improvements should not be too small, as change bears some fixed costs, but improvements also shouldn’t be too large either as learning costs will become prohibitive. Any factor that will increase the gross benefits of adoption or decrease the costs will enlarge the range of technologies that will be adopted.<sup>21</sup>

## 5. The effects of enhancing competition on technology adoption

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<sup>21</sup> Another alternative for endogenizing the costs of learning would be the introduction of technology-specific knowledge. This technology-specific knowledge may be general (that is, as a technology is longer being used, everybody can employ it more productively), but also generation specific (that is, older people will have more experience and can therefore use a technology more efficiently than younger people). Both types of specific knowledge are lost upon adoption and result in adoption being less profitable. Additionally, old people have much more to lose than young people as they stand to lose the experience they have gained with the old technology, which makes the older people particularly resistant to change.

In this section, we will discuss how a change in rivalry between firms producing the quality-differentiated product will affect workers' resistance to change. We will model enhanced competition as an increase in the substitution elasticity between high-tech goods.<sup>22</sup> The question whether competition will foster the adoption of new technologies and thereby foster economic growth then boils down to the question whether the increase in productivity required to make middle-aged consumers equally well-off becomes smaller when competition increases. Hence, we have to determine whether  $\partial\gamma^*/\partial\epsilon$  is negative. From equation (13) we can straightforwardly show that competition will foster economic growth. This result is easily understood. An increase in productivity increases the total cake that can be divided between workers and the owners of ideas. In addition, the share of the increase in the cake that is obtained by the workers positively depends on the elasticity of substitution between high-tech goods (see Appendix A.3). If the elasticity of substitution is close to one, the owners of ideas receive almost all of the rents associated with the adoption of the new technology. As a consequence, resistance to adoption by workers will be large. If, on the other hand, most of the increase in the cake goes to the workers, resistance will be limited. This is also illustrated in Figure 2. An increase in competition shifts the gross benefit curve counter clockwise and hence lowers the critical productivity increase (see the dashed line).

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<sup>22</sup> We can also model increased competition as an increase in the number of firms producing high-tech goods ( $N$ ). From equation (13), it is immediately evident that an increase in the number of high-tech firms will lower the required increase in productivity and will thus tend to foster economic growth (note that  $\sigma > 1$ ). We return to this issue in section 6 where we allow for endogenous determination of  $N$  (which is then determined by competitive factors).

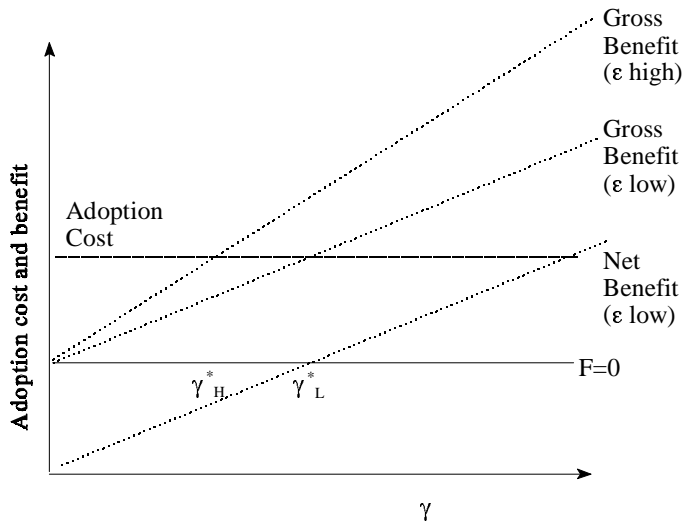


Figure 2 Enhanced competition

## 6. Free entry and the effects of tougher competition on resistance to change

So far, we studied the characteristics of the model under the assumption that the number of high-tech firms is exogenously given. This implies that persistent profits can exist; profits are not competed away by entry of new firms. In a model where knowledge is tied to firms, this assumption can be defended. However, it is interesting to consider the characteristics of the model once we drop this assumption. Such an exercise is interesting for various reasons. Firstly, it can be seen as a check for robustness of previously derived results. Secondly, it is interesting as it gives additional insights on the effects of competition on technology adoption.

The solution of the model under the assumption of free entry and exit is straightforward after introducing a fixed production cost<sup>23</sup> (for details see Appendix B).

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<sup>23</sup> Fixed costs are introduced in this section only as they do not qualitatively affect the equilibrium with blocked entry. Without any fixed cost, the number of high-tech firms would tend to infinity under free entry.

Performing the same procedure as in section 4, we can determine the critical increase in productivity that is required for middle-aged workers to be indifferent between adopting the new technology and sticking to the old one. This critical increase is again given by equation (13), where the allocation of workers to the high-tech sector and the number of firms are now given by

$$L_{xi} = \frac{\mu(\varepsilon-1)L_f}{\varepsilon-\mu(\varepsilon-1)}, \quad (15)$$

$$N = \frac{\theta L}{L_f} \left[ 1 - \frac{\mu(\varepsilon-1)}{\varepsilon} \right], \quad (16)$$

where  $L_f$  is a fixed cost. We restrict  $\mu$  to be smaller than  $\varepsilon/(\varepsilon-1)$  to guarantee an economically meaningful equilibrium with a positive number of firms and positive firm size. Equation (15) says that high-tech firms become larger, the larger the fixed cost and the stronger competition is. This is easily understood as large fixed costs and strong competition requires firms to sell and produce a lot in order to break even. The number of high-tech producers is determined in equation (16). There are less firms active when fixed production costs are higher, and when economies of scale become more important.

