Endogenous growth and environmental policy: are the processes of growth and tertiarization in developed economies reversible?

Benoît Desmarchelier, Faïz Gallouj

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Abstract

The starting point for this article is the idea put forward by Gadrey (2008 [21]; 2010 [22]) that environmental problems and a policy of addressing them by introducing an environmental tax could trigger economic contraction and downscaling and a shrinking of the service sector in developed economies. The purpose of this article is to test these hypotheses using an evolutionary simulation model. To this end, we use a model of endogenous growth and structural change into which an environmental dimension is incorporated. The results of our simulations certainly reveal structural change within service industries but no change in the distribution of employment between services and manufacturing. Furthermore, we show that the environmentally desirable stagnation of labor productivity in the capital goods sector is compatible with a largely positive growth trend in the economy as a whole, with the development of knowledge-intensive business services apparently able partially to offset the stagnation of productivity in the capital goods sector. We conclude by emphasizing the need for environmental innovation in service activities and cast doubt on the long-term effectiveness of an environmental tax in the fight against pollution.

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1 Introduction

The theoretical debates on how to explain and to evaluate the development of the service sector set the post-industrial and neo-industrial schools against each other in the 1970s. The post-industrialists (Bell, 1973 [7]; Fourastié, 1949 [17]) saw the advent of the service economy as an ineluctable consequence (which was not to be perceived negatively) of the conjunction of a productivity law and a demand law. For their part, the neo-industrialists (Gershuny, 1978 [24]; Gershuny and Miles, 1983 [25]; Bacon and Eltis, 1976 [2]; Attali, 1981 [1], Lipietz, 1980 [26]), more or less implicitly, took a negative view of the process of tertiarization; for them, manufacturing industry was the engine of growth and deindustrialization a pathology. The intensity of these debates has gradually faded, with the post-industrialist perspective becoming more firmly established as contemporary economies became recognized as being irremediably service economies. Thus, public policies have supplemented defensive strategies aimed at curbing the process of deindustrialization with offensive strategies aimed at exploiting the resources of the service sector (in particular, potential sources of jobs).

The concept of sustainable development, which emerged out of an essentially industrial and technological background (Djellal and Gallouj, 2009 [11]), initially served to reinforce the argument that the development of the service sector was an irreversible process, a trajectory into which economies were locked. After all, although some services are acknowledged to be particularly harmful to the environment (particularly transport), the dominant general hypothesis is that the assumed intangibility of services tends to make them environmentally friendly. Services, it is argued, are almost by their very nature 'green' activities (OECD, 2000 [29]).

In some particularly stimulating studies, one of the leading European proponents of the post-industrialist school, Jean Gadrey (2008 [21]; 2010 [22]), suggests that this optimistic view of a service economy that will be asymptotically dominant in the long term should be revised. In a prospective analysis that can be described as neo-industrial, he argues that *"the historical trend towards an increase in the share of services in total employment and value added will be modified and possibly reversed in developed countries, as will the trend towards economic growth and productivity gains, as they are currently defined and measured"*. In other words, the historical process of service sector expansion is reversible and the future of services, as with other

activities, will be heavily dependent on their link to the environmental problematic. Furthermore, economic contraction or downscaling (décroissance, literally de-growth) appears to be a plausible scenario[1]
.

Gadrey's argument is that service economies, contrary to certain preconceived ideas, are also damaging to the environment. The intangibility of services is not necessarily a criterion of environmental sustainability, since the production of intangible outputs depends directly and indirectly on non-renewable energy and natural resources just as much as does that of tangible products. The other criterion by which services are defined, namely, the fact that they are interactive or co-produced (simultaneous physical presence of service provider and customer), is often synonymous with travel and hence with pollution. After all, the service economy is based on mobility (on the part of customers, service providers or the medium of service provision). Furthermore, actually putting this coproduction into practice (known in management sciences as 'servuction') requires the mobilization of many tangible elements (physical spaces and technical tools) the construction, operation and maintenance of which make use of non-renewable natural resources. From the perspective of coproduction, services appear almost 'by nature' as particularly environmentally unfriendly.

In order to back up his argument, Gadrey suggests that one of the main explanatory models of service-sector growth, namely Baumol's unbalanced growth model (Baumol, 1967 [3]), should be modified to incorporate environmental externalities. According to this well-known model, the development of the service sector is made possible by the productivity gains achieved in the capital-intensive sectors (the so-called 'progressive' sectors, mainly manufacturing industry). The workforce no longer required in these sectors is in effect transferred to the so-called 'stagnant' sectors (services for the most part), which are characterized by a low level of automation and lower productivity gains.

Thus, Gadrey takes the view that if environmental externalities are internalized (by means of taxes or other mechanisms), the revised version of Baumol's model leads to different conclusions. The internalized environmental externalities can be likened to the assumed fixed

[1]Gadrey (2008 [21]) does, after all, advance the hypothesis that *"many necessary changes in the production (of goods or services) will be accompanied by a reduction in labour productivity, at least as it is currently measured"* (p.13).

cost *"of a stagnant service (provided by nature)"* that refuses to adapt to productivity gains in its "work". In this way, Gadrey introduces an element of stagnation into manufacturing production, which was initially assumed to be progressive by nature. The cost of this stagnant element could make the labor factor relatively less costly than using more productive but polluting technologies. Thus manufacturing firms could be encouraged to switch to more labor-intensive technological trajectories. Service firms, for their part, would find it more difficult to follow similar trajectories because their production process is by its nature already labor-intensive. If reflected in their prices, the additional costs the tax would impose on them should cause the volume of demand for services to decline, which would free up workers for employment in the manufacturing sector.

The conclusion of Gadrey's argument is that, if environmental externalities are taken into account, the historical process of tertiarization in our economies should be reversed: the service sector will shrink and there will be a return to more labor-intensive processes in the traditional sectors, which today are highly capital-intensive (including agriculture). Moreover, Gadrey does not exclude a reduction in productivity and growth over the long term (economic contraction hypothesis), since it is highly likely that *"the costs of nature's services per unit produced in manufacturing industry"* will increase in the future.

The aim of this article is to use a multi agent-based computer model to test the hypothesis that the historical process of growth in the share of services in wealth and employment will be reversed and, more generally, that economic activity will contract. It is divided into two sections. In the first section, we develop a growth model that accounts for the dynamic of service sector growth and for the relationship between services and economic growth. To this end, we adapt an evolutionary growth model that draws on Dosi et al. (2006 [13], 2008 [14] and 2010 [15]), we also consider the modelling of environmental policies. In section 2, we carry out a number of simulations in order to test the model's behavior over the long term. Finally, we test the validity of the hypotheses of economic contraction and reversal of the service sector's growth dynamic.

2 An agent-based model of economic growth and tertiarization

To address the question of the future of tertiarization and growth, we propose to start from an existing industrial growth model, the multi-agent model of Dosi et al. (2006[13]; 2008[14] and 2010[15]). We are amending it so that it will produce growth in service activities. This model is particularly interesting, first because it reproduces a wide range of stylized facts, and second because it relies on a "vintage capital" growth engine, which is therefore naturally industrialist. This model is able to generate sustained growth of GDP through regular decisions of industrial firms to increase and to modernize their productive capital stock. It consists of two populations of agents (firms that produce machines and firms that produce consumer goods with the machines), and demand defined by an aggregate relationship.

In the economic literature (Baumol, 1967 [3]; Fuchs, 1968 [19]; Stanback, 1979 [33] ; Gadrey, 1992 [20]; Schettkat and Yocarini, 2006 [32]; Lorentz and Savona, 2008 [27]), three main factors determining the increase in the share of GDP and employment attributable to the service sector are identified : 1) lower growth in labor productivity in service industries than in manufacturing ; (2) the shift in end consumer preference towards services, and (3) the demand for services from service firms. These factors indicate how to modify Dosi et al.'s model so that it generates a tertiarization of employment and production. First we must add a population of low-productivity final service firms. Next, we add a population of firms that produce business services, and finally, we individualize the consumers and provide them with an income elasticity of demand for services greater than 1.

Our model thus has five populations of interdependent agents (capital goods firms, final goods firms, business services firms, final service firms and individual consumers). In the following subsections, we discuss the behavior of these populations and the way in which we introduce the environmental policy.

