Innovation and Sectoral Employment :
A Trade-Off between Compensation Mechanisms*

by

Bernd Ebersberger* and Andreas Pyka**

November 1999

JEL: J3 L2 O3

Key-words: Innovation, employment, compensation-mechanisms, simulation, evolutionary economics

Abstract

The question whether technological progress displaces employment or whether technological advance is beneficial for the level of employment has been in the core of economic dispute for over two centuries. The beneficial might be achieved by several compensation mechanisms within the economic system. In this paper we categorize these compensation mechanisms into two basic categories that reflect the different nature of the ideas ruling the compensation. We discriminate the mechanisms *employment despite of innovation* from *employment via innovation.*

In the context of new innovation economics we model an artificial industry implementing both compensation mechanisms. Simulation analysis is used to examine the short run and the long run properties of the model. There we focus on the influence of wage restraint policy on the functioning of the compensation mechanism.

---

* A draft version of this paper was presented at the annual EAEPE conference in Prague, November 4-9 1999. We thank those who participated in our session, and in particular the chairman C. Dannreuther, for helpful comments.

* University of Augsburg, Universitaetsstr. 16, D-86135 Augsburg,Germany, ph. +49-821-598-4179, fax: +49-821-598-4229, e-mail: bernd.ebersberger@wiso.uni-augsburg.de

** INRA-SERD, Université Pierre Mendés-France, F-38040 GRENOBLE Cédex 9, fax: +33-4-76-82-54-55 pyka@grenoble.inra.fr

1. Introduction

Ever since economics became a science, technological advance has been on the research agenda questioning among other things whether it is a determinant of decreasing employment or whether new jobs are created by it. In the 90s, when mass unemployment became a crucial problem for nearly all industrialized countries, particularly for Europe this issue has become even more pressing. One of the often mentioned reasons for the non satisfactory employment situation is that in an economic environment characterized by fast technological change the factor labor is increasingly displaced by new technologies.

In search of a scientific explanation for this phenomenon neoclassical economists mainly refer to price rigidities and especially to reduced downward flexibility of wages that hinder (neo)classical compensation mechanisms[1] from working appropriately. According to this line of reasoning larger employment could be reestablished by reducing the price of labor, or - putting it dynamically - by reducing the wage growth rates, which may not exceed productivity growth. The ideas governing this argument could be labeled *'employment despite of innovation'*. However, the claim for such a moderate development of wages, although obviously favoring employment in the first place, seems to be unbalanced concerning the importance attributed to the introduction of new technologies, nowadays. In this respect a further compensation mechanism, recently formalized by Katsoulacos (1984 and 1986), seems to play a significant, or even a dominant role. In particular, this mechanism focuses on the creation of employment by the introduction of product innovation. This could be termed *'employment via innovation'*.

The aim of our paper is to introduce a formal setting which allows the incorporation of both compensation mechanisms. Furthermore, it allows for testing their relevance in an artificial industry. Drawing on models of the innovation process, including the concepts of *uncertainty*, *heterogeneity* and *knowledge*, brought forth by *Schumpeterian* and evolutionary economics, the analyst finds himself beyond the frontiers of an analytical treatment, and simulation analysis becomes inevitable.

In this respect, the modeling framework of a dynamic heterogeneous oligopoly, introduced by Cantner and Pyka (1998), represents a helpful setting for our intention to investigate the relationship of innovation and employment on a sector level. Here, firms compete in two dimensions: on the one hand, price competition propelled by process innovation, on the other hand, quality competition driven by product innovation. In the production process firms employ unskilled workers which are also responsible for process innovation through simple learning curve effects. In the R&D laboratories firms employ engineers engaged in the exploration of uncertain technological opportunities. Although firms are able to optimize production decisions myopically, the allocation of R&D resources, however, cannot be subject to an optimizing calculus. Instead, the concept of *routines* is invoked (Nelson / Winter 1982) to model the firms' R&D engagement. In situations of *'unsatisfycing'* profit development firms are induced to modify their routines.

---

[1] The term ‘compensation theory’ dates back to Karl Marx, having in mind the various kinds of compensation discussed by classical economists. Neoclassical economists added another mechanism: compensation via the decrease in wages (Wicksell 1967). For contemporary discussion on the issue Heertje (1978) revived the notion of ‚compensation mechanisms‘.

In the second section we start by introducing the basic concepts of modern innovation theory which constitute the general framework in which the firms in our artificial industry operate. Building on this, in the third section the simulation model is developed which is numerically analyzed in section 4. In particular, we draw on a scenario-analysis. The scenarios will only differ as to how the wages of the unskilled workers adjust to productivity improvements. Wages in these two scenarios do not vary within the industry. In the first scenario the idea *employment despite of innovation* prevails: the wages are kept down by a *gentlemen agreement* of the wage-bargaining actors. In the second scenario, however, wages follow the average productivity development and set a precedent for the idea *employment via innovation*. This approach allows us to compare employment figures and the technological development among firms and scenarios. Furthermore the specific impacts of the different compensation mechanisms are identified. On this basis, we are able to show that focusing only on factor-cost reduction does not lead to sustained improvement of sector employment. But a thus induced potential technological backwardness may lead to even worse employment problems in the long run. Some conclusions and an outlook for further research are given in section 5.

2. Technological Development in the Perspective of Evolutionary Economics

In order to analyze the interplay of both compensation mechanisms *employment despite of innovation* and *employment via innovation* sketched in the introduction we first have to introduce the idea of the innovation process as it is developed in new innovation economics. This approach sharply differs from traditional approaches in neoclassical industrial economics and finds its theoretical background in the paradigm of evolutionary economics. The following paragraphs are supposed to briefly introduce some of the most important concepts of the evolutionary-economic theory of technological development we draw upon in constructing our simulation model.

2.1 Technological Opportunities

Invoking concepts of modern epistemology the process of technological development generally is considered to show features of punctuated equilibria (Mokyr, 1990)[2]. Whereas in normal phases technological progress proceeds incrementally along specific technological paths, there also exist irregular phases of strong turbulence questioning dominating technological approaches (so-called competence destroying technological change (Tushman/ Anderson, 1986)) and being the origin of totally new possibilities of the technological development.

The specific technological paths are characterized with the help of the concept of technological opportunities which describe the development potentials of a specific technology. An important feature of the technological opportunities of a single technology (so-called *intensive technological opportunities* (Coombs, 1988) is that they are not unrestricted but are limited due to technological and scientific bottlenecks.[3] For firms moving

---

[2] In this respect, many largely overlapping concepts exist, e.g. the paradigm/trajectory approach (Dosi, 1982), innovation avenues and technological guideposts (Sahal, 1985).

[3] In the literature, this relationship is known as *Wolf's Law*, e.g. the endeavors of a further acceleration of microprocessors by an increasing miniaturization of components is hampered by scientific bottlenecks. Those occur in the form of quantum theoretic laws that prevent further miniaturization when the distance between different components reached the size of an electron. This minimum distance proved to be necessary for a stable electron flux.

along a certain technological path this means that further progress is increasingly difficult to achieve with advancement on this path. In other words, the intensive technological opportunities become increasingly depleted by their exploitation. Accordingly, on the one hand, they provide for a regular development of a technological strand, on the other hand, however, they also provide only for limited possibilities of firms to struggle successfully in competition characterized by strong innovative elements.