By substituting the latter two equations into the solution for  $\gamma^*$  (equation (13)), we can obtain a closed-form expression for  $\gamma^*$  (see Appendix B). We are particularly interested in the effect of competition on this critical productivity shift. To that end, we need to evaluate

$$\frac{d\gamma^*}{d\varepsilon} = \frac{\partial\gamma^*}{\partial\varepsilon} + \frac{\partial\gamma^*}{\partial N} \frac{dN}{d\varepsilon} + \frac{\partial\gamma^*}{\partial L_{xi}} \frac{dL_{xi}}{d\varepsilon}. \quad (17)$$

The first term on the right hand side is the direct effect from competition on technology adoption, and the two other terms are the indirect effects. We discuss these effects in

turn:

- the direct effect captures the same mechanism as described in section 5: increased competition lowers the price of the high-tech good and thereby increases real income of workers which makes them more inclined to adopt the new technology. Since profits earned by the high-tech firms are driven down to zero, competition does not have an effect on the share of the cake that accrues to workers;
- the first indirect effect is only relevant in the free entry model as it operates through changes in the number of high-tech producers. We know that  $dN/d\varepsilon < 0$ . When competition is intensified, mark-ups decline and less firms will survive in the presence of fixed operation costs. Furthermore,  $\partial\gamma^*/\partial N < 0$ ; the reduction of product variety makes workers worse-off and hence the increase in productivity required to keep them equally well-off increases. This “variety-effect” works against the direct effect.
- with respect to the second indirect effect, we know that  $dL_{X_i}/d\varepsilon > 0$ ; high-tech firms become larger when competition is intensified in order to recoup their fixed production costs. Furthermore,  $\partial\gamma^*/\partial L_{X_i} < 0$  if there are economies of scale in production of high-tech goods ( $\mu > 1$ ). So this “scale-effect” has a similar sign as the direct effect. Competition increases firm size and results in the remaining firms better exploiting economies of scale, thereby reducing consumer prices and increasing their real income.

In contrast with section 4, the relationship between growth and competition is no longer unambiguous. As shown in Appendix B, the relationship between  $\gamma^*$  and  $\varepsilon$  is only negative, provided that the parameter measuring the taste for variety is smaller than the mark-up (that is,  $\sigma < \varepsilon/(\varepsilon-1)$ ). In the special case in which the taste for variety and the mark-up are exactly equal, the elasticity of substitution does not affect the critical increase in productivity (this is the case that is explicitly considered by Dixit and Stiglitz, 1977). When the taste for variety is large, productivity should increase relatively strong in more competitive environments to make middle-aged workers

equally well-off.<sup>24</sup> The intuition behind this result is the following. An increase in competition makes high-tech firms larger and reduces the equilibrium number of high-tech firms (and thereby the variety of high-tech goods available to consumers). This makes consumers worse-off. On the other hand, an increase in competition reduces the distortion due to mark-up pricing and increases real income of consumers, which makes them better off. When the taste for variety is low, the latter effect dominates and increased competition needs to be accompanied by a relatively low increase in productivity for the middle-aged worker to be equally well-off. If, on the other hand, the taste for variety is strong, the former effect dominates and the increase in productivity required to make middle-aged workers equally well-off upon adoption of the new technology is larger in more competitive environments.

## 7. A general CES-utility function

In our basic framework we imposed perfect substitutability between consumption and leisure. This assumption is relaxed in this section in order to study the robustness of the previously derived results. Hence, we turn back to the CES-utility function - equation (1) - and consider the characteristics of the model for more general values of  $\alpha$ .

Analytically, the case when consumption and leisure are imperfect substitutes ( $\alpha < 1$ ) only affects the specification of the  $F$ -function. Details can be found in Appendix C. Since the expression for  $\gamma^*$  cannot be solved in closed-form, we resort to a graphical analysis to describe the qualitative effects from intensified competition on the critical productivity increase at different degrees of substitution possibilities between consumption and leisure.

To understand the effects of competition on the willingness of consumers to adopt an improved technology at different degrees of substitution between leisure and consumption it is important to recognize that the decision to adopt affects consumers' utility in essentially two ways:

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<sup>24</sup> We refer to De Groot and Nahuys (1998) and Benassy (1998) for a discussion on these issues in a slightly different context.



1. There is an instantaneous negative effect due to the loss in leisure associated with learning. This instantaneous effect is more negative if competition is more fierce as the reduction in leisure ‘hurts’ more if the consumption level is high.<sup>25</sup> The better substitutes leisure and consumption are, the less the instantaneous effect differs at different degrees of competition. In the limiting case of perfect substitutability considered above, the negative instantaneous effect is independent of competition. Hence, the negative learning effect is increasing in the degree of competition (unless  $\alpha=1$ ) as the reduction in leisure time associated with adoption is weighted more heavily.
2. There is a future positive effect of adoption on utility associated with increased productivity. This positive effect is stronger the larger the productivity increase and is reinforced by tougher competition.