2.1 Industrial firms (consumer goods and capital goods suppliers)

This part of the model draws largely on Dosi et al's model. It represents the basis of the functioning of our two industrial sectors. They consist of two manufacturing sectors: one produces capital goods using labor as the only factor of production, while the other purchases these capital goods and labor in order to produce a final good. The economically active population is assumed to be constant. For each time period, the sequence of events is as follows:

In Dosi et al.'s model, firms i in the final goods sector receive information on latest-generation machines from firms k in the capital goods sectors. In the amended version we are proposing, producers of final goods choose a supplier randomly; the probability for a supplier k of being chosen is proportionate to his competitiveness C_{kt}. This competitiveness is measured by the equation 1.

$$C_{kt} = \left(\frac{A_{kt}}{P_{kt}}\right)^{\iota} \tag{1}$$

A_{kt} is the labor productivity of the machine provided by supplier k. ι is a positive real number that reflects the sensitivity of final goods producers to the ratio $\frac{A_{kt}}{P_{kt}}$ of the capital goods supplier. The higher this number, the greater will be market selection in the choice of supplier. P_{kt} is the price proposed by k, which is measured by (2):

$$P_{kt} = (1+\mu) \times \frac{W_t}{A_{kt}} \tag{2}$$

In this price equation, μ is the profit margin[2] and W_t is the macroeconomic wage, such that:

$$W_t = W_{t-1} \times \left(1 + \psi \frac{\Delta \bar{A}_t}{\bar{A}_{t-1}}\right) \tag{3}$$

where ψ is the level of wage indexation to labor productivity; $\psi \in [0;1]$ and $\bar{A}_t$ is average macroeconomic productivity[3].

As in Dosi et al.'s model, final goods producers i, having chosen a supplier k, decide on their replacement investments. Let A_{mit} be the

[2]As all profit margins in our model are identical, regardless of sector, they are denoted by the same term μ in all sectors.

[3]The model we are proposing comprise 4 sectors. If $\bar{\pi}_{it}$, A_{kt}, A_{jt}, A_{zt} are, respectively, labor productivity in the final goods firm i, the capital goods firm k, the final service firm j and the intermediate service firm z and N is the total number of firms, then average macroeconomic productivity at time t is given by:

$$\bar{A}_t = \frac{\sum_i \bar{\pi}_{it} + \sum_k A_{kt} + \sum_j A_{jt} + \sum_z A_{zt}}{N}$$

productivity of a final goods producer's machine m and b a (positive real) parameter that reflects the final goods producer's psychology. Machine m will be replaced if the condition 4 is fulfilled.

$$\frac{P_{kt}}{\frac{W_t}{A_{mit}} - \frac{W_t}{A_{kt}}} \leq b \tag{4}$$

The final goods producer i will replace its capital goods more frequently the higher is b. Thus it makes its investment decisions on the basis of an imperfect measure (since there is no strict trade-off between the cost and the advantages of the replacement) and an arbitrary parameter that has its roots, one might say, in the notion of animal spirits.

In Dosi et al.'s model, i's entire stock of machines is compared, as just outlined above, to the new machine offered by the supplier. In our amended model, on the other hand, the comparison will be restricted to half of the final goods producer's machines, namely, those that are least productive[4].

A final goods producer's capital stock determines its production capacity. In other words, the 'direct' productivity of any machine is unitary. However, the machines differ in the productivity A they confer on the workers. Consequently, a firm i will expand its capacity when its anticipated order volume exceeds its production capacity, namely its capital stock, K_{it}. It should be noted that, since i takes its decisions in a situation of uncertainty as to its outlets, the firm will not invest until the missing capacity exceeds a certain threshold α. The capital stock associated with this threshold will be written K_{it}^{Trig}, with $K_{it}^{Trig} = (1+\alpha)K_{it}$. Firm i's investment[5] in capacity EI_{it} is given by (5).

$$EI_{it} = \begin{matrix} 0 \quad if \quad K_{it}^{Need} < K_{it}^{Trig} \\ K_{it}^{Need} - K_{it} \quad if \quad K_{it}^{Need} \geq K_{it}^{Trig} \end{matrix} \tag{5}$$

Because of the unitary productivity of the machines tools, K_{it}^{Need} is equal to the firm i's desired level of production Q_{it}^d. Noting S_{it} the stocks inherited by i from the previous time steps, Q_{it}^d is given by the equation 6.

$$Q_{it}^d = Q_{it-1}^d + \beta(Q_{it-1}^r - Q_{it-1}^d) - S_{it} \tag{6}$$

[4]Our firm reviews only half of its capital goods because we take the view that the firm is not rational in its investment decisions.

[5]The machines are delivered at the end of the period.

Q^r_{it-1} represents the volumes actually ordered from the firm in the previous period and $\beta \in [0;1]$ determines the speed with which the firm adapts to changes in demand. If this desired level of production is positive, the firm i demands a number of work hours $L^d_{it} = \frac{Q^d_{it}}{\bar{\pi}_{it}}$ on the labor market, with $\pi_{it} = \frac{\sum_m A_{mit}}{K_{it}}$. The same rule applies for the provider of machine tools k but on the basis of Q^r_{kt}, it's actual perceived orders[6]. Thus $L^d_{kt} = \frac{Q^r_{kt}}{A_{kt}}$. If L_{kt} and L_{it} are the labor actually obtained by a capital goods firm and a final goods producer, respectively, the volumes produced are given by the relations (7) and (8).

$$Q_{kt} = A_{kt}.L_{kt} \tag{7}$$

$$Q_{it} = \bar{\pi}_{it}.L_{it} \tag{8}$$

The workers who are hired earn a wage, unlike those who are not working. This wage is used for consumption. In Dosi et al.'s model, demand for consumption goods is defined on an aggregate basis by means of a dynamic replicator. Since we are planning subsequently (although not in the present paper) to model individual consumer behavior with regard to pollution, we decided to model the individual consumer. This individual consumer selects a final goods producer i randomly in proportion to the latter's attractiveness V_{it} (9).

$$V_{it} = \left(\frac{1 + Ms_{it-1}}{P_{it}}\right)^{\zeta} \tag{9}$$

Ms_{it-1} is the firm i's market share during the preceding period, ζ is a positive real number representing consumer sensitivity to the ratio $\dfrac{1 + Ms_{it-1}}{P_{it}}$ and P_{it} is the product price, such that $P_{it} = (1 + \mu)\frac{W_t}{\bar{\pi}_{it}}$. This pricing rule is frequently used in evolutionary vintage capital models (Ciarli et al., 2010 [10]). One of its advantages is that it prevents the wages paid being too low relative to the sales prices of the final products. However, the sale price does not take account of the capital stock, which is costly for the firm . Thus, in view of the regular expense incurred in making frequent purchases of new capital goods, firms record negative profits, in some cases for several consecutive periods. This is a particular weakness of this type of model. In order to counter this difficulty, we do as Dosi et al. do and allocate a significant volume of initial liquidity to the firms (see the table 2).

[6]The machine tools providers produce in just-in-time.

For each consumer c, the quantities ordered are computed as $Q^d_{ct} = \frac{Bud_{ct}}{P_{it}}$, where Bud_{ct} is consumer c's budget at time t. Let Bud^r_{ct-1} be the consumer's residual budget from the previous period. If the consumer/worker has managed to find a job during the current time step, then $Bud_{ct} = Bud^r_{ct-1} + W_t$.

Firms in the capital goods sector innovate. A capital goods firm k that makes profits will use part of them (half by convention in this paper) to finance its R&D activities. The firm innovates if the following condition (10) is fulfilled.

$$U(0;1) < 1 - e^{-\eta . R\&D_{kt}} \tag{10}$$

$U(0;1)$ is a random draw using a uniform law, $R\&D_{kt}$ represents the R&D expenditure of firm k and η is a scale parameter. If the condition is satisfied, then k has succeeded in developing a new prototype. However, this prototype may be more or less efficient relative to the current technology. In our model, the capital goods firm performs a new draw $U(-0.5;0.5)$ in order to reassure itself about its prototype's level of performance. If the result is positive, the new prototype is retained and will be put into production in the following period. In this case, the new machine's productivity will be that of the old machine, supplemented by the result of the second random draw.

The firms i calculate their profits Π_{it}, which are added to their liquid assets. With Q^s_{it}, the volumes sold (they may be lower than those produced, in which case there will be an involuntary build-up of stocks $Q_{it} - Q^s_{it}$) and with K^R_{it} the capital volume actually received by the firm $i$in period t, Π_{it} is given by (11).

$$\Pi_{it} = P_{it}.Q^s_{it} - W_t.L_{it} - P_{kt}.K^R_{it} \tag{11}$$

K^R_{it} may be lower than the volume of capital goods ordered. In our version of the model, after all, the firm pays only for those machines it has received and, in contrast to Dosi et al., if a firm's order has not been completed in period t, the client firm may change supplier in the following period.