Yet, this does not mean that progress comes to rest whenever the intensive technological opportunities are depleted. The technological opportunities of specific technological paths do not co-exist unrelatedly but there are several feedback mechanisms to scientific progress and advances in other technologies (Klevorick et al., 1987, 1995) which open up new potentials for further development, discussed under the heading of *extensive technological opportunities* (Coombs, 1988). Of course, escaping from the pressure of increasingly exploited intensive technological opportunities via exploration of new extensive opportunities is a costly effort and requires firms willing to invest resources in highly uncertain endeavors.

2.2 Technological Uncertainty

With uncertainty, the second important concept of modern innovation economics is touched upon. Whereas the problem of technological uncertainty, always immanent in innovation processes (see e.g. Witt, 1992) is avoided by traditional industrial economics by referring to the concept of risk and drawing on expected values of a principally known innovation, evolutionary approaches put significant weight on the emergence of true novelties, by their very existence with unknown characteristics.

Referring to the above introduced concepts of intensive and extensive technological opportunities, it becomes clear that both kinds of opportunities go hand in hand with qualitatively different forms of technological uncertainty. Whereas the direction and impact of exploiting the intensive opportunities along specific and well-defined technological paths can be roughly anticipated, this does in no way apply to the exploration of the extensive technological opportunity space.

Consequently, firms are no longer able to draw on an optimization calculus in their planning of innovative endeavors and the assumption of perfect rationality has to be replaced by the concept of an only *bounded rationality* (Simon, 1991). For an operationalization of this, Nelson and Winter (1982) have introduced the notion of *routines* – decision rules underlying innovation processes which are often described simply as *rules of thumb* deviated from past experience and future expectations which, however, come very close to real firm decisions.[4]

2.3 Knowledge

Dismissing the assumption of perfect rationality shows a further important consequence for innovation processes heavily emphasized by modern innovation theory. Knowledge is considered to be the basic ingredient for the development of true novelties and can no longer

[4] See e.g. Silverberg and Verspagen (1994) „To provide some anecdotal evidence, we recall an interview with the director of R&D of the Japanese firm Canon published in the Financial Times some years ago. The director reported that the firm has some time before raised its R&D/turnover ratio from 11% to $11^1/_2$%. This appeared to have been beneficial to the firm, so that the directors were now debating whether to cautiously raise it even further.“

simply be acquired by investing resources into R&D activities. Technological development shows to be of a cumulative nature meaning that present technological improvements build on successful innovation achieved in the past.[5] Accordingly, without acquiring previous knowledge of a specific technological path the most recent developments cannot be understood and transferred for own purposes. Accordingly, the innovative actors are characterized by only imperfect capabilities which depend on their history, i.e. they are *path-dependent*.

However, a *bit-by-bit* cumulative technological change can also be punctuated by major advance with the consequence that the technological capabilities developed so far lose their importance and are displaced by new competencies. It is this feature of the technological shift, leading to technological obsolescence of previous accumulated knowledge which Tushman and Anderson (1986) have in mind, when they coined the notion of *competence destroying technological change*. The introduction of an innovation, seen as a shift to a new technological path, therefore, very likely means that an innovative firm has to depreciate significant parts of the know-how it was drawing on in its previous production processes.

3. The Model

In the following section we want to briefly sketch the components of the simulation model and the integration of the concepts of modern innovation economics introduced above. We start with an outline of the underlying market mechanism.

- *Demand and Market*

Consumers can discriminate the goods produced in the industry by price and quality. Thus, the demand relationship creates competition in price and quality space, where each dimension is driven by a single force. Reduced costs of production allow firms to reduce prices and with it to increase the number of units sold. Whereas rising quality, i.e. the introduction of a new variety of the product characterized by higher quality, increases the consumers' valuation of the products opening up the opportunity for firms to charge higher prices.

In their decisions concerning the output markets firms optimize myopically. They set the price so as to maximize profits. On factor markets associated with production of the final goods the decision is also subject to an optimizing calculus. On factor markets related to research, however, firms employ routines.

As the goods are horizontally differentiated by quality we employ a model of a heterogeneous oligopoly in the fashion of the one previously introduced by Cantner and Pyka (1998) to represent the industry. The industry initially consists of n firms where each firm i faces a linear demand relationship.

$$p_{it} = a_{it} - x_{it} + \sum_{\substack{j \neq i \\ j \in F}} d_{ijt} \, p_{jt} \quad \forall i \in F \tag{1}$$

The reservation price a_{it} depends on the product quality offered by firm i. It increases with product quality, implying that higher quality leads to a higher willingness to pay for the goods.

[5] See e.g. Nelson (1987).

The index set of all firms in the oligopoly is denoted by *F*. Similar to Kuenne (1992) we model this relationship between the integer quality q_{it} and reservation price a_{it} by

$$a_{it} = a_0 \cdot n_t^{(0.25\Sigma|rq_{ij}|/(n_t-1)-1)} \qquad \forall i \in F\ . \tag{2}$$

The relative distance of firm *i* to firm *j* in quality space is given by rq_{ijt}, where the maximum absolute distance is 1. The sign of rq_{ijt} is denoted srq_{ijt} indicating superior quality of firm *i* relative to firm *j* by a positive value.

The price for a good in equation (1) is influenced by the prices of any other good *j* weighted by d_{ijt} which in absolute terms declines with distance in quality space. The weighting factor of the influence d_{ijt} shown in figure 1 is defined as

$$d_{ijt} = srq_{it}(1 - rq_{it}) \qquad \forall i, j \in F,\ i \neq j \tag{3}$$

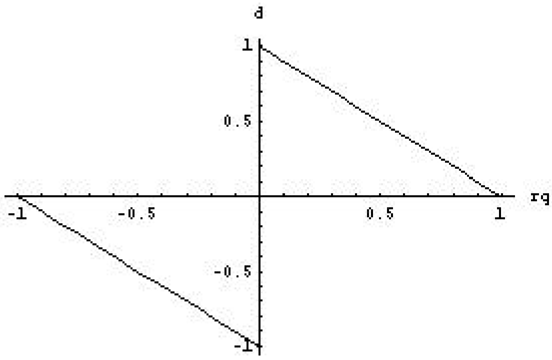

Figure 1 d$_{ijt}$ dependent on the relative quality position *rq*$_{it}$

In period *t* firm *i* sets the price p_{it} based on competitors' prices p_{it-1} of the previous period $t-1$ so as to maximize profits. The resulting reaction functions are given by

$$p_{it} = \frac{a_{it} + c_{it}}{2} + \frac{1}{2(n_t - 1)} \sum_{\substack{j \neq i \\ j \in F}} d_{ijt} p_{jt-1} \qquad \forall i \in F \tag{4}$$

$$x_{it} = \frac{a_{it} - c_{it}}{2} + \frac{1}{2(n_t - 1)} \sum_{\substack{j \neq i \\ j \in F}} d_{ijt} p_{jt-1} \qquad \forall i \in F \tag{5}$$

A few comments on the notation of (4) and (5) are necessary here. c_{it} is firm *i*'s average cost of production and n_t is the number of elements in the index set *F* and represents the number of firms still being present in the oligopoly at time *t*.

- Production and Learning Curve Effects

The firms produce the final product with a constant returns to scale technology, where the production function assumes that all capital goods are entirely represented by the labor productivity l_{it} (see e.g. Cooper and Haltiwanger, 1993; Tronti and Tanda, 1998).

$$x_{it} = l_{it} \cdot n_{it}^{work} \cdot d^{t-1} \quad \forall i \in F \tag{6}$$

The amount of unskilled labor employed in the production process is n_{it}^{work}, the capital stock is physically depreciated with the rate δ and the time the capital stock has been in use for is denoted by τ.