There are thus two opposing effects of competition on the willingness to adopt. This is illustrated in Figures 3a-3c. These figures depict the  $F$ -function as a function of the productivity increase ( $\gamma$ ) at different degrees of competition. Each figure represents a different case with respect to the elasticity of substitution between leisure and consumption (*i.e.*,  $\alpha>0$ ,  $\alpha=0$  and  $\alpha<0$ , respectively). The first effect just described is reflected in the fact that at a high degree of competition,  $F$  is relatively low at  $\gamma=1$  (at which only the first, instantaneous effect is captured by  $F$ ). If the productivity increase associated with adoption increases,  $F$  increases and the more so the stronger competitive forces are (reflected by the relative steepness of the two  $F$ -curves). Consumers are indifferent between adopting and keeping with the status quo if  $F=0$ . The answer to the question whether competition is good for growth depends on whether the  $F$ -curve associated with a high degree of competition intersects the dotted line, representing  $F=0$ , to the left of the intersection of the  $F$ -curve associated with the low degree of competition with the horizontal axis.

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<sup>25</sup> Stated differently, the marginal utility of leisure positively depends on consumption, and consumption is higher in a more competitive environment.

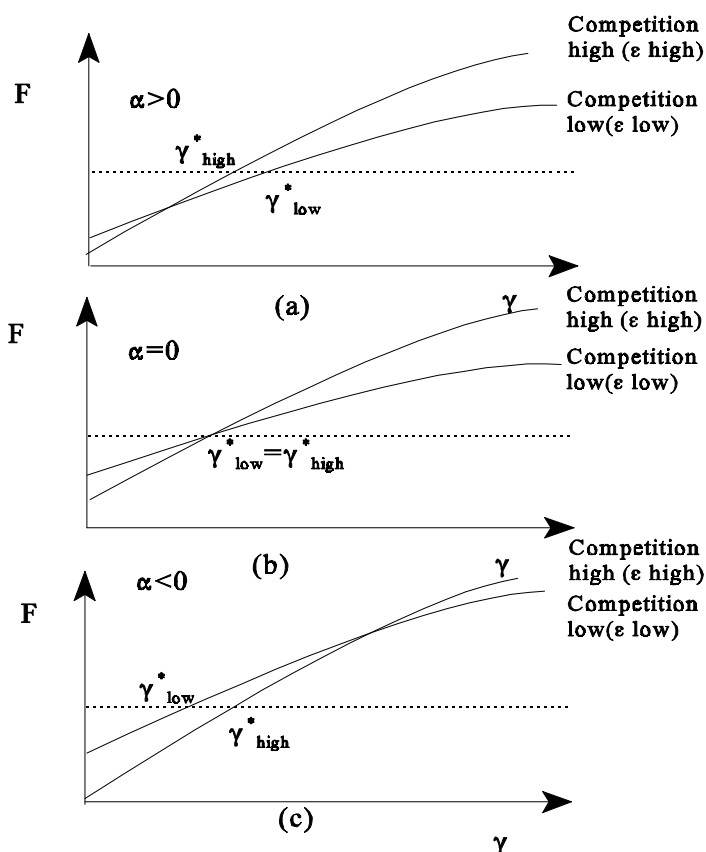


Figure 3 Enhanced competition with CES-utility

In general, we can show that competition has no effect on the willingness to adopt if  $\alpha=0$  (see Appendix C). In terms of our figures, this is depicted in Figure 3b in which the  $F$ -curves associated with different values of  $\epsilon$  intersect the  $F=0$  axis at one single point. The positive effect of competition on the willingness to adopt is, in other words, exactly offset by the negative (instantaneous) effect of competition on the willingness to adopt. In case leisure and consumption are relatively good substitutes ( $\alpha>0$ ) competition is good for growth (*i.e.* the future positive effect of competition dominates). This is represented in Figure 3a. If on the other hand leisure and consumption are relatively bad substitutes ( $\alpha<0$ ) competition is bad for growth (*i.e.* the instantaneous effect dominates) as depicted in Figure 3c. Summarizing: competition is good for growth provided that consumers are sufficiently flexible in that they are willing to accept a current loss in leisure which is to be compensated by a future increase in consumption.

## 8. Conclusions

Productive efficiency is largely determined by the applied technology. Two observations stand out: first, technologies actually implemented differ vastly across countries; second, within countries many technologies that would obviously improve firms' efficiency are not adopted. In this paper, we provide an explanation for these observations. It is well documented that the adoption of a new technology often requires an investment by the firm. But the introduction of a new technology could also turn existing operation methods obsolete, and employees may have to learn how to operate the new technology. Since the latter effect is often ignored, we concentrated in this paper on the benefits and costs of technology adoption for the worker who has to get acquainted with the new technology. If the costs of adoption for the worker exceed the benefits that can be reaped, workers will engage in activities aimed at keeping the old technology in place.

This paper showed by anecdotal historical evidence that resistance to change might indeed be an important ingredient in the explanation of huge productivity differences across countries, as well as differences in technologies employed by different firms. Historical evidence shows that an important cause for blocked technology adoption is resistance of workers instead of resistance of firms.

We developed a simple overlapping generations model to formalise these ideas. The model shows that the prime motive for resistance to technology comes from the fact that older workers have limited time to get a sufficiently substantial "return on their investment". Hence, ageing might also be a problem from this perspective. Moreover, it was shown that increased competition tends to increase the likeliness of adoption and hence accelerates growth, which is a well-documented phenomenon in descriptive material. More specifically, it was shown that competition is good for growth provided that consumers are sufficiently flexible in that they are willing to accept a current loss in leisure which is to be compensated by a future increase in consumption.

Apart from extensions discussed earlier, there are several interesting ways in which the model could be extended and refined. The first is the introduction of

imperfect substitution in production between labour from different age groups. A second extension would be to describe the bargain over the surplus associated with the adoption of the technology between the firm and its workers.