Those firms the liquid assets of which become negative are withdrawn from the market and immediately replaced by new ones, which are copies of one of the survivors. This implies that the number of firms in the model is constant. Again, this is a fairly strong but common hypothesis in evolutionary models (cf., among others, Dosi et al., 2006 [13], 2008 [14] and 2010[15]; Ciarli et al., 2010 [10]; Lorentz and Savona, 2008 [27]).

2.2 Adding service sectors and incorporating the factors driving tertiarization

As with most multi-sectoral growth models, the model described above consists solely of manufacturing industries, and the distinction between intermediate and final goods industries explicitly highlights the way in which the engine of industrial growth operates. In order to take account of the dynamic of service sector development, we propose, firstly, to add two sectors, namely, the final and intermediate services sectors, and, second, to introduce three factors driving tertiarization: productivity differential, the role of intermediate services and the evolution of consumer preferences.

The final services sector we are incorporating has the characteristics discussed by Baumol (1967, [3]; 1983 [5]). This sector is stagnant, that is to say that the firms within it do not themselves generate any productivity gains, although they may benefit from productivity gains by making use of intermediate services. Services cannot be stocked, and so are consumed at the same time as they are produced. Consequently, production takes place on a just-in-time basis, but firms' production capacities remain limited nonetheless. In concrete terms, final services firm j makes adaptive forecasts Q^d_{jt} (as in the equation 6 but without stocks) based on the demand directed at it (i.e. on the basis of its output). Thus, a firm's demand for labor is given by $L^d_{jt} = \frac{Q^d_{jt}}{A_{jt}}$, with A_{jt} the firm j's labor productivity. If L_{jt} is the volume of work hours obtained by j on the labor market, the final j's maximum output in period t is given by $Q^{Max}_{jt} = A_{jt}.L_{jt}$, with $P_{jt} = (1+\mu)\frac{W_t}{A_{jt}}$ the price of the final service firm.

We also incorporate into our model a knowledge-intensive intermediate services (KIBS) sector. This sector is also stagnant, but it has the specific characteristic of being able to induce productivity gains in the other sectors of the economy (final and intermediate goods, as well as final services) (Gallouj, 2002 [23]; Roberts and al., 2000 [31]; Camacho and Rodriguez, 2010 [9]). The production capacity of a knowledge-intensive service firm z is determined by its number of workers L_{zt}. Thus z's production capacity Q^{Max}_{zt} is given by $Q^{Max}_{zt} = L_{zt}$. This unitary productivity is the basis for price formation in the sector's firms : $P_{zt} = (1+\mu)W_t$.

Drawing in particular on Gallouj (2002 [23]), we regard the knowledge-intensive service firm z as being defined by a level of knowledge H_{zt}. In each period, firms in the three other sectors choose a knowledge-intensive service provider at random. They then compare their own level of knowledge H_t with that of the chosen service provider. If they note the existence of a cognitive differential, that is if $\frac{H_{zt}}{H_t} > 1$, then they enter into a transaction. This transaction proceeds as follows[7]:

- The client firm draws a number using a uniform law $U(H_t; H_{zt})$. The result will indicate its new level of knowledge, which may, at most, equal the supplier's.
- This new level of knowledge may give rise to an increase in labor productivity in the client firm, by facilitating an organizational innovation, for example. Thus, this firm will make a new draw in $U(-0.25; 0.25)$. The result, if positive, will increase labor productivity in the client firm by the number drawn. Although a negative result is unlikely in reality, the interval of possible values is defined by $[-0.25; 0.25]$ since, in this way, the firm has a one in two chance that the innovation will not take place. After all, a draw using an interval $[0; 0.25]$ would mean that virtually every draw would have a positive result. It should also be noted that the effect of this innovation on the client firm's productivity is assumed to be weaker than that of the capital goods producers' product innovations; however, the organizational innovation has the advantage of being applicable to all firms in the economy. It should further be noted that the organizational innovation generated by this transaction makes it possible to increase internal productivity in the capital goods firms.
- This innovation will gradually make the replacement investment less attractive for final goods producers i. The reason is that, if the organizational innovation is successful, labor productivity on the i's machines will rise, such that the condition (4) for making the replacement investment will be increasingly seldom fulfilled. Consequently, we have constructed a mechanism capable of shifting the model's engine of growth towards the service sector (in fact, making it less and less tangible) in a way that is totally endogenous.

[7] Our knowledge accumulation process is similar to that for material capital, but brings into play a number of random events. A similar approach can be found in Baumol, Litan and Schramm (2007 [4]): "*business firms' investment in knowledge creation is analogous to their investment in new equipment that promises to make employees more productive. But unlike investment in a new machine, which has more or less predictable productivity-enhancing consequences, investment in knowledge discovery is fraught with uncertainty*" (p. 51).

In each period, KIBS firms spend money on training for their staff. This expenditure is proportional to their revenue. If Q^s_{zt} denotes the volume of services produced by z, the firm makes a draw in $U(0;1)$ in order to ascertain whether this training actually increases its employees' knowledge. There will be an increase if condition 12 is fulfilled.

$$U(0;1) < 1 - e^{-\Theta . P_{zt} . Q^s_{zt}}, \tag{12}$$

where Θ is the share of revenue invested in staff training. If the training is successful, the firm's knowledge will increase by the result of a new draw in $U(0;0.5)$.

The intermediate services firms hire their new staff at the end of each period. In view of the sums invested in staff training, when an individual is hired he remains hired. In other words, employees are hired for an indefinite period in the knowledge-intensive services sector. The corollary of this is that a hire becomes very risky and thus firms in the sector will hire at most just one employee per period if there are employees without work (and therefore available) and if demand for their services has exceeded their production capacities by a sufficiently large margin. If ϖ denotes the threshold beyond which a new hire is sought and Q^d_{zt} is the demand for the KIBS firm's services, then this firm will make an offer of employment if $Q^d_{zt} > (1 + \varpi)L_{zt}$.

Final services firms' entries and exits from the market obey the same rules as those set out above. A firm exits when its liquidity becomes negative and it is immediately replaced by a new firm that is a copy of one of the survivors. However, KIBS firms do not obey this rule since they quit the market when their market share becomes zero. The reason for this is that, when a KIBS firm has not been selected during a particular period, it cannot innovate (its innovations are, after all, a function of its revenues). Consequently, it will never again be selected by a client because of the relative cognitive lag it displays.

As far as final demand is concerned, a consumer's budget is distributed between goods and services in accordance with Engel's law. We assume that final goods, viewed in their entirety, are basic products, while final services are non-basic products. It is further assumed that services have always been a part of individuals' consumption behavior and that goods will also always be a part of that behavior. Because of these assumptions, Engel's (diachronic) law will take the form of a variable ϱ that obeys a logistical law and is used to decide on the sums allocated to the consumption of services. If ε_{min} and ε_{max}

are, respectively, the minimum and maximum share of the budget allocated to the consumption of services and ε is a scale parameter:

$$\varrho = \varepsilon_{min} + \frac{\varepsilon_{max} - \varepsilon_{min}}{1 + e^{(-W_t + \varepsilon)}} \quad (13)$$

Thus, the share of the budget allocated to the consumption of goods is given by $1 - \varrho$.

All things considered, these significant changes should mean that the model is able to generate growth in a wholly endogenous way, as well as a shift in demand and output towards service activities.

2.3 Adding an environmental dimension

In order to assess the idea put forward by Gadrey of a shrinking of service sectors and of a de-growth of the GDP following the implementation of an environmental tax, we propose introducing environmental policy into our growth model in the shape of a Pigouvian tax on greenhouse gas emissions (GES). In order to observe the effects of this tax on macro and meso-economic dynamics, several elements are added to the model.

Capital goods are now described in terms of two forms of productivity: labor productivity, A, and environmental productivity, B. With Q^s_{it}, the quantity produced by a final goods firm i; its emission level E_{it} is given by (14).

$$E_{it} = \frac{Q^s_{it}}{\bar{B}_{it}} \quad (14)$$

$\bar{B}_{it}$ is the firm i's environmental productivity[8]. This productivity is calculated on the basis of the average of the environmental productivities B_{mit} of the firm's m machines, such that $\bar{B}_{it} = \frac{\sum_m B_{mit}}{K_{it}}$.

The environmental productivity B_{kt} of a firm k that produces capital goods is merged with that of the machine put up for sale. Thus, the level of emissions E_{kt} for a producer k is given by $E_{kt} = \frac{Q^s_{kt}}{B_{kt}}$.