Several empirical investigations reveal a high correlation in the advent of product and process innovation (Smolny, 1999, Rottmann and Ruschinski, 1998). So we assume the capital stock of the firm to be replaced upon the arrival of product innovation. Therefore the rate δ of physical depreciation or obsolescence of the capital stock has no influence on the decision of machine replacement. Hence the rate of depreciation of physical capital is set to 1 reducing the production function to

$$x_{it} = l_{it} \cdot n_{it}^{work} \quad \forall i \in F \ . \tag{7}$$

Although in equation (7) labor productivity l_{it} of firm *i* is independent of the installation time τ of the capital stock and the quality level q_{it} of the output produced, it is not completely fixed. Experience is a source of continuous improvement of production processes (Arrow 1962) with a firm moving along its technological path, thereby exploiting the intensive opportunity space. A simple learning curve relationship affecting the labor productivity captures this learning-by-doing effect. Thus, in the model incremental technological progress along a single technological path is approximated by improvements of labor productivity which is determined by the cumulative output of a single product generation or quality level produced by firm *i*

$$l_{it} = \gamma \cdot \frac{1}{\lambda - 0.25\ \mathrm{Ln}(1 + x_{it}^{cum})} \quad \forall i \in F \tag{8}$$

In equation (8) firm *i*'s cumulative output is denoted by x_{it}^{cum} and both γ and λ are parameters. The formulation in (8) secures that doubling the cumulative output leads to an approximate 2% to 3% increase in labor productivity.

Once the wage for the unskilled workers w_{it}^{work} is determined by the labor market below, the average cost c_{it} for firm *i* can be determined.

$$c_{it} = 1/l_{it} \cdot w_{it}^{work} \quad \forall i \in F \tag{9}$$

Hence the profit that the oligopolist realizes in period *t* is

$$\pi_{it} = (p_{it} - c_{it})x_{it} \quad \forall i \in F \ . \tag{10}$$

- Shifts to new Technological Paths – Product Innovation

The oligopolists are not only engaged in production activities but also engage in R&D activities. Concerning the appropriation of profits a firm in the model finds itself confronted with the situation that costly R&D personnel can be financed from π_{it} or that he can please shareholders by distributing the profit. This problem cannot be solved by an optimizing calculus due to technological uncertainty but rather is it routines that are employed by the firm: a fraction of the profit denoted by s_{it} is spent on R&D personnel n_{it}^{eng} and the remaining part $(1\text{-}s_{it})\cdot\pi_{it}$ is distributed among shareholders. So, for a given s_{it} the amount of R&D expenditure strongly depends on the profit earned complying with both theoretical and empirical evidence (e.g. Stiglitz, 1993, Smolny and Schneeweiss, 1999).

Although firms myopically optimize their production decisions, the firms are modeled with a satisficing behavior with respect to their R&D efforts. Firms only change their strategies in employing R&D personnel in cases when the gap between the desired and the realized result exceeds a certain threshold. Gaps can basically open up in two directions. The gulch can be caused by unfulfilled expectations of external factors like shareholders for instance (case 1), or it can be an internal expectation gap (case 2). The different gaps, however, may call for conflicting remedies. Both facets are present in the model; the firm changes the routines only in two instances.

case 1 Once the oligopolist realizes a product innovation ($q_{it} > q_{it-1}$) it is time to devote a fair share of the profits to the shareholders. Shareholders will urge the oligopolist to comply with their notion of increasing the shareholder value and to buy into their understanding as $s_{it} = 0$ being the fair share. So whatever s_{it} was before the product innovation occurred, all profits will be distributed among the shareholders there after.

case 2 Once the oligopolist notices an undesirably low growth of the profit – below the minimum expected rate r - he realizes that there is no room remaining to reduce the costs, the intensive technological opportunities are depleted, and no more room for pleasing the shareholders. New extensive technological opportunities have to be sought to secure the existence of the firm. So a larger fraction of the profit has to be devoted to R&D.

Equation (11) formalizes the updating of the firms' strategies.

$$s_{it} = \begin{cases} 0 & if \quad q_{it} > q_{it-1} \\ s_{it} + s & if \quad \dfrac{p_{it} - p_{it-1}}{p_{it-1}} < r \\ s_{it} & \text{else} \end{cases} \qquad \forall i \in F \tag{11}$$

The expenditure on R&D can be used by firms as a strategic means to improve the competitive position in the heterogeneous oligopoly by improving the firm's quality relative to the quality produced by competitors. In this context a quality improvement is to be seen as the exploration of new extensive opportunities which manifests itself in a product innovation. For product innovation we do not distinguish whether (1) a quality level has been reached within the oligopoly for the first time, i.e. the quality-leader improves his quality, or (2) the quality level has already been present in the oligopoly, i.e. a firm other than the quality-leader catches up and increases its quality level. Hence, in line with the concept of a cumulatively built up knowledge base, we exclude the possibility of a simple imitation of external technologies. In the context of our heterogeneous oligopoly the mean effort to improve from quality level k to quality level l is equal for all firms no matter how many firms have undergone this quality improvement before. One might argue that this is equivalent to assuming that the wheel has to be reinvented over and over again. But, as we explicitly consider actors with imperfect knowledge bases, simple imitation is not very likely to occur. Furthermore, for reasons of simplicity, in the model, technological spillovers are excluded, what makes perfect imitation additionally not a very likely event.[6] Finally, by the very nature of the heterogeneous oligopoly, the firms in the model never produce homogenous products.

Concerning product innovation firms are confronted with true technological uncertainty. Regarding this, it becomes obvious why we draw on routinized behavior introduced above. The relationship between the firms' efforts to introduce a new product and the specific event of a successful product innovation is not known to the firms in the oligopoly[7]. However, firms are aware that they have to be engaged in R&D and therefore employ R&D personnel n_{it}^{eng}. With the help of the accumulated knowledge by the engineers and scientists the probability to successfully complete the exploration of the extensive technological opportunity space and to introduce an innovation increases.

A product innovation occurs for firm *i*, if the cumulated R&D employment exceeds a randomly distributed threshold θ_{ij}. Additionally, not only the innovation process of a single product innovation is cumulative, but also the sequence of different product innovations is characterized by a strong cumulativeness and path dependency: to reach a certain quality level, the firm has to master the preceding stages in order to accumulate the necessary knowledge and experience. Figure 2 depicts this process.

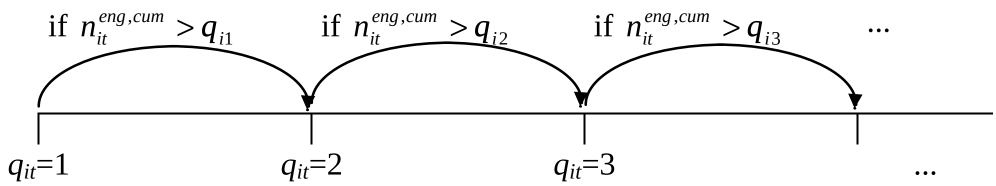

Figure 2 The process of quality improvement

Once a product innovation occurs for a firm the knowledge gathered in the previous production processes becomes obsolete and the respective firm again is confronted with low labor productivity. However, also the intensive opportunity space is refreshed and offers new possibilities for improving labor productivity. Further, in the ongoing search for new technological opportunities, the previous knowledge accumulated in the exploration of extensive technological opportunities in the R&D laboratories of the respective firm also becomes obsolete. Accordingly, we consider the case of *competence-destroying* technological progress, the knowledge stock of a firm is replaced every time a new product quality enters its production and the workers' experience in manufacturing the old, lower-quality product becomes outdated. To represent this formally, the initial value of the productivity is restored by resetting the cumulated output variable.