Although these extensions are interesting in their own right, they will not affect the basic mechanisms described in this paper. What crucially matters for the question whether a new technology will be adopted is the size of the rent generated with the new technology, the speed with which this rent can be consumed and the way it is divided over various stakeholders within the economy.

## References

- Aghion, P. and P. Howitt (1998): "Market Structure and the Growth Process", *Review of Economic Dynamics*, Vol. 1, pp. 276-305.
- Antonelli, C. (1995): *The Economics of Localized Technological Change and Industrial Dynamics*, Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Atkinson, A.B. and J.E. Stiglitz (1996): "A New View of Technological Change", *Economic Journal*, Vol. 79, pp. 573-578.
- Basu, S. and D.N. Weil (1996): "Appropriate Technology and Growth", *Quarterly Journal of Economics*, Vol. 113, pp. 1025-1054.
- Benassy, J.P. (1998): "Is There Always too Little Research in Endogenous Growth with Expanding Product Variety?" *European Economic Review*, Vol. 42, No. 1, pp. 61-69.
- Baily, M.N. (1993): "Competition, Regulation, and Efficiency in Service Industries", *Brookings Papers on Economic Activity, Microeconomics*, Vol. 2, pp. 71-130.
- Baily, M.N. and H. Gersbach (1995): "Efficiency in Manufacturing and the Need for Global Competition", *Brookings Papers on Economic Activity, Microeconomics*, Vol. 4, pp. 307-347.
- Caselli, F. (1999): "Technological Revolutions", *American Economic Review*, Vol. 89 No. 1, pp. 78-102.

- Chari, V.V. and H. Hopenhayn (1991): “Vintage Human Capital, Growth, and the Diffusion of New Technology”, *Journal of Political Economy*, Vol. 99, pp. 1142-1165.
- Dixit, A.K. and R.S. Pindyck (1994): *Investment under Uncertainty*, Princeton University Press, Princeton.
- Dixit, A.K. and J.E. Stiglitz (1977), “Monopolistic Competition and Optimum Product Diversity”, *American Economic Review*, Vol. 67, pp. 297-308.
- The Economist (1998): “BMW’s British Bruises” December 5<sup>th</sup>, pp. 78.
- Groot, H.L.F. de and R. Nahujs (1998): “Taste for Diversity and Optimality of Economic Growth”, *Economic Letters*, Vol. 58, No. 3, pp. 291-295.
- Helpman, E. and A. Rangel (1998): “Adjusting to a New Technology: Experience and Training”, *NBER Working Paper*, No. 6551, Cambridge, MA.
- Holmes, T.J. and J.A. Schmitz, Jr. (1994): “Resistance to Change and Trade between Areas”, *Research Department Staff Report* 184, Federal Reserve Bank of Minneapolis.
- Howarth, R.B., and B. Andersson (1993): “Market Barriers to Energy Efficiency”, *Energy Economics*, october, pp. 262-272.
- Jaffe, A.B. and R.N. Stavins (1994): “The Energy Paradox and the Diffusion of Conservation Technology”, *Resource and Energy Economics*, Vol. 16, pp. 91-122.
- Jovanovic, B. (1995): “Learning and Growth”, *NBER Working Paper*, No. 5383, Cambridge, MA.
- Jovanovic, B. and Y. Nyarko (1996): “Learning by Doing and the Choice of Technology”, *Econometrica*, Vol. 64, No. 6, pp. 1299-1310.
- Klundert, Th. van de and S. Smulders (1997): “Growth, Competition and Welfare”, *Scandinavian Journal of Economics*, Vol. 99, No.1, pp. 99-118.
- Krusell, P. and J. Rios-Rull (1996): “Vested Interests in a Positive Theory of Stagnation and Growth”, *Review of Economic Studies*, Vol. 63, pp. 301-329.
- Machiavelli, N. (1961): *The Prince*, Penguin Books, Baltimore.

- Mokyr, J. (1990): *The Lever of Riches: Technological Creativity and Economic Progress*, New York, Oxford University Press.
- Olson, M. (1982): *The Rise and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities*, Yale University Press, New Haven.
- Parente, S.L. (1995): "A Model of Technology Adoption and Growth", *Economic Theory*, Vol. 6, No. 3, pp. 405-420.
- Parente, S.L. and E.C. Prescott (1994): "Barriers to Technology Adoption and Development", *Journal of Political Economy*, Vol. 102, pp. 298-321.
- Prescott, E.C. (1998): "Needed: A Theory of Total Factor Productivity", *International Economic Review*, Vol. 39, pp. 525-551.
- Schumpeter, J.A. (1939): *Business Cycles: a Theoretical, Historical, and Statistical Analysis of the Capitalist Process*, McGraw-Hill, New York.
- Stiglitz, J.E. (1987): "Learning to Learn, Localized Learning and Technological Progress", In: P. Dasgupta and J.E. Stiglitz (eds.): *Economic Policy and Technological Performance*, Cambridge: Cambridge University Press.
- Sutherland, R.J. (1991): "Market Barriers to Energy-Efficiency Investments", *Energy Journal*, Vol. 12, pp. 15-34.
- Wolcott, S. (1994): "The Perils of Lifetime Employment Systems: Productivity Advance in the Indian and Japanese Textile Industries, 1920-1938", *Journal of Economic History*, Vol. 54, pp. 307-324.