Given that the interactive aspect of service activities is a source of pollution (Gadrey, 2008 [21]; 2010 [22]), a (final or intermediate)

[8]Variable $\bar{B}_{it}$ should not be confused with the environmental intensity of the productive process of the firm i. Indeed, $\Upsilon_{it} = \frac{E_{it}}{Q^s_{it}}$ is environmental intensity for firm i, whereas here $\bar{B}_{it} = \frac{Q^s_{it}}{E_{it}}$.

service firm's emission level E_{jt} (or E_{zt} in the case of a KIBS firm) can be considered proportional to the number of customers N_{jt}.

$$E_{jt} = \phi.N_{jt}, \tag{15}$$

where ϕ is a positive real number. In our simulations, it is less than unity. This choice is obviously arbitrary, as is the decision to opt for a linear relationship between the level of pollution and the number of customers. However, as we are advancing the (simplifying) hypothesis that service firms do not engage in environmental innovation, this choice does not really have any effect on the model's macroeconomic dynamic.

The unitary tax T is assumed to be such that $T \geq 1$. It represents the price to be paid in compensation for the emission of one unit of greenhouse gas. If PE_{it} is the amount of environmental taxes to be paid by a firm i, we have $PE_{it} = T \times E_{it}$. These taxes will be added to firms' costs. Firms will, therefore, pass these new costs on in their sales prices. For a capital goods firm j, the price becomes:

$$P_{jt} = (1+\mu)\left(\frac{W_t}{A_{kt}} + D \times \frac{T}{B_{kt}}\right), \tag{16}$$

where D is a dummy variable that has the value 0 when there is no tax and the value 1 when the tax is applied. This is a convenient way of showing the effect of the introduction of a tax on firms' behavior in the course of a simulation. By analogy, the final goods firms' new price will be given by (17).

$$P_{it} = (1+\mu)\left(\frac{W_t}{A_{it}} + D \times \frac{T}{\bar{B}_{it}}\right) \tag{17}$$

In the case of (final and intermediate) service firms, the sale price becomes (18).

$$P_{it} = (1+\mu)\left(\frac{W_t}{A_{it}} + D \times \frac{T \times E_{jt-1}}{Q^d_{jt}}\right), \tag{18}$$

where Q^d_{jt} is the expected volume of services produced by the firm. The presence of E_{jt-1}, the level of pollution, means the service firm makes short-sighted forecasts of the number of customers it will have in period t.

The rule governing decisions on replacing a machine for the final goods firms i will also be affected. Thus, a machine m will from now on be replaced by i only when the new condition (19) is fulfilled.

$$\frac{P_{kt}}{\left(\frac{W_t}{A_{mit}} + D \times \frac{T}{B_{mit}}\right) - \left(\frac{W_t}{A_{kt}} + D \times \frac{T}{B_{kt}}\right)} \leq b \quad (19)$$

Capital goods suppliers k' competitiveness index will also be altered by the introduction of a tax. In other words, once the tax is in force, final goods producers will also have to put a value on their machines' environmental productivity. The new index will be written thus:

$$C_{kt} = \left(\frac{A_{kt}}{P_{kt}} + D \times \frac{B_{kt}}{1+T}\right)^{\iota} \quad (20)$$

As far as the capital goods producers' innovation behavior is concerned, an ideal scenario is assumed in which the firm k is able to change its innovation trajectory when the tax is introduced. In concrete terms, prior to the tax, the firm k innovates but is little concerned with the effect of the innovation on its machine's environmental productivity. Thus, when the firm has adopted a new prototype, a new draw in $U(-0.5; 0.5$ is carried out. The result is added to the former environmental productivity B_{kt-1}, whether it is positive or negative[9]. After the tax is introduced, however, the firm k reverses its priorities. Thus, a prototype machine will be adopted if its environmental productivity is greater than that of the machine currently on sale, regardless of the evolution of labor productivity. This hypothesis of a change of innovation trajectory has been adopted in order to provide an analytical framework that is close to the scenario addressed by Gadrey.

Consumer preferences are not altered by environmental taxes, for several reasons:

1. Since firms add the tax in full to their sale prices, consumers will already be suffering a reduction in their purchasing power, particularly as far as service industries are concerned, for which the model does not provide any opportunities for environmental innovations.
2. It is assumed in the model that all firms that are able to do so will introduce environmental innovations. In other words, final

[9]We are assuming that there is a non-linear relationship between the environmental productivity of capital goods and the productivity that these capital goods confer on labor. Such a relationship can be justified by the literature on environmental Kuznets curves (Panayotou, 2000 [30]).

consumer preferences would neither slow down nor accelerate the environmental innovations if they existed.

3. We are concerned with growth and structural change; policies directed at consumers (labels etc.) serve merely to influence choices between identical or substitutable products (Bleda and Valente, 2009 [8], for example) and not between goods and services, which are known to be complementary (Stanback, 1979 [33]).

3 Results of the simulations

In this section, we study the impact of the environmental tax on economic growth and tertiarization. To ensure the credibility of the results, we first assess the empirical relevance of the emerging dynamics obtained without an environmental policy. Each result presented in this section comes from an average of ten simulations, each with a different "seed" to generate random numbers used by the computer to calculate the model.

3.1 Relevance of the dynamics without environmental taxes

Figure 1 shows the evolution of the logarithm of GDP over 500 periods and its confidence interval (each endpoint presents an error of the first kind of 5%). The logarithm grows steadily with no major changes in trend and within a confidence interval showing stable amplitude. But its trajectory reveals that the growth rate of GDP is decreasing over time. The model of Dosi et al. [13], for its part, did succeed in generating a constant growth rate. This difference is explained by the presence of tertiary sectors in our simulated economy. Figures 2 and 3 show a clear tertiarization of employment over the first 250 periods. This is because we hypothesized that the KIBS sector was completely stagnant and that the final services sector was relatively stagnant. Indeed, although it is unable to innovate on its own, the final services sector can benefit from productivity gains resulting from the use of KIBS. As for the KIBS sector, it certainly generates innovations for its customers, but we assumed in section 2.2 that these innovations result in lower productivity growth than that which results from the purchase of new machines. Thus, the way in which we modelled the tertiary sectors explains the gradual slowdown in growth.

Should we therefore conclude that our simulated economy will become asymptotically stagnant as in Baumol's model (1967 [3])? Our answer is no because, in Baumol's model, stagnation of GDP comes from the complete lack of productivity gains in the service sector, while in the model proposed here, consumer services, which account for most jobs, experience moderate productivity gains thanks to the KIBS sector. Thus, we can predict that our economy is moving towards an asymptotic situation of constant but low growth. Is the decline in the growth rate of GDP following tertiarization empirically verified? A number of observations suggest that this is the case. Stock and Watson (1999 [34]) found a slowing trend of GDP growth in the United States since the late 1960s, also observed for France, the United Kingdom, Japan, West Germany and the Netherlands starting in the early 1970s (Maury et Pluyaud, 2004 [28]; Fournier, 2000 [18]). We therefore consider this slowing economic growth trend during the tertiarization process as relevant.

Figure 4 shows that the transition to a less productive and therefore more employment-intensive service economy generates a rationing of labor demand, since the overall unemployment rate is zero once the shift in employment towards the service sector is complete. Finally we note (figure 5) that our tertiarized economy continues to emit increasing amounts of greenhouse gases (GHG), which is quite relevant. This is the problem we will seek to resolve with the help of an environmental tax. But before that, we propose to evaluate the model's ability to reproduce realistic economic cycles. Indeed, the model proposed by Dosi et al. was able to reproduce relevant economic cycles based on those seen in the United States and we believe that a study of the cyclical behavior of our aggregate variables can tell us more about how our tertiary sector functions.

To study the cyclical behavior of the variables in our model, we use the method proposed by Stock and Watson (1999 [34]). We isolate the cyclical component of our aggregate series by applying the band-pass filter of Baxter and King (1999 [6]) to their values in logarithm[10]. The cyclical components of our series of GDP and total investment in capital goods are shown in figure 6. This shows that our model, as with that of Dosi et al., is capable of reproducing a well-known stylized fact: investment is pro-cyclical and much more volatile than GDP.

[10]The values of the filter parameters are those recommended by Baxter and King [6] and Stock and Watson [34], namely, $k = 12$, $lower\ frequency\ bound = 8$, $upper\ frequency\ bound = 32$. In doing so, we must support the implicit assumption that a time period of our model corresponds to an actual quarter.