[6] „*When imitation is attempted under conditions that permit only limited access to the thing being imitated, it becomes very similar to innovation and of course is unlikely to yield an exact copy.*“ (Winter, 1984, p. 292)

[7] In this point, a particular advantage of the simulation technique shows up. Here it is possible to draw on probability distributions, the statistical relationships are hidden from the actors in the model. In a standard optimization approach this differentiation of the researcher and the modeled world is not possible.

The threshold θ_{ij}, responsible for the event of a product innovation, is a random variable generated by subtracting an exponentially distributed variable from a fixed limiting value. The resulting distribution is sketched in figure 3.

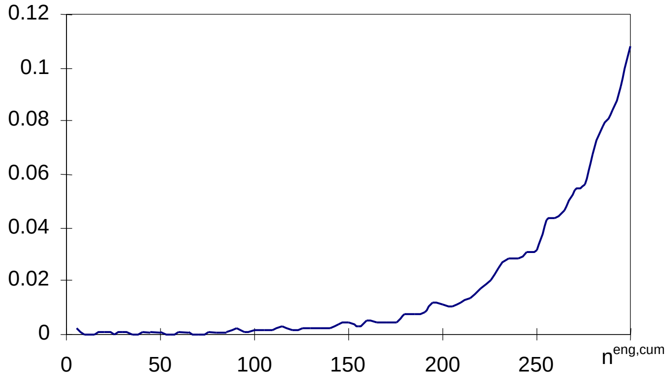

Figure 3 Distribution of the threshold variable

- Labor Market

Now let us turn to the labor market. Both types of workers, the production workers and the R&D personnel are hired on labor markets and are compensated by wage w_{it}^{work} and w_{it}^{eng} respectively.

The wage for the R&D personnel firm *i* faces in *t* is driven by the corresponding changes in demand for scientists and engineers from period *t*-2 to the previous period *t*-1,

$$w_{it}^{eng} = \left(n \cdot \frac{\sum_j n_{jt-1}^{eng} - \sum_j n_{jt-2}^{eng}}{\sum_j n_{jt-2}^{eng} + e} + 1 \right) \cdot w_{it-1}^{eng} \tag{12}$$

where ν and ε represent fixed parameters. The wage $w_{.}^{work}$ for the production workers, however, is tied to average productivity changes.

$$w_{it}^{work} = \left(w_i \cdot \frac{\sum_j l_{jt-1} - \sum_j l_{jt-2}}{\sum_j l_{jt-2}} + 1 \right) \cdot w_{it-1}^{work} \tag{13}$$

The variable ω_i allows us to specify the influence of productivity changes on the wages, where $\omega_i \in [0,1]$. Hence ω_i is the crucial variable to generate different scenarios as it represents the degree of how much the collective wage bargaining actors like governments, unions and employers have agreed on wage restraint in this sector. It can be seen as being determined outside the model.

- Exit

In the case firm *i* has too large a distance to the quality leader and produces under costs that are too high to compete neither in the price dimension nor in the quality dimension of the goods market, it is forced to exit the industry. The exit removes *i* from the index set *F* that contains the remaining firms in the industry.

At this point of the discussion all components of the model are specified. Now let us have a look on the potential compensation mechanisms that are implemented in the model.

- *Compensation Mechanisms in the Model*

The continuous improvement of the production process causes labor productivity to increase over time. Equation (7) shows that at a given output level employment decreases. This displacement could be compensated by increasing output. This increase in output, however, can be induced by declining prices in turn stimulated by falling cost (equation (5)). Depending on the impact ω_i productivity changes have on wage formation the average cost of production may fall with rising labor productivity. This relationship opens up the opportunity for the *compensation through price reductions* to be effective. It is at the same time a rough representation of *the compensation through falling wages*.

On the other hand, we have customers with preference for new quality. New quality, i.e. new products introduced by product innovation increase the willingness to pay for the goods (equation (2)) and the amount of goods demanded. Product innovation offers the firms the possibility to gain market shares and, consequently, may foster employment in this context. This relationship portrays the *compensation through new products*.

4. Simulation Analysis

In the following section we want to explore, how the two different compensation mechanisms are affected by different schemes of wage formation indicated by different values of the wage restraint variable ω_i. The two scenarios that we are going to examine, are polar cases. ω_i takes the value zero in scenario I for all firms in the industry. Thus productivity changes in the industry have no influence on the wages $w_{\cdot}^{work}$. All firms pay the same wages and the wages are fixed to the initial level. This relationship represents the case of the wage bargaining actors finding a consensus for extreme wage restraint. The wages are kept down artificially. In the second scenario ω_i is one for all firms. Accordingly, the average percentage productivity change translates into percentage changes of the wages. The wage bargaining actors have agreed, that wage restraint is not an issue in this very industry.

In order to closely inspect the behavior of the firms in the model we implement it into a numerical computer simulation. The simulation is run for 1,500 periods on an artificial time scale and the simulation is re-run 100 times. The results of the 100 runs are used to compute the means to be presented in the following sections in order to avoid distortions due to the several stochastic elements in the model (*Monte-Carlo-Simulation*). A sensitivity analysis of our results with respect to parameter variations can be found in the appendix of this paper. Table 1 summarizes the basic simulation layout.

	Scenario I	Scenario II
Equations	(2)-(13)	(2)-(13)
No. of firms in the oligopoly	10	10
t_0	1	1
t_{max}	1500	1500
No. of runs	100	100
ω_i	0 for all i	1 for all i

Table 1 Scenario I and scenario II

For any simulation run in any scenario we start with the same value for the strategic variables s_{i1} displayed in table 2.

Firm	s_{it}
firm 1	0.2
firm 2	0.26
firm 3	0.32
firm 4	0.38
firm 5	0.44
firm 6	0.50
firm 7	0.56
firm 8	0.62
firm 9	0.68
firm 10	0.74

Table 2 Initial values of s_{it}

In the following section we are going to explore the situation of the individual oligopolist and the whole industry in three dimensions – the economic, the technological and the employment dimension. We will mainly focus on the different development processes along the time line as to distinguish short- and long-run effects.

4.1 Economic Situation

Scenario I

First we want to observe the industry's situation in the economic sphere as displayed by the individual firm's profits. In figure 4 the profits of all firms of the oligopoly are portrayed. For explanational purposes, however, we concentrate on two selected firms only (firms 5, 10). Firm 10 initially devoting the highest share to R&D (see table 2) on average is the first to innovate and gains tremendously from early innovating. It realizes rising profits induced by rising quality and increased consumers' assessment until the competitors also improve their quality and challenge the position of firm 10.