## Appendix A. The basic model

### A.1 The allocation of labour

In this Appendix, we will solve for the allocation of labour in the basic model. For this aim, we first need to establish consumer and producer behaviour. Each consumer maximises his utility in two steps. In the first step, he maximises his consumption index subject to his budget constraint (where it leads to no confusion, we suppress indices):

$$\max c = x^\theta y^{1-\theta} \quad s.t. \quad xP_X + yP_Y \leq cP_c = I, \quad (\text{A.1})$$

where  $x$  refers to the demand of an individual consumer for a bundle of high-tech commodities (with corresponding price index  $P_X$ ),  $y$  refers to the demand for traditional goods (with corresponding price  $P_Y$ ), and  $I$  is income (which equals wage income  $wl$  for a worker and profits for an owner of ideas). Our non-satiation assumption implies that the budget constraint is always binding. Notice that profit income does not accrue to workers, but flows back to the idea owners. The corresponding first order conditions are given by  $x = \theta I / P_X$  and  $y = (1 - \theta) I / P_Y$ . Or, combining these two conditions,

$$\frac{xP_X}{yP_Y} = \frac{\theta}{1-\theta}. \quad (\text{A.2})$$

So the income share allocated to high-tech and traditional goods is equal to  $\theta$  and  $1 - \theta$ , respectively (and is independent of the level of income). The price index  $P_c$  is then straightforwardly derived as

$$P_c = \left( \frac{P_X}{\theta} \right)^\theta \left( \frac{P_Y}{1-\theta} \right)^{1-\theta} \quad (\text{A.3})$$

In the second step, he maximises  $x$  subject to the income share allocated to high-tech products

$$\max x \quad s.t. \quad \sum_{i=1}^N \check{x}_i p_{xi} \leq xP_X. \quad (\text{A.4})$$

This yields the demand for a good index  $i$

$$\check{x}_i = x \left( \frac{p_{xi}}{P_X} \right)^{-\varepsilon} \quad \text{where} \quad P_X = N^{1-\sigma} \left[ \frac{1}{N} \sum_{i=1}^N p_{xi}^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} . \quad (\text{A.5})$$

Producers in the X-sector maximise profits,  $\pi_i = X_i p_{xi} - L_{Xi} w$ , subject to the production technology and the demand equation for good  $i$ . From the first order condition for a maximum, we arrive at the well-known mark-up relation

$$p_{xi} = \frac{\varepsilon}{\varepsilon-1} \frac{w}{\mu h_i L_{Xi}^{\mu-1}} . \quad (\text{A.6})$$

Firms in the Y-sector operate under perfect competition so

$$P_Y = w . \quad (\text{A.7})$$

Under the assumption of symmetry of high-tech goods, we can then derive that

$$x = N^\sigma \check{x} \quad \text{and} \quad P_X = N^{1-\sigma} \frac{\varepsilon}{\varepsilon-1} \frac{w}{\mu h_i L_{Xi}^{\mu-1}} . \quad (\text{A.8})$$

Due to the utility function being homothetic, it holds that

$$\frac{\check{x}_i}{y} = \frac{h_i L_{Xi}^\mu}{L_Y} . \quad (\text{A.9})$$

We can then rewrite goods-market equilibrium as

$$\frac{x P_X}{y P_Y} = \frac{N^\sigma \check{x}_i N^{1-\sigma} \frac{\varepsilon}{\varepsilon-1} \frac{w}{\mu h_i L_{Xi}^{\mu-1}}}{y w} = \frac{N \varepsilon L_{Xi}}{\mu (\varepsilon-1) L_Y} = \frac{\theta}{1-\theta} \quad (\text{A.10})$$

In combination with the requirement for labour-market equilibrium,

$$L_Y + N L_{Xi} = L , \quad (\text{A.11})$$



we arrive at the solution for the allocation of labour to the high-tech sector,

$$L_{Xi} = \frac{\theta\mu(\varepsilon-1)L/N}{(1-\theta)\varepsilon + \theta\mu(\varepsilon-1)}, \quad (\text{A.12})$$

which corresponds to equation (7) in the text.

### A.2 The critical productivity increase

Using that  $c = x^\theta y^{1-\theta}$  in combination with the above results, we find

$$c = w \frac{\bar{l}}{P_c} = w \frac{\bar{l}}{\left(\frac{P_X}{\theta}\right)^\theta \left(\frac{P_Y}{1-\theta}\right)^{1-\theta}} = \bar{l} \left( \frac{\theta(\varepsilon-1)\mu h L_X^{\mu-1}}{\varepsilon N^{1-\sigma}} \right)^\theta (1-\theta)^{1-\theta}. \quad (\text{A.13})$$

Note that adoption increases  $h$  with a factor  $\gamma$  so we can derive that  $c^A = \gamma^\theta c^{NA}$ . For  $\alpha=1$ , the  $F$ -function for the medium aged is then given by

$$F_{t_1, t_1-1} = \delta [c_{t_1, t_1-1}^A - c_{t_1, t_1-1}^{NA}] - \zeta \bar{s} = \delta (\gamma^\theta - 1) c_{t_1, t_1-1}^{NA} - \zeta \bar{s}. \quad (\text{A.14})$$

The critical productivity increase to keep the middle-aged consumers indifferent between adopting and not adopting is found by putting  $F$  equal to zero and is given by

$$\gamma^* = \left[ 1 + \frac{\zeta \bar{s} (\varepsilon N^{1-\sigma})^\theta}{\delta \bar{l} (\theta(\varepsilon-1)\mu h L_X^{\mu-1})^\theta (1-\theta)^{1-\theta}} \right]^{1/\theta}. \quad (\text{A.15})$$

This expression corresponds to equation (13) in the text.