Table 1: Cross correlations with output (band-pass filtered variables)

Lag	−4	−3	−2	−1	0	1	2	3	4
PIB	−0.1473	−0.1582	0.5447	0.8711	1	0.8703	0.5397	0.1496	−0.1559
Investment (K)	−0.3348	−0.0786	0.2611	0.5458	0.6580	0.5643	0.3256	0.0532	−0.1547
Service employment	−0.0676	−0.1191	−0.2027	−0.2569	−0.2120	−0.0756	0.0893	0.2294	0.3156
Manufacturing Employment	−0.2072	0.0850	0.4031	0.6246	0.6732	0.5493	0.3192	0.0717	−0.1246
Consumption of Services	−0.0188	0.0140	0.0463	0.0960	0.1525	0.1861	0.1822	0.1521	0.1225
GHG Emissions	−0.3499	−0.1952	0.0403	0.2906	0.4842	0.5634	0.5059	0.3325	0.1003

The cross-correlation structure of the aggregate variables of the model with GDP (lag = 0) is shown in Table 1. These results are compared with the cross-correlation structure obtained by Stock and Watson for the U.S. economy (figure 7). The behavior of GDP in our model is similar to that shown by these two authors. Tangible investment and industrial employment have satisfactory pro-cyclicality, while consumption of services, though it has the desired pro-cyclical nature, is insufficiently volatile. In our model, tertiary employment appears to be counter-cyclical. This dynamic is contrary to that observed by Stock and Watson, but quite in line with the industrialist assumption of the unproductive nature of the consumer services sector. The anti-cyclical nature of tertiary employment reveals that the service sectors behave as sponge sectors: in a crisis, workers ousted from industry find employment in services, whereas they find industrial employment during the next upswing in the economic cycle. Finally, we highlight the pro-cyclical, but slightly delayed nature of greenhouse gas emissions: a peak in GDP results in a peak in emissions, but with a lag of one period. We have no basis for comparison for this variable, but it is reasonable to assume that such behavior is plausible.

Overall, the model seems to be able to satisfactorily reproduce a wide range of stylized facts. However, it is relatively weak in reproducing a realistic cyclical movement of tertiary employment. This is probably due to the industrialist nature of some of our assumptions. However, this weakness does not limit the ability of our model to study sectoral employment movements over a long period, following the introduction of an environmental tax. Indeed, the overall structural change the model produces is very relevant. The model also generates an increase in greenhouse gas emissions, which allows us to study the impact of the introduction of an environmental tax. This is discussed in the next subsection.

3.2 Results with an ecotax

Given that developed economies are service economies, the tax comes into effect from period 500 onwards, i.e. once the shift in employment towards the service sector is complete. The effect of four levels of tax on GDP is illustrated in Figure 8. The higher the rate of tax, the deeper the initial recession will be. This phenomenon is explained by the immediate increase in the price paid by consumers. The higher the rate of tax, the greater the decline in real incomes and, consequently, in consumer demand, which causes a sharper decline in production when the tax level is high. However, it is not the contraction scenario that emerges in the long term. All the scenarios are, after all, characterized by a resumption of growth, although the trend is changed compared to the scenario without the tax. The slowdown in the GDP growth trajectory is explained by a certain uncoupling of the growth trend from overall productivity, due to the stagnation of the labor productivity of capital goods (Figure 9). Nevertheless, the trend remains positive by virtue of the effect of knowledge-intensive services on overall productivity. In parallel with the evolution of GDP, the unemployment rate (figure 10) rises sharply but eventually returns to its pre-tax level as growth resumes.

In order to explain this resumption of growth, we focus on the evolution of the sectoral distribution of jobs. At first sight (Figure 11a), nothing has really changed. However, at a more detailed level of analysis (Figure 11b), the situations are more contrasting, with a shift in employment from final to intermediate services.

The first thing to note is that it is the final products sectors (both goods and services) that have been affected by the tax. This reflects the effect of the price increase on final demand. The intermediate sectors, on the other hand, saw a growth in employment levels at the time the tax was introduced. We have, after all, been considering a scenario tending towards the ideal, in which the environmental tax is accompanied by a change in technological trajectory for manufacturing firms. Thus, final goods producers exchange their old polluting machines massively for cleaner machines, giving rise to the cyclical increase in employment in the capital goods sector. Employment in this sector ultimately fares a little better in the medium term than in the scenario without tax, since intermediate services have a little less influence on final goods producers' replacement investment decisions. In our model, our hypothesis is that these services have no effect on the machines' environmental productivity.

In the case of intermediate services, the growth in employment levels can be explained by two factors. First, firms' demand for these services depends more on strategic considerations (knowledge differential) than on price considerations. It could be said that, as the regulatory environment changes, the increasing demand for knowledge-intensive services can be justified by the need to adapt that firms may experience. Second, the employment growth also stems from KIBS providers' reluctance to dismiss their employees. After all, as Gallouj (2002 [23]) notes, retention of their workforce is a necessary condition of their survival[11]. Running parallel to these shifts in the distribution of employment that help partially to sustain final demand, the change in capital goods producers' technological trajectory, which causes their machines' labor productivity to stagnate, gives rise to only a slight fall in the macroeconomic productivity growth rate (Figure 9). This phenomenon can be explained by the organizational innovations brought about by intermediate services.

This increase in macroeconomic productivity leads to a rise in wages, and thus also in demand, which helps gradually to lift the GDP growth trend. For all that, however, is this growth cleaner? Figure 12 shows that the answer is a positive one. Before the introduction of the tax, pollution was increasing more and more, despite the tertiarization of the economy (as Gadrey [22] has already observed). Due in part to the recession, the tax causes an immediate break in the trend. Thus the environmental tax seems to be an effective instrument to use in an emergency. Furthermore, it would seem that the higher the level of tax, the lower is the long-term pollution level. This can be explained fairly easily by the level of GDP itself, which is lower than without the tax (Figure 8). Since manufacturing firms have changed technological trajectory, the dynamic element that explained the initial increase in pollution is inhibited, but the level of emissions in our simulated economy quickly passes a threshold to reach a somewhat higher level. This observation can be explained by the pollution caused by service activities (Figure 13). This pollution is a consequence of the interactive nature of services, which requires travel. In our model, it is assumed that firms are unable to reduce this pollution. This observation, as with that concerning the level of polluting emissions produced by service activities when their interactive aspect is taken into account, reveal the crucial importance in the long term of environmental innovation in services.

[11]Gallouj (2002 [23]) notes in this regard that "*the organizational memory of KIBS firms is heavily dependent on the loyalty of its staff. The loss of certain members of staff produces an effect akin to amnesia or a cognitive haemorrhage*" (p.274).

3.3 Alternative scenarios

Until now, we have been assuming that the introduction of an environmental tax is accompanied by a change of technological trajectory among capital goods producers. This is a somewhat optimistic hypothesis[12]. Alternative scenarios can be envisaged that also make it possible to isolate the respective effects of the tax and firms' change of technological trajectory. We propose to analyze the macro and mesoeconomic dynamics generated by our model, first when the tax does not give rise to the desired change of trajectory and, second, when a change of trajectory occurs but without any taxation policy. Figure 14 shows the logarithm of the GDP series obtained for these two scenarios.

As already observed above, the introduction of the tax is reflected in our model in a sudden and severe recession. Moreover, as Figure 9 led us to suppose, manufacturing firms' change of technological trajectory is responsible for the relative weakening of the growth trend. This supposition is confirmed here by the parallel paths our GDP series take in the two scenarios with a change of technological trajectory. However, a somewhat unexpected phenomenon should be noted: although the scenario with the tax but without a technological response from firms tends to follow a path comparable to the control scenario without an environmental dimension, its path is somewhat unstable. This instability is evident in the increasing confidence interval of the GDP for this scenario (Figure 15). It is explained by the application of the tax, which will weigh all the more heavily on manufacturing firms' prices the more their machines are polluting. Since the relationship between capital goods' labor productivity and their environmental productivity is based on random draws, the prices become more volatile, which in turn makes the volumes of final goods ordered more volatile as well. Thus in this scenario, the introduction of an environmental tax is a factor in the amplification of business cycle fluctuations. Figure 16, which compares the evolution of the unemployment rate in the various scenarios, shows a long-term unemployment rate tending asymptotically towards 15% when a tax is

[12] Dosi and Grazzi (2006 [16]) take the view that the long-term trend towards the replacement of human inputs by machinery and other equipment (which is much more efficient but also more polluting) constitutes a technological paradigm in Dosi's sense of the term (Dosi 1982 [12]). Noting that a paradigm shift is an "*extraordinary*" event (p.12), these two authors consider it very unlikely that growth will become sustainable in the long term. Similarly, they consider the hypothesis that a tax could lead to a substitution of inputs (which is, as already noted, the basis of Gadrey's argument (Gadrey 2010 [22])) to be "*a far-fetched idea with little empirical support*" (p.14).

introduced without a technological response from firms.