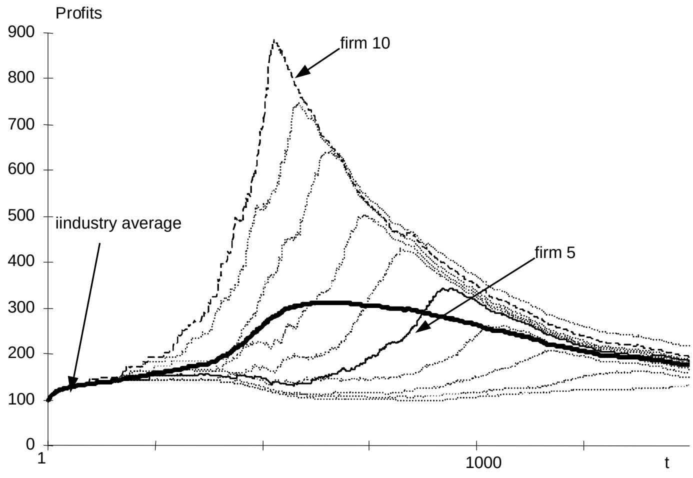

Figure 4 Scenario I - Profits

This development can be also detected by examining the costs. Figure 5 extracts the profit of firm 10 and displays it in combination with the costs born by firm 10. Early innovation grants the position of quality leadership to this firm enabling it to increase its market share considerably. Thereby room to maneuver is opened up for firm 10 which is used to exploit the intensive opportunities and increase productivity with rising cumulative output. The early downswing of the costs on the first technological path is attributed to constantly improving productivity. As firm 10 realizes that the intensive opportunities are exhausted it searches for new extensive opportunities by rising the fraction spent on R&D. The rising costs in the second stage around t=500 reflect the successful introduction of a product innovation by this firm. A new product generation is introduced and due to the competence-destroying nature of technical progress also low labor productivity characterizes the production of the new commodity at early stages. However, due to a rich intensive opportunity space on this new technological path, labor productivity improves with cumulated output. The firm is able to reduce its costs again, however, now the cost-reduction does not completely translate into increasing profits as also the competitors are able to switch to new technological paths. This way, the price component in competition significantly gains in importance again. Fiercer

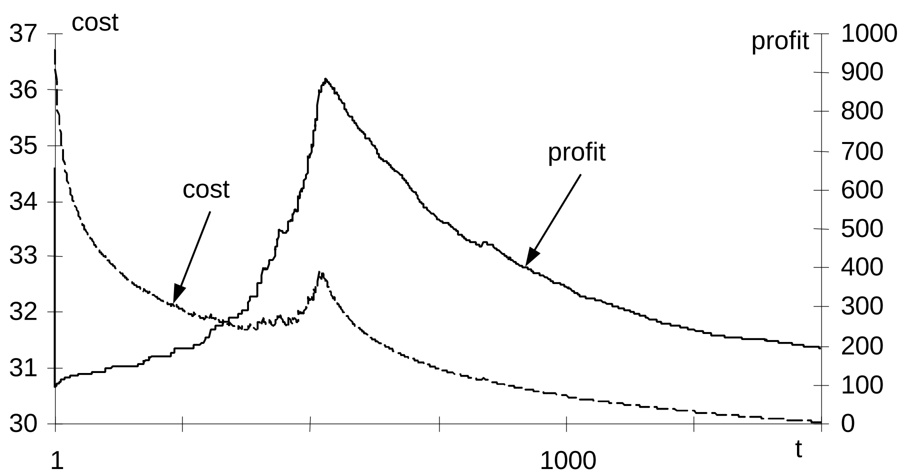

Figure 5 Scenario I - profits and costs of the quality leader (firm 10)

competition can not be compensated by cost reductions exclusively, and accordingly, profits decline. Even a change of strategy resulting from falling profits can be no cure to price competition in the situation of profits declining too steeply. In this situation of fierce price competition causing a sharply declining residual firms do not have the (financial) power to accumulate enough R&D and build up new competencies to further explore the extensive opportunity space and introduce another product innovation.

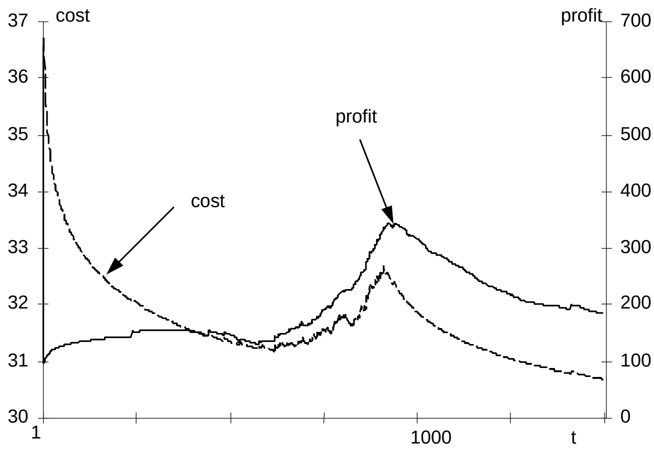

Figure 6 Scenario I – profits and costs of a technologically lagging firm (firm 5)

In figure 6 the profits and costs of a firm which, with respect to the introduction of an innovation, is technologically lagging are depicted. This firm 5 faces slightly increasing profits in the beginning which are caused by the improvement of its labor productivity. With the introduction of a product innovation of firm 10 around t=500 firm 5 is confronted with slightly falling profits as now technological lagging firms lose demand in quality competition.

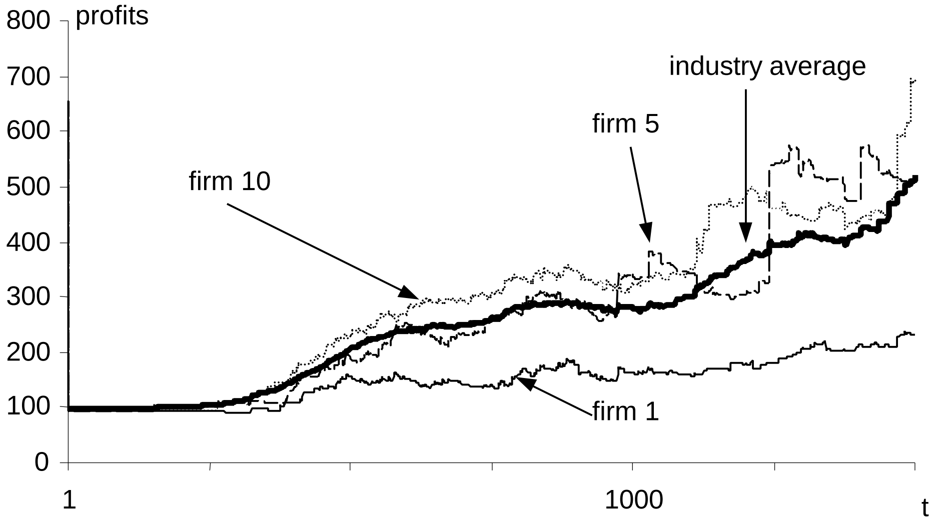

Figure 7 Scenario II – Profits

However, declining profits induce a change in the strategy variable to foster R&D, which turns out to be successful a likewise early introduction of a new product increases profits again. With this product innovation firm 5 catches up to the technology frontier and is able to gain from its improved quality position, as long as the other still technological lagging firms are not yet able also to catch up. Like the leading firm 10, also firm 5 finally is not able to escape declining profits on its second technological path in this scenario.

Scenario II In the second scenario the wages are no longer kept constant but are allowed to rise with average labor productivity (w_i=1). Figure 7 shows the development of profits of three selected firms as well as the industry average profit development. Compared to the first scenario as a first difference the jagged appearance of the curves is striking. The development in this scenario does not show the regular character of the previous one but seems to include quite different dynamics. Moreover, the firms in scenario II seem at least on average to be in the position to maintain a positive trend in profit development.