### A.3 Division of the cake

The next step is to determine the effects of an increase in productivity on the share of the ‘total cake’ that accrues to workers. This share is equal to the share that workers get in total nominal income and thus equals

$$\frac{wL}{wL + N\pi_i} = \frac{L}{L + NL_{Xi} \left( \frac{\varepsilon}{(\varepsilon-1)\mu} - 1 \right)}, \quad (\text{A.16})$$

where  $L_{xi}$  is determined from equation (A.12). According to this equation, the labour income share increases when competition is intensified.

## Appendix B. Free entry

### B.1 The allocation of labour and the equilibrium number of firms

In this Appendix, we will solve the model under the regime of free entry and exit of firms. For this aim, we need to slightly change the producer's problem in that we have to add a fixed cost. We express the fixed cost in terms of labour. The introduction of this fixed cost is essential to obtain a finite solution for the number of high-tech firms, but it does not affect the basic conclusions to be drawn. The  $i$ -th producer's maximisation problem thus looks like

$$\max \pi_i = X_i p_{xi} - (L_{xi} + L_{fi})w , \quad (\text{B.1})$$

where  $L_{fi}$  denotes firm  $i$ 's fixed production costs. Since fixed production costs do not affect the firm's optimal pricing strategy, the mark-up relation is again given by equation (A.6). Entry of new high-tech firms continues until profits are driven down to zero (assuming perfect divisibility of firms). Imposing symmetry and putting  $\pi_i=0$  yields

$$L_X = \frac{\mu(\varepsilon-1)L_f}{\varepsilon - \mu(\varepsilon-1)} . \quad (\text{B.2})$$

This is equation (15) in the main text. Using the symmetry-assumption, labour market equilibrium is determined by

$$L_Y + N(L_X + L_f) = L . \quad (\text{B.3})$$

Combination of these expressions gives the number of high-tech producers,

$$N = \frac{\theta L}{L_f} \left[ 1 - \frac{\mu(\varepsilon-1)}{\varepsilon} \right] , \quad (\text{B.4})$$

which corresponds to equation (16) in the text.

### B.2 The critical productivity increase

Similar to Appendix A.2 we can determine the critical productivity increase and the impact of increased competition. Again:

$$F_{t_1, t_1-1} = \delta [c_{t_1, t_1-1}^A - c_{t_1, t_1-1}^{NA}] - \zeta \bar{s} = \delta (\gamma^\theta - 1) c_{t_1, t_1-1}^{NA} - \zeta \bar{s} . \quad (\text{B.5})$$

Substituting (A.13), (B.2) and (B.4) in the  $F$ -function and rewriting yields:

$$F_{t_1, t_1-1} = A \delta (\gamma^\theta - 1) (\varepsilon - 1)^{\mu \theta} \varepsilon^{-\sigma \theta} (\varepsilon - (\varepsilon - 1) \mu)^{(\sigma - \mu) \theta} - \zeta \bar{s} , \quad (\text{B.6})$$

where

$$A = L^{(\sigma-1)\theta+1} \theta^{\sigma\theta} \mu^{\theta\mu} h^\theta (1-\theta)^{(1-\theta)} L_f^{(\mu-\sigma)\theta} . \quad (\text{B.7})$$

The explicit solution for  $\gamma^*$  follows directly from setting (B.6) equal to zero. By straightforward application of the implicit function theorem the sign of  $\partial \gamma^* / \partial \varepsilon$  is determined by:

$$- \frac{\left( \frac{\varepsilon}{\varepsilon-1} \mu - \sigma \right) (\varepsilon - (\varepsilon-1)\mu) + (1-\mu)(\sigma-\mu)\varepsilon}{\varepsilon(\varepsilon - (\varepsilon-1)\mu)} . \quad (\text{B.8})$$

Since we impose  $\mu$  to be smaller than  $\varepsilon/(\varepsilon-1)$ , the sign of the derivative of the critical productivity increase with respect to the elasticity of substitution is determined by the numerator of (B.8). It is then straightforwardly shown that:

$$\text{sgn.} \left( \frac{\partial \gamma^*}{\partial \varepsilon} \right) = \text{sgn.} \left( \sigma - \frac{\varepsilon}{\varepsilon-1} \right) . \quad (\text{B.9})$$

## Appendix C. Solution of the model with a general CES-utility function

We now return to the general utility function as specified in equation (1) and no longer impose perfect substitutability between consumption and leisure activity. All previous calculations still hold, except the calculation of  $\gamma^*$  which is now for the medium-aged based on

$$\begin{aligned}
F_{t_1, t_1-1} &= [(c_{t_1, t_1-1}^A)^\alpha + \zeta(1 - \bar{l} - \bar{s})^\alpha]^{1/\alpha} - [(c_{t_1, t_1-1}^{NA})^\alpha + \zeta(1 - \bar{l})^\alpha]^{1/\alpha} \\
&+ \delta[(c_{t_1+1, t_1-1}^A)^\alpha + \zeta(1 - \bar{l})^\alpha]^{1/\alpha} - \delta[(c_{t_1+1, t_1-1}^{NA})^\alpha + \zeta(1 - \bar{l})^\alpha]^{1/\alpha} = 0 .
\end{aligned} \tag{C.1}$$

Now note that  $c_{t_1+1}^A = \gamma^\theta c_{t_1+1}^{NA} = \gamma^\theta c_{t_1}^{NA} = \gamma^\theta c_{t_1}^A$ . Defining the consumption at  $t=t_1$  as  $c$ , we can rewrite equation (C.1) as

$$\delta \left[ \frac{\gamma^{\theta\alpha} c^\alpha + \zeta(1 - \bar{l})^\alpha}{c^\alpha + \zeta(1 - \bar{l})^\alpha} \right]^{1/\alpha} + \left[ \frac{c^\alpha + \zeta(1 - \bar{l} - \bar{s})^\alpha}{c^\alpha + \zeta(1 - \bar{l})^\alpha} \right]^{1/\alpha} = 1 + \delta . \tag{C.2}$$

This equation implicitly yields the solution for  $\gamma^*$  and is analysed graphically in section 7.