The evolution of each sector's share in total employment is illustrated in (Figures 3, 11b, 17a and 17b) for all three alternative scenarios and for the control scenario in which there is no environmental dimension.

Whether there is a tax or a change of technological trajectory, the short-term disruptions in the sectoral distribution of employment are the same: the shares of the final products sectors in total employment decline sharply, while those of the intermediate sectors increase. However, the scenarios diverge over the long term. Thus, the environmental tax without any technological response seems to cause the relative shares of the service sectors in total employment to increase. However, this increase seems to be linked to the relative weakness of the demand for goods, since, in this scenario, as we noted above, the tax has a significant influence on the prices of goods in the long term and thus on the volume of demand. It is environmental innovations that enable manufacturing industry to retain its share of jobs, since they reduce the influence of the tax on the prices of final goods.

The effect of these various scenarios on greenhouse gas emissions is largely predictable: the tax causes production to fall drastically in the short term, which is reflected in an immediate reduction in emissions (Figure 18). In the long run, however, it is firms' technological response that is important, since it is this response that will prevent emissions from rising again. As such, the scenario in which there is a tax but no change of trajectory, which seems to be the most plausible, according to Dosi and Grazzi (2006 [16]), may be even less enviable than the control scenario without an environmental dimension. After all, we have already pointed out that, in this scenario, business cycle fluctuations are more strongly amplified than in the others, and these fluctuations give rise to irregular peaks of pollution, some of which are much greater than the emissions in the control scenario.

4 Conclusion

Service economies are characterized by a high level of interaction between producers and consumers. In many cases, this gives rise in turn to high levels of mobility, which is a source of considerable environmental externalities. Gadrey advances the particularly stimulating hypothesis that, if the problems around sustainable development were taken into account in services, for example, through the introduction of an environmental tax, the probable result would be a process of economic contraction and a shrinking of the service sector. We used our model to test this hypothesis. Our simulations produced four significant results:

1. because of their strong growth in contemporary economies, intermediate services may be a means of reconciling GDP growth with a reduction in the volume of pollution;
2. an environmental tax may produce a structural change, but this may well have a greater impact on the distribution of jobs between final and intermediate services than between manufacturing and services;
3. the environmental tax proves to be a highly effective instrument for reducing pollution in the very short term because of its ability to slow down economic activity very suddenly, while its influence in the longer term is determined to a large extent by the technological response that firms are willing or able to offer. (After all, if a tax turns out to be insufficient to bring about a change of technological trajectory among firms, then it may very well be a factor in amplifying business cycle fluctuations, which will in turn lead to significant pollution peaks);
4. the question of pollution and environmental innovations in service activities proves to be of decisive importance in the long term. Our working hypothesis was that this pollution could not be reduced; however, environmental innovations are still possible in the transport sector. Similarly, the most polluting service activities could also be persuaded to review their location policies with a view to reducing the distance between themselves and their customers (by moving back to town centres, for example). These examples of environmental innovations would reduce the environmental impact of the interactive aspect of service activities, although it seems doubtful that this impact will be reduced in the short term. It should also be noted that knowledge-intensive business services can also give rise to environmental innovations among their clients (Djellal and Gallouj, 2009 [11]).

Thus, in conclusion, we broadly support Gadrey's appeal for a 'revolution in the service economy', the main aim of which would be to draw up an environmental balance sheet for service activities and assess their capacity for environmental innovation.

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Figure 1: Logarithm of GDP without tax

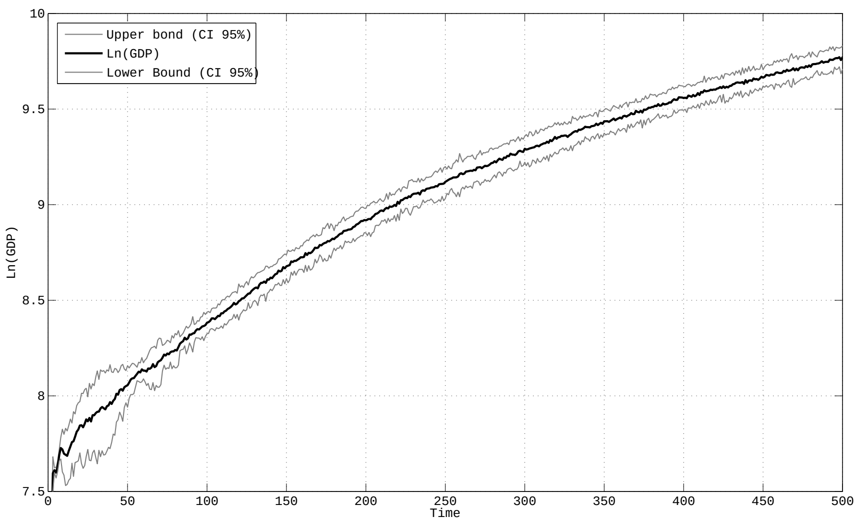


Table 2: Parameters' values

Description	Symbol	Value
Firms' markup coefficient	μ	0.33
Parameter for indexation of wages to labor productivity	ψ	1
Initial wage	W_0	1.5
Initial macroeconomic productivity	A_0	1.5
Firms' psychological parameter for replacement investment	b	8
Firms' adaptability to a variation in demand	β	0.5
Final goods firms' sensitivity to the competitiveness of capital goods firms	ι	1
Consumers' sensitivity to the attractiveness of final products	ζ	2
Scale parameter in capital goods producers' innovation processes	η	0.01
Share of intermediate service firms' revenue dedicated to staff training	Θ	0.5
Parameter for KIBS firms' hiring decisions	ϖ	0.2
Minimum share of services in household consumption	ε_{Min}	0.1
Maximum share of services in household consumption	ε_{Max}	0.8
Scale parameter in the Engel's law	ε	2
Parameter of customers' greenhouse gas emissions in service firms	ϕ	0.5
Number of capital goods producers		5
Number of final goods producers		25
Number of final services providers		50
Number of KIBS providers		5
Number of consumers/workers		1000
Final goods producers' initial capital stock	K_0	80
Firms' initial financial resources		10000