In order to capture the processes behind this development figure 8 exemplarily shows the costs and profits of a single firm (firm 10). Firms in scenario II do not face falling costs as increasing productivity is on average absorbed by wage increases. Hence the profit situation for firms in scenario II becomes unsatisfactory more quickly, causing the firms to change their strategy earlier. Employment of R&D personnel starts to increase making the event of product innovation more likely. There are no rising profits due to almost constant costs in the first place. After around 250 periods the R&D efforts start to pay for firm 10. It manages to exploit the extensive opportunities and introduces its first innovation. A better position in the quality competition makes profits begin to rise even though there are no significant change in costs.

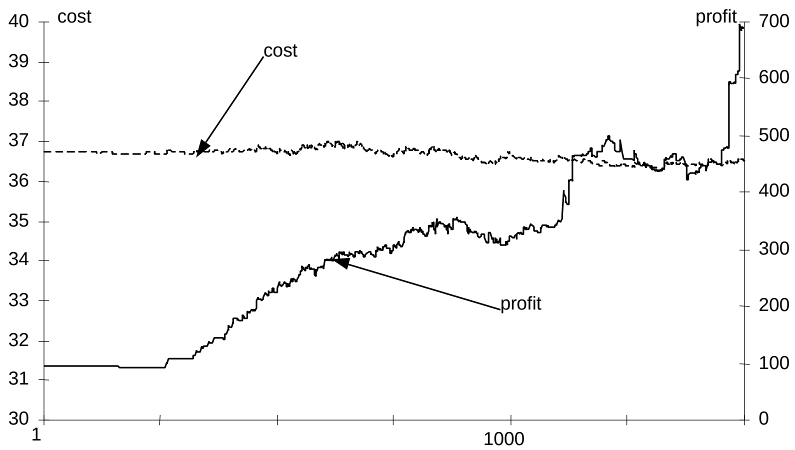

Figure 8 Profits and Costs of Firm10

To compare the economic situation of the whole industry we plot average industry profits in one diagram (figure 9).

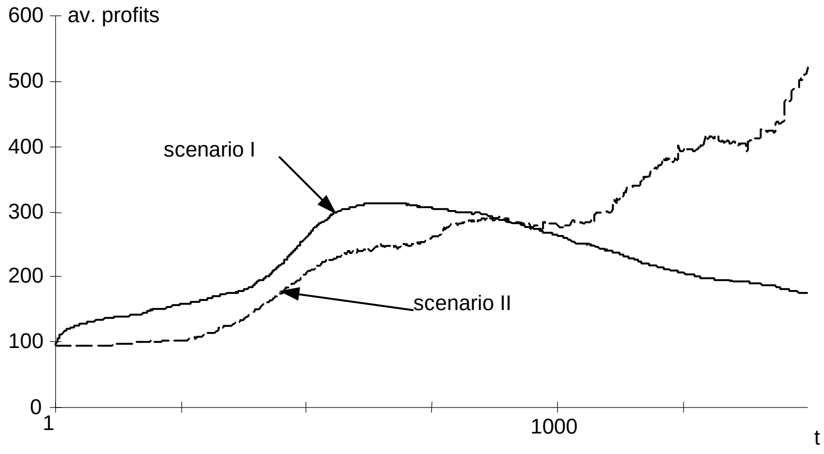

Figure 9 : Average Profits of Firms in Scenario I and Scenario II

Although profits in scenario II look not that promising in the beginning firms start to search for new opportunities and profits end up on a higher level compared to that in scenario I. The only difference between scenario I and scenario II is, that in scenario I wages are not tied to productivity improvement, whereas in scenario II average productivity gains fully translate into increasing wages leaving costs almost constant. Wage restraint as modeled in scenario I gives an incentive for firms to be content with the overall situation and concentrate efforts on incremental improvements of process technologies and realizing profits. On the other hand, wages growing with average productivity generate a stronger incentive for the firms to improve also quality and to engage in risky and uncertain exploration of new extensive technological opportunities. Striving for quality improvement represents a possibility to escape price competition by emphasizing the quality component of competition. Price competition leads to falling profits in the long run (figure 4 scenario I) whereas combining price and quality competition opens up the possibility for increasing profits (figure 7 scenario II).

Technological Situation

The technological situation of an individual firm in the industry can be summarized by the quality level produced; and so can the whole industry. The average quality level in our model does not only indicate the technological situation concerning the product quality it also depicts the vintage of the production technology and the pace of change.

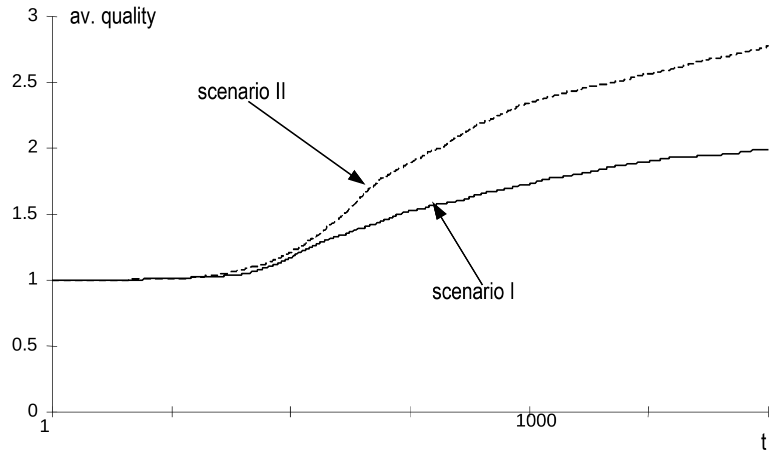

Figure 10 Average quality level produced.

As can be seen in figure 10, at any time beyond period t=300 superior technology can be found in scenario II. Both the level of the technology and the pace of the technological progress is higher for scenario II. The result indicates that wage restraint discourages product innovation in our model causing technological backwardness for the industry in the long run.

We can also try to find a proxy for the age of the capital stock used by the firms. As the capital stock in our model is technologically obsolete upon the arrival of a product innovation in the guise of a higher product quality, the average probability for a product innovation gives a proxy for the probability of a capital stock being replaced.

From the simulation results we compute the probability of a capital stock of a certain vintage to be still in use in different time periods. In figure 11 we print the probability of a capital stock being set up in period 20 and period 250 respectively to still be installed on all remaining time periods.

One can see that at any time a capital stock installed in scenario II is more likely to be removed than a capital stock in scenario I. Hence firms in scenario I tend to produce on an older capital stock compared to firms in scenario II. We can conclude that wage restraint not only causes technological backwardness concerning the products but also concerning the capital stock.

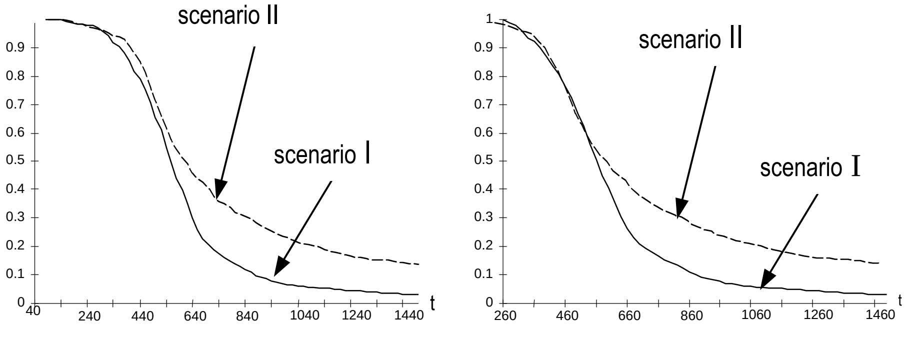

Figure 11 Probability of a capital stock installed in t=20 (left) and t=250 (right) still being installed in all remaining periods

Pace of change can be determined by the slope of the curve in the q-t-diagram. Here it is higher for scenario II than for scenario I at any time of the simulation. Note that the rate of technical change is not exogenously given but determined within the model.