Finally, let us consider the special (Cobb-Douglas) case in which  $\alpha \rightarrow 0$ . The utility function then simplifies to

$$u = c^\beta v^{1-\beta} \quad \text{where} \quad \beta \equiv \frac{1}{1+\zeta} \tag{C.3}$$

We can thus write the  $F$ -function as

$$F = c^\beta (1 - \bar{l} - \bar{s})^{1-\beta} - c^\beta (1 - \bar{l})^{1-\beta} + \delta [(\gamma^\theta c)^\beta (1 - \bar{l})^{1-\beta} - c^\beta (1 - \bar{l})^{1-\beta}] \tag{C.4}$$

where  $c = c_{t_1}^A = c_{t_1}^{NA} = c_{t_1+1}^{NA} = c_{t_1+1}^A / \gamma^\theta$ . Putting  $F$  equal to zero, the critical productivity increase is straightforwardly derived as

$$\gamma^* = \left[ 1 + \frac{1}{\delta} \left( 1 - \left( \frac{1 - \bar{l} - \bar{s}}{1 - \bar{l}} \right)^{1-\beta} \right) \right]^{\frac{1}{\theta\beta}} > 1 \tag{C.5}$$

Note that this critical increase does not depend on the strength of competition as explained and elaborated upon in section 7.

## Appendix D. Solution of the model with a general CES-utility function and endogenous labour supply

In this Appendix we consider the case of a CES-utility function and allow for endogenous labour supply. The time constraint reads as

$$v = 1-l-s = \begin{cases} 1-l & \text{no schooling} \\ 1-l-\bar{s} & \text{schooling} \end{cases} \quad (\text{D.1})$$

Extensive numerical simulation, for which the set up is provided in this appendix, learns that the lessons drawn in Section 7 remain valid when labour supply is endogenous.

The individual consumer maximises his utility in four steps. In the first step he decides whether it is optimal to engage in resistance activity (we return to this step below). In the second step, optimal consumption and labour input are determined. The Lagrangian corresponding to this problem takes the following form

$$\mathcal{L} = [c(.)^\alpha + \zeta(1-l-s)^\alpha]^{1/\alpha} + \lambda(c(.)P_c - wl) . \quad (\text{D.2})$$

The first order conditions are given by

$$\mathcal{L}_c: [c(.)^\alpha + \zeta(1-l-s)^\alpha]^{1/\alpha-1} c^{\alpha-1} + \lambda P_c = 0 , \quad (\text{D.3})$$

$$\mathcal{L}_l: -[c(.)^\alpha + \zeta(1-l-s)^\alpha]^{1/\alpha-1} \zeta(1-l-s)^{\alpha-1} - \lambda w = 0 , \quad (\text{D.4})$$

$$\mathcal{L}_\lambda: c(.)P_c - wl = 0 . \quad (\text{D.5})$$

Elimination of the Lagrange multiplier  $\lambda$  from the first two FOCs yields

$$\left( \frac{c(.)}{1-l-s} \right)^{\alpha-1} = \zeta \frac{P_c}{w} . \quad (\text{D.6})$$

Or,

$$c(.) = (1-l-s) \left( \zeta P_c / w \right)^{1/(\alpha-1)} . \quad (\text{D.7})$$

The third step of the optimization determines how much of consumption expenditures is spent on traditional and high-tech goods, respectively, while the fourth step determines how much of

expenditures on high-tech goods is spent on varieties of the high-tech good. The solutions of these steps are as discussed in Appendix A.1. From the Cobb-Douglas structure of the composite good we have

$$P_c = \left( \frac{P_X}{\theta} \right)^\theta \left( \frac{P_Y}{1-\theta} \right)^{1-\theta} = w \left( \frac{N^{1-\sigma} \frac{\varepsilon}{\varepsilon-1} \frac{1}{\mu h L_{Xi}^{\mu-1}}}{\theta} \right)^\theta \left( \frac{1}{1-\theta} \right)^{1-\theta}. \quad (\text{D.8})$$

Using the resulting expression for  $P_c/w$  we find

$$c(.) = (1-l-s) \left[ \zeta \left( \frac{N^{1-\sigma} \varepsilon}{\theta(\varepsilon-1)\mu h L_{Xi}^{\mu-1}} \right)^\theta \left( \frac{1}{1-\theta} \right)^{1-\theta} \right]^{1/(\alpha-1)}. \quad (\text{D.9})$$

Using income-spending equality ( $P_c c = wl$ ) we can derive (after some rearranging)

$$l = \frac{1-s}{1 + \zeta^{1/(1-\alpha)} \left[ \left( \frac{\theta(\varepsilon-1)\mu h L_{Xi}^{\mu-1}}{\varepsilon N^{1-\sigma}} \right)^\theta (1-\theta)^{1-\theta} \right]^{\alpha/(\alpha-1)}}, \quad (\text{D.10})$$

where

$$L_{Xi} = \frac{\theta \mu (\varepsilon-1) L/N}{(1-\theta) \varepsilon + \theta \mu (\varepsilon-1)}. \quad (\text{D.11})$$