Figure 2: Share of employment in industry and services

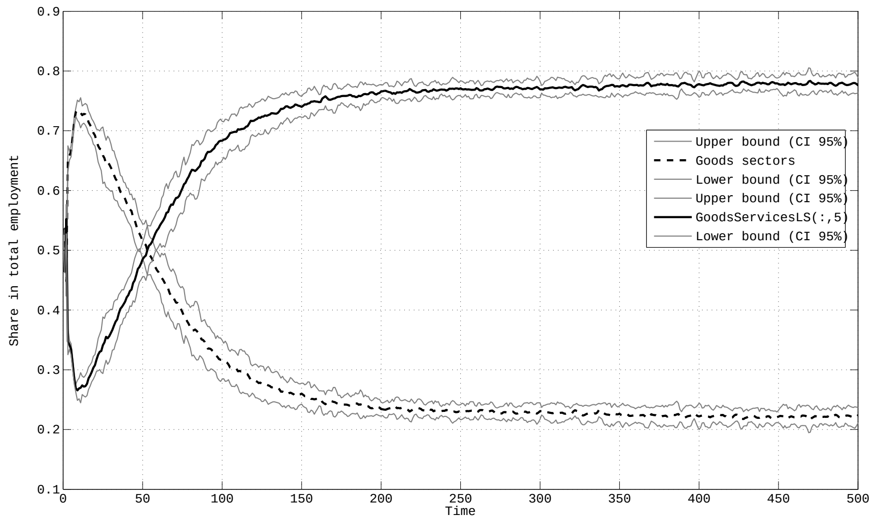


Figure 3: Share of employment in the various sub-sectors of the model

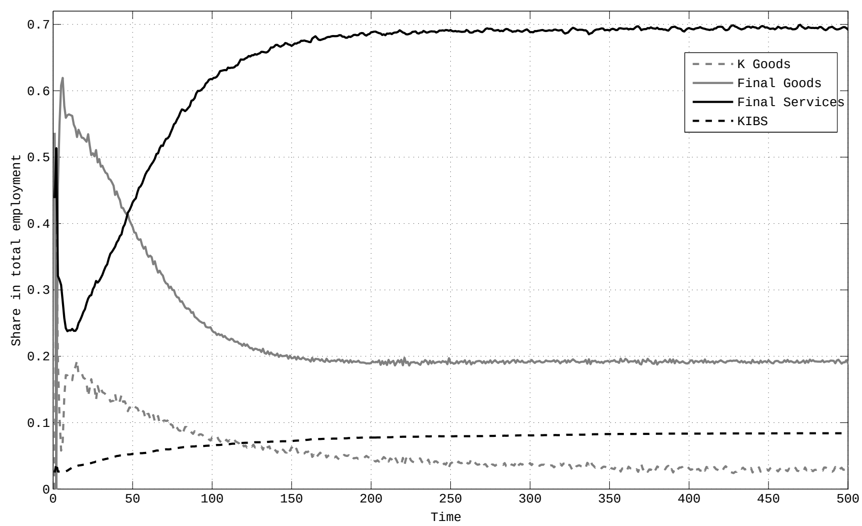


Figure 4: Dynamics of unemployment rate

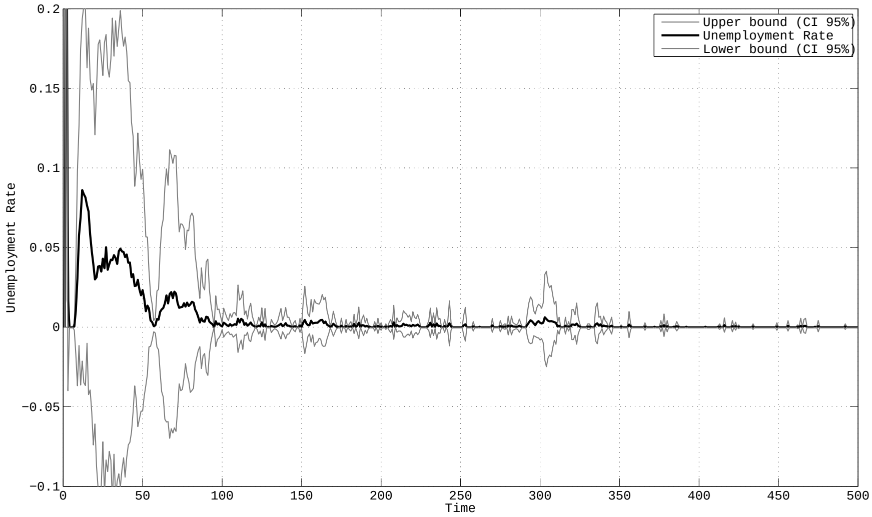


Figure 5: Evolution of greenhouse gas emissions

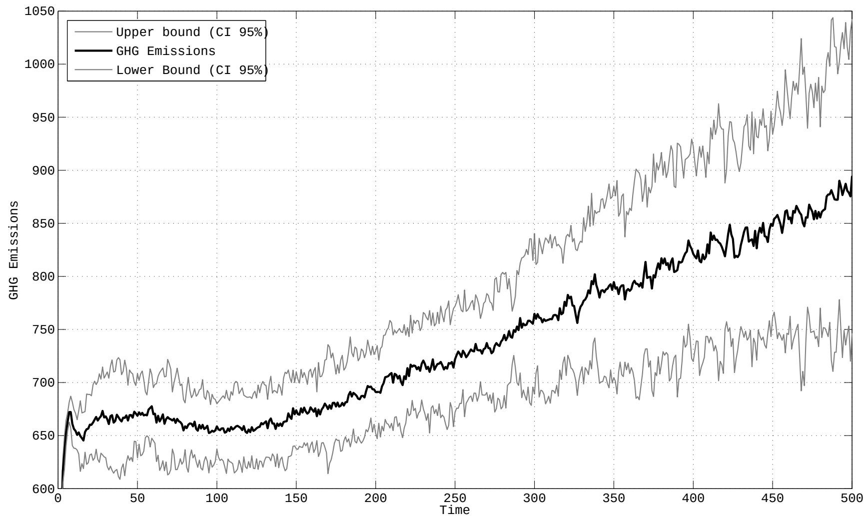
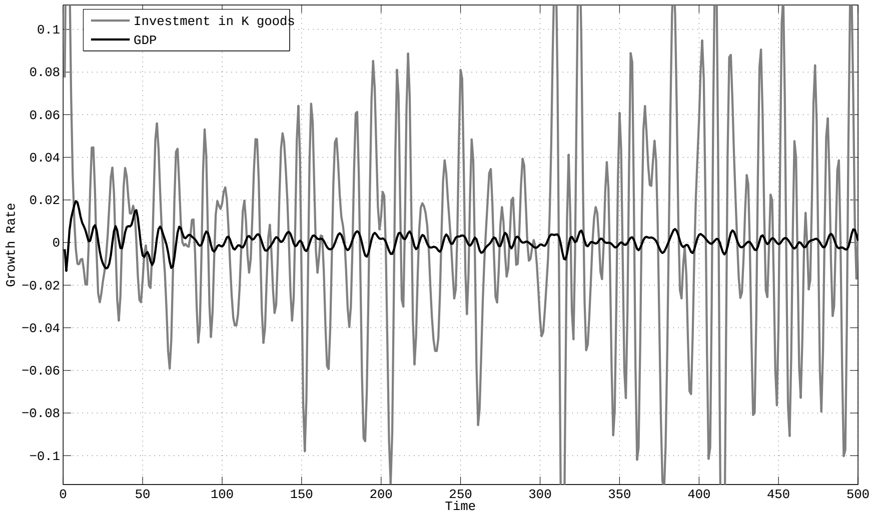


Figure 6: Tangible investment cycles and GDP cycles



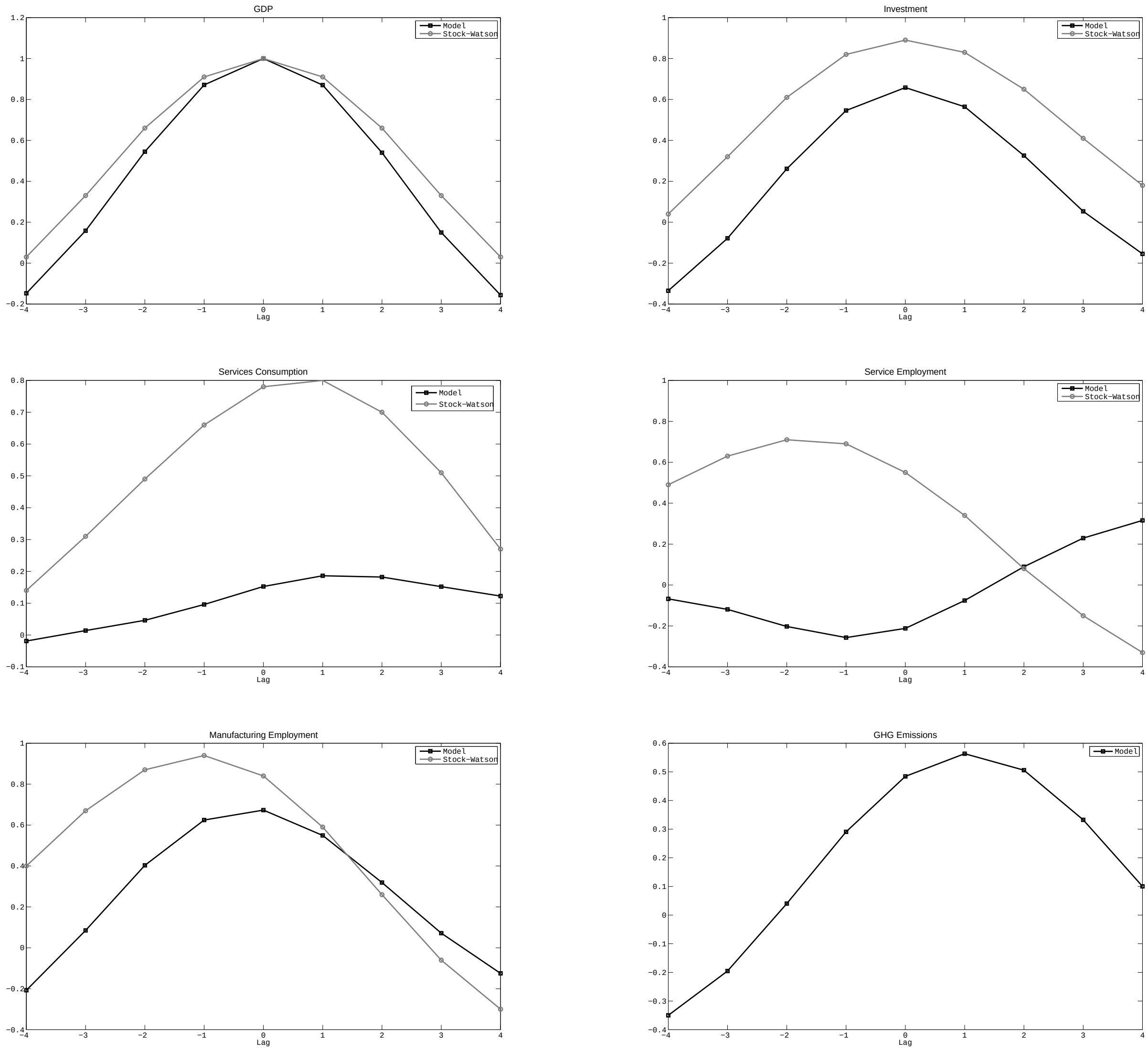


Figure 7: Comparison of the cyclical behavior of the aggregate variables in our model and in the U.S. economy suggested by Stock and Watson (1999 [34])