4.3 The Employment Situation

To examine the employment effect of a wage restraint policy we may concentrate on the average employment of n^{work} -worker displayed in figure 12.

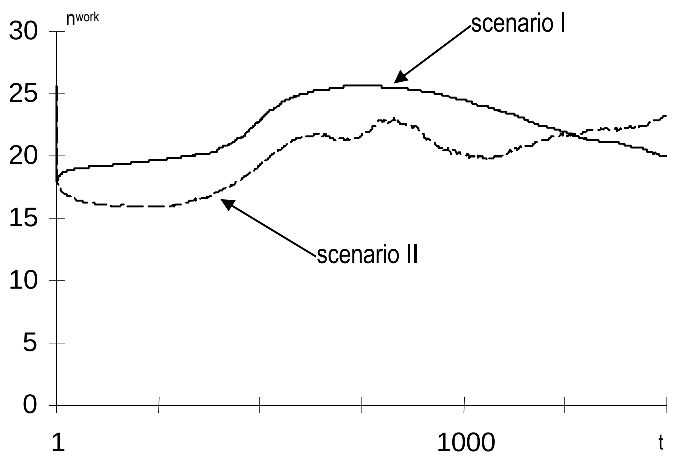

Figure 12 Average employment of n^{work} worker

One detects that although starting from an equivalent level of employment both scenarios exhibit different employment paths. In scenario I which models wage restraint average employment rises from the beginning until the peak employment level is reached around period t=750. Employment falls thereafter. In scenario II, however, where wage increases bid away productivity gains induced by process innovation we detect falling employment in the first place.

In the short run rising productivity and wage restraint, the dynamic equivalent of falling wages, determine falling costs which in turn cause output to rise. The increase in output is strong enough to (over-)compensate for the increased productivity and the employment expands. Scenario II teaches us that abandoning the wage restraint policy, so giving up the policy of falling wages, in this context means to have relatively constant costs although learning curve effects rise productivity. Employment, however, is affected negatively by the renouncement of wage restraint. Increasing productivity, while exploiting the intensive opportunities, leads to reduced employment, as the compensation through reduced costs and falling wages cannot work properly. Hence, employment falls.

Up to this point, say period 400 of our artificial time scale, we can tell the story about the compensating and therefore positive employment effect of reduced costs and falling wages. We can likewise tell the story of the disadvantageous employment results yield by wage increases induced by productivity growth. We have therefore identified the ‘usual suspects’ as being to blame for the negative employment situation in scenario II.

In the long run, however, our model shows that the situation for the industry under the wage restraint policy worsens. Wage restraint causes the productivity changes to fully translate into average cost changes. This in turn creates too large an incentive for the firms to exploit the intensive opportunities and compete only in the price dimension. By almost exclusively relying on price competition the firms restrict their own clearance to build up competencies to explore extensive opportunities. Hence the search for new quality to compete in both available dimensions turns out to be underestimated in an environment characterized by wage restraint. The compensation through falling wages and the compensation through cost reductions, that secured employment in the short run cannot compensate for the employment effects in the long run.

Firms in scenario II realize at an early point of time that price competition would reduce the profit as an indicator of economic success, as the wage setting regime bids away any gains that might occur through the learning curve effects. This leaves an incentive to search for new technological paths. The endeavor proves to be successful to produce higher quality products compared to firms in scenario I attracting consumers and increasing profits and employment. Not relying on the compensation though falling costs and wages in the first place starts to pay after a while when the long run effects of product innovation begin to work.

After having inspected the model one might not be sure that the story told about rising wages and costs as the usual suspects still holds true in the long run. One might be inclined to argue that in the long run recourse to the rising wages according to productivity improvements might press firms to turn away from exploiting the intensive opportunities only. One might even be inclined to state that the search for extensive opportunities induced by the usual suspects is the driving force for guaranteeing employment in the long run.

As is the case in any simulation study the question arises as to what extent the model results depend on the parameter values used for simulation. The sensitivity analysis of our model documented in the appendix, however, shows that the results are quite robust concerning simultaneous parameter perturbations affecting the demand and the technological sphere.

5. Conclusions

The paper provides a simulation analysis of a heterogeneous industry in order to investigate short- and long-run impacts of technological innovation on employment. Competition is characterized by two dimensions: on the one hand, price competition is responsible for firms to gain market shares by reducing their costs via process innovation. On the other hand, quality competition plays a major role, driven by product innovation which allows the firms to differentiate from competitors and gain in consumers' assessment. With respect to the relationship of technological progress and employment the two opposed compensation mechanisms discussed in the literature can be summarized under the heading *employment instead of innovation* and *employment via innovation*. The aim of our paper is to include these processes in a dynamic setting in order to understand how the compensation mechanisms work and interact in the course of time.

Our results suggest that firms in an industry are able to enlarge the demand for their products by decreasing the respective prices. This can be achieved by improving their production technologies, i.e. increasing their productivity. The employment can be maintained or even enlarged, although ever decreasing number of workers are necessary to produce the same level of output, as long as demand at least grows enough to compensate the productivity effect on employment. In our model this exploitation of intensive technological opportunities is implemented via a deterministic learning curve effect. However, firms can only reduce their output prices if their input prices remain constant or change only moderately. With wages oriented at productivity growth the possibility to reduce prices is excluded hampering the compensation mechanism - *employment despite of innovation* - to work properly. Therefore, at least in the short run constant or only moderate growing wages are a mean for guaranteeing employment.

Besides this compensation mechanism which focuses on the dimension of price competition, the second dimension of quality competition is considered to exert a certain influence on employment, which, however, is not as immediately visible as the influence of reducing production costs. In the case of constant wages, firms are able to realize considerable success by paying attention more or less exclusively on price competition. In the case of wages increasing with productivity the margin for reducing prices is much smaller and the economic success of this strategy is continuously threatened by increasing factor costs. Here, firms are exposed a stronger incentive to escape the pressure of pure price competition by differentiating themselves from their competitors. This can be done by engaging in the exploration of extensive technological opportunities and introducing a product innovation. Due to the intrinsic uncertainty of this kind of innovation process the firms are no longer able to optimize their decisions but draw on routinized behavior. With respect to the development of the employment situation in this scenario, our model's results suggest that in the long run an industry continuously under wage pressure is able to employ more people than an industry, where wages are kept down artificially, all other factors being equal. This sheds light on the meaning of *employment via innovation*: the finally even increasing trend in employment is maintained by a advanced capital stock in that industry.

Of course, our results have to be interpreted carefully. In our paper we are only discriminating between two scenarios with constant and increasing wages, thereby implicitly assuming an industry where technology plays an important role. It is quite obvious that our results are not valid in technological more moderate environments.