In order to determine the equilibrium of the model with endogenous labour supply, it is crucial to recognize that there can exist two equilibria in the model:

- (A) the medium-aged are in favour of adoption. In this case, the young will also be in favour of adoption and both engage in schooling after which adoption of the new technology takes place. The old disfavour adoption in any case as they have nothing to gain from it (under the assumption that  $\mu > 1$ );
- (NA) the medium-aged disfavour adoption. In this case, it is useless for the young to engage in schooling as the new technology will not be adopted in any case. So in this equilibrium, nobody engages in the costly activity of getting acquainted with the new technology.

These are the only two equilibria that can exist in the model. So what needs to be done is to determine the  $F$ -function for the medium-aged (taking into account that these are the only two equilibria) in order to determine whether adoption will take place or not. In the first equilibrium with adoption, we get

$$\begin{aligned}
l_{t_1, t_1}^A &= \frac{1-\bar{s}}{f^1(L_{Xit_1})}, \quad l_{t_1, t_1-1}^A = \frac{1-\bar{s}}{f^1(L_{Xit_1})}, \quad l_{t_1, t_1-2}^A = \frac{1}{f^1(L_{Xit_1})}, \\
L_{Xit_1}^A &= f^2(L_{t_1}^A), \quad L_{t_1}^A = \sum_{\tau=0}^2 P_{t_1-\tau} l_{t_1, t_1-\tau}^A.
\end{aligned} \tag{D.12}$$

where

$$\begin{aligned}
f^1(L_{Xit_1}) &= 1 + \zeta^{1/(1-\alpha)} \left[ \left( \frac{\theta(\varepsilon-1)\mu h L_{Xi}^{\mu-1}}{\varepsilon N^{1-\sigma}} \right)^\theta (1-\theta)^{1-\theta} \right]^{\alpha/(\alpha-1)} \quad \text{and} \\
f^2(L_{t_1}^A) &= \frac{\theta\mu(\varepsilon-1)L_{t_1}^A/N}{(1-\theta)\varepsilon + \theta\mu(\varepsilon-1)}.
\end{aligned} \tag{D.13}$$

So we get a system of five equations in five unknowns ( $l_{t_1, t_1}^A$ ,  $l_{t_1, t_1-1}^A$ ,  $l_{t_1, t_1-2}^A$ ,  $L_{Xit_1}^A$ ,  $L_{t_1}^A$ ) which can be solved and yields the solution for  $c_{t_1, t_1-1}^A$ . The solution for  $c_{t_1+1, t_1-1}^A$  (with the new, higher level of productivity) is easily computed as before, under the assumption that no generation engages in schooling. In the second equilibrium, with no adoption, we get

$$\begin{aligned}
l_{t_1, t_1}^{NA} &= \frac{1}{f^1(L_{Xit_1}^{NA})}, \quad l_{t_1, t_1-1}^{NA} = \frac{1}{f^1(L_{Xit_1}^{NA})}, \quad l_{t_1, t_1-2}^{NA} = \frac{1}{f^1(L_{Xit_1}^{NA})}, \\
L_{Xit_1}^{NA} &= f^2(L_{t_1}^{NA}), \quad L_{t_1}^{NA} = \sum_{\tau=0}^2 P_{t_1-\tau} l_{t_1, t_1-\tau}^{NA}.
\end{aligned} \tag{D.14}$$

So we again get a system of five equations in five unknowns ( $l_{t_1, t_1}^{NA}$ ,  $l_{t_1, t_1-1}^{NA}$ ,  $l_{t_1, t_1-2}^{NA}$ ,  $L_{Xit_1}^{NA}$ ,  $L_{t_1}^{NA}$ ) which can be solved and yields the solution for  $c_{t_1, t_1-1}^{NA}$ . The solution for  $c_{t_1+1, t_1-1}^{NA}$  (with the old level of productivity) is again easily computed. We can then establish the  $F$ -function as

$$\begin{aligned}
F_t &= \delta[(c_{t+1, t-1}^A)^\alpha + \zeta(1-l_{t+1, t-1}^A)^\alpha]^{1/\alpha} + [(c_{t, t-1}^A)^\alpha + \zeta(1-l_{t, t-1}^A - \bar{s})^\alpha]^{1/\alpha} - \\
&\delta[(c_{t+1, t-1}^{NA})^\alpha + \zeta(1-l_{t+1, t-1}^{NA})^\alpha]^{1/\alpha} - [(c_{t, t-1}^{NA})^\alpha + \zeta(1-l_{t, t-1}^{NA})^\alpha]^{1/\alpha} = 0.
\end{aligned} \tag{D.15}$$

This expression can only be analysed numerically, but yields an expression for  $\gamma^*$ .

Although it is impossible to derive an analytical expression for the critical productivity increase  $\gamma^*$  one important result is easily established: relaxing the assumption that the old generation has to engage in schooling although they have passed away when the technology becomes effective does not alter the results. The intuition is clear: despite the fact that the old do not lose time due to learning, they dislike the fact that the young and medium-aged learn as their labour supply reduces consequently (and hence the prices of the high-tech good increase).

Note that for this result the non-linearity or scale effect introduced by the assumption that  $\mu \geq 1$  is crucial.