In a way, in the model some of the reasoning of A. Kleinknecht (1998) is included. Kleinknecht's arguing on a national level shows that the Dutch consensus and wage restraint oriented policy of *loonmatigating* in the last 15 years has had a quite negative effect on the national efforts in R&D and the respective development of the technological basis of the country, although the success of this policy on Dutch employment figures cannot be denied. Following Kleinknecht, the Netherlands are now in a somewhat dangerous position, as with only moderate exogenous shocks their economy is threatened by a decreased ability to adapt to the changed situation which could cause serious problems on labor markets. Our model captures the same mechanisms on a sectoral level within an economy and highlights the importance of an adequate functioning of the Schumpeterian compensation mechanism *employment via innovation* for a future positive development of employment.

In order to find empirical evidence for this kind of compensation mechanism on our agenda for future work is the identification of sectors where employment strongly depends on the introduction of new technologies. This can be done, on the one hand, with the help of industry case studies, on the other hand, the combination of industry employment figures with technology flow analysis seems to be a promising way.

References

Arrow, J. K. (1962) The Economic Implications of Learning by Doing, Review of Economic Studies 29, 155-173.

Cantner, U. / Pyka, A. (1998), Absorbing Technological Spillovers, Simulations in an Evolutionary Framework, Industrial and Corporate Change, Vol. 7, 369-394.

Coombs, R. (1988), Technological Opportunities and Industrial Organization, in: Dosi, G. et al. (eds..), Technical Change and Economic Theory, London: Pinter Publishers.

Cooper, R. / Haltiwanger, J (1993), The Aggregate Implication d of Machine Replacement: Theory and Evidence, American Economic Review 83, 360-382.

Dosi, G. (1982), Technological Paradigms and Technological Trajectories: A suggested Interpretation of the Determinants and Directions of Technological Change, Research Policy, Vol. 11, 147-162.

Heertje, A. (1977) Economics and Technical Change, London: Weidenfeld and Nicolson.

Katsoulacos Y. S. (1984) Product Innovation and Employment, European Economic Review 26, 83-108.

Katsoulacos Y. S. (1986) The Employment Effect of Technological Change, Brighton: Wheatsheaf,.

Kleinknecht, A. (1998) Is labor market flexibility harmful to innovation? Cambridge Journal of Economics 22, 387-396.

Klevorick, A. K. / Levin, R. C. / Nelson, R. R. / Winter, S. G. (1987), Appropriating the Returns from Industrial Research and Development, Brookings Papers on Economic Activity, Vol. 3, 783-820.

Klevorick, A. K. / Levin, R. C. / Nelson, R. R. / Winter, S. G. (1995), On the Sources and Significance of Interindustry Differences in Technological Opportunities, Research Policy, Vol. 24, 185-205.

Kuenne, R. E. (1992), The Economics of Oligopolistic Competition, Cambridge, Mass: Blackwell Publishers,.

Mokyr, J. (1990), The Lever of Riches, New York: Oxford University Press,.

Nelson, R.R. (1987), Understanding Technical Change as an Evolutionary Process, Amsterdam: Elsevier, North Holland.

Nelson, R. R., Winter, S. G. (1982), An Evolutionary Theory of Economic Change, Cambridge, Mass.: Cambridge University Press.

Rottmann, H. / Ruschinski, M. (1998) The Labor Demand and the Innovation Behavior of Firms, Jahrbücher für Nationalökonomie und Statistik217, 741-752.

Sahal, D. (1985), Technological Guideposts and Innovation Avenues, Research Policy, Vol. 14, 61-82.

Silverberg, G. / Verspagen, B. (1994), Learning, Innovation and Economic Growth: A Long-run Model of Industrial Dynamics, Industrial and Corporate Change, Vol. 3, 199-223.

Simon, H.A. (1991), Bounded Rationality and Organizational Learning, Organization Science, Vol. 2, 125-134.

Smolny,W / Schneeweiss. T (1999) Innovation, Wachstum und Beschäftigung: Eine empirische Untersuchung auf der Basis des ifo-Unternehmenspanels, Jahrbücher für Nationalökonoie und Statistik 218, 453-472.

Stiglitz, J.E. (1993) Endogenous growth and cycles, NBER working paper series 4286.

Tronti, L. / Tanda, P. (1998) Technical Progress, Life of Capital and Employment, Labour 12, 389-424.

Tushman, M.L. / Anderson, P. (1986), Technological Discontinuities and Organizational Environments, Administrative Science Quarterly, Vol. 31, pp. 439-465.

Wicksell, K. (1967) Lectures on political economy, London: Lowe and Brydone (first ed. 1901-1906).

Winter, S.G. (1984), Schumpeterian Competition in Alternative Technological Regimes, Journal of Economic Behavior and Organization, Vol. 5, 287-320.

Witt, U. (1992), Evolutionary Economics: Some Principles, Journal of Evolutionary Economics, Vol. 2, 163.

Appendix – Sensitivity Analysis

The two figures below show the results of a sensitivity analysis of the model, illustrating the effect of parameter variation on the simulation results. The aim of a sensitivity analysis is to investigate the behavior of the model given perturbations of the model's parameters. As the behavior of the model is driven by consumers' valuation of new products and the changing production technology due to process innovation we choose to perturbate a parameter of the demand (a_0) and a parameter of the production technology (γ) simultaneously. The simulation was carried out using various parameter combinations (a_0', γ') systematically drawn from the parameter space with $90 \leq a_0' \leq 110$ and $4 \leq \gamma' \leq 6$. The resulting employment path was correlated with the employment path reported in the paper, which represented the parameter vector (100,5). The light shaded areas indicate parameter combinations that yield a correlation coefficient larger than 0.9. whereas for the dark shaded area the correlation coefficient was at least 0.8. The black dots indicate the parameter vector (100,5).

The sensitivity analysis was carried out for both scenarios. Figure 13 and figure 14 displays the results for scenario I and scenario II, respectively.

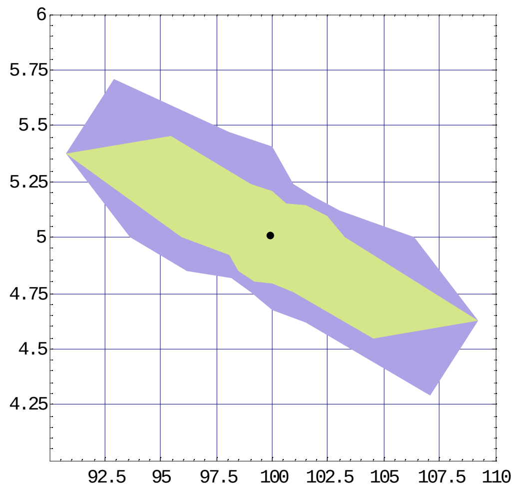

Figure 13 Sensitivity of scenario I

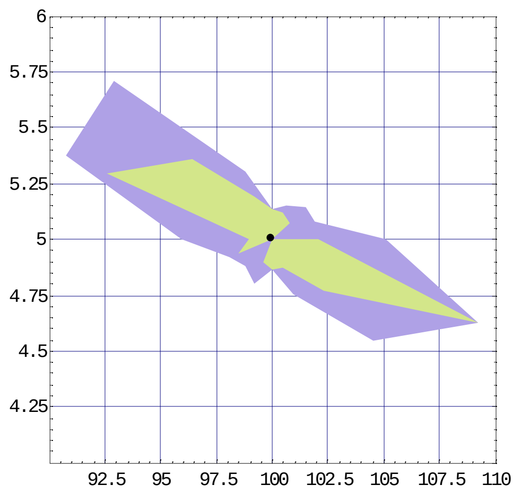

Figure 14 Sensitivity of scenario II