Figure 8: Impact of different levels of tax on GDP (log)

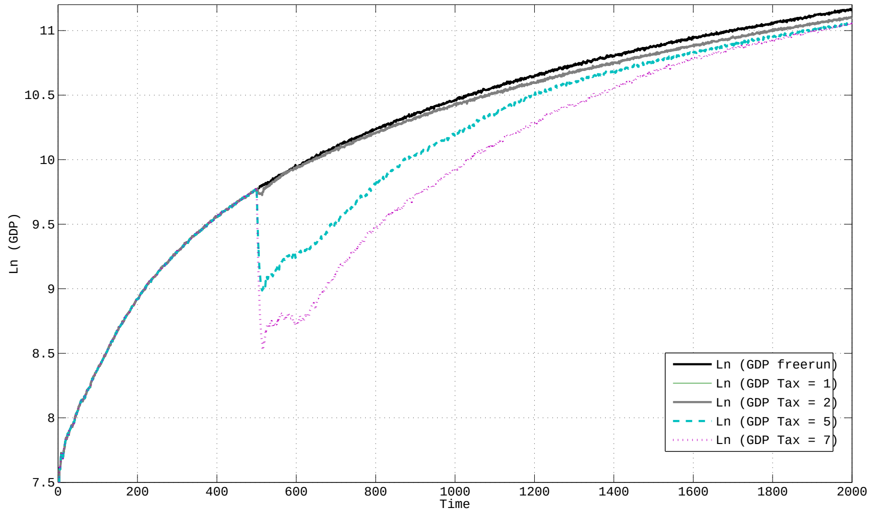


Figure 9: Change of technological trajectory of capital goods producers

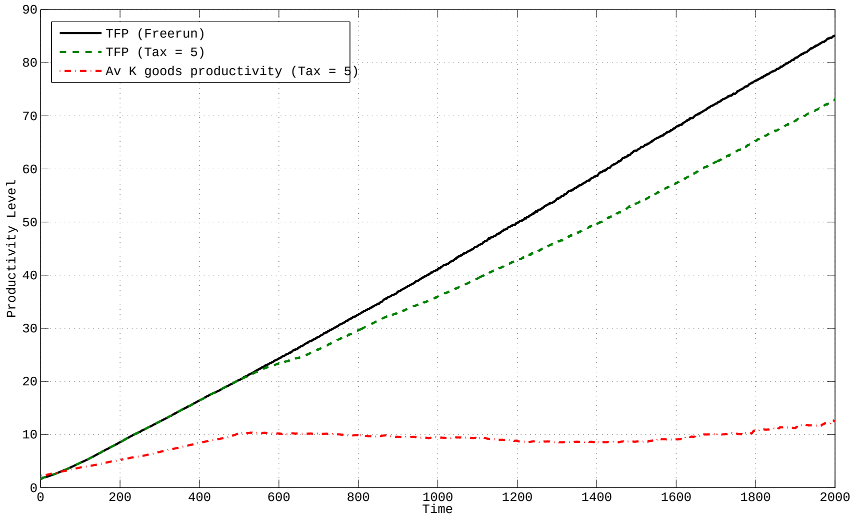
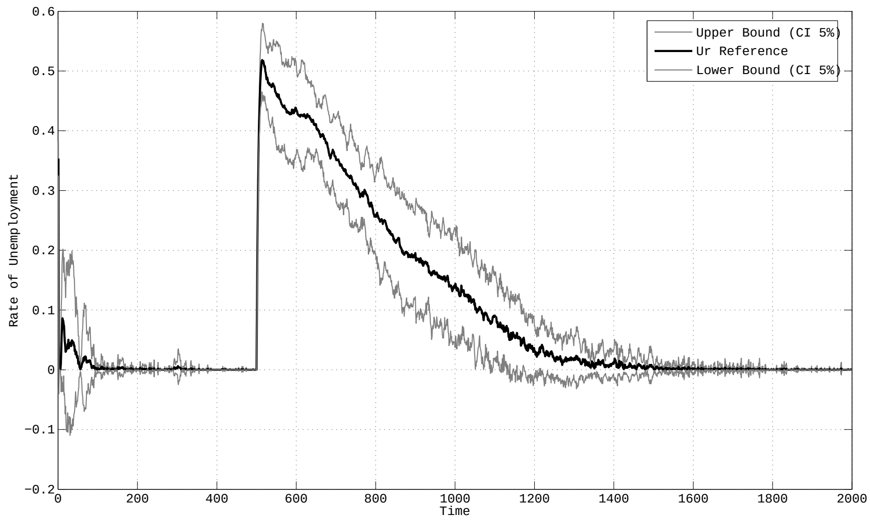
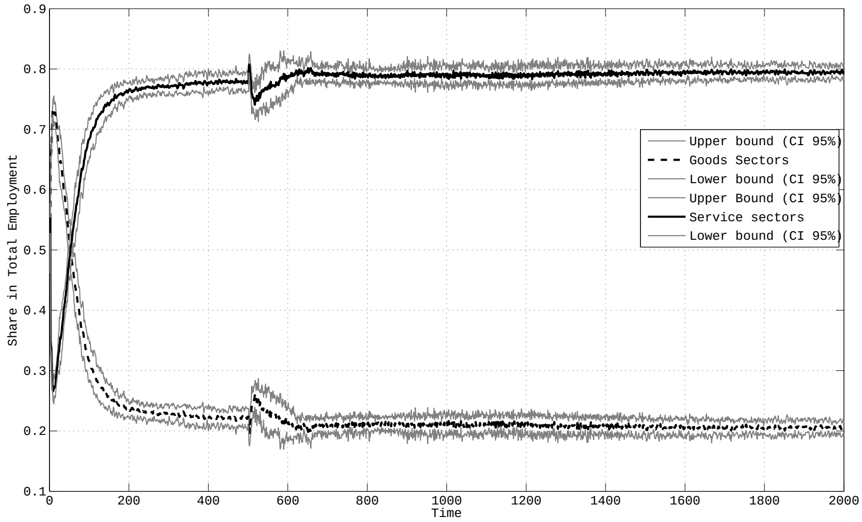
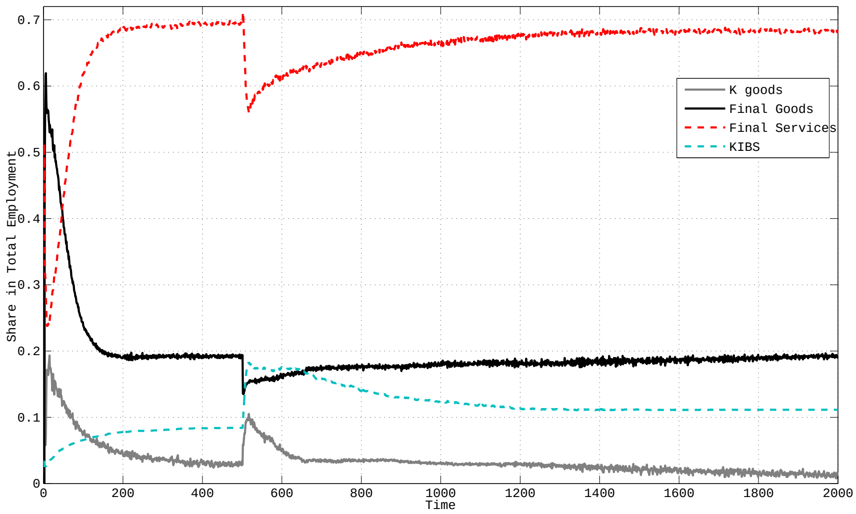


Figure 10: Impact of the tax at 5 euros on the unemployment rate





(a)



(b)

Figure 11: Sectoral share in employment (tax = 5 euros) (a) aggregate sectors, (b) disaggregated sectors

Figure 12: Impact of different levels of tax on overall pollution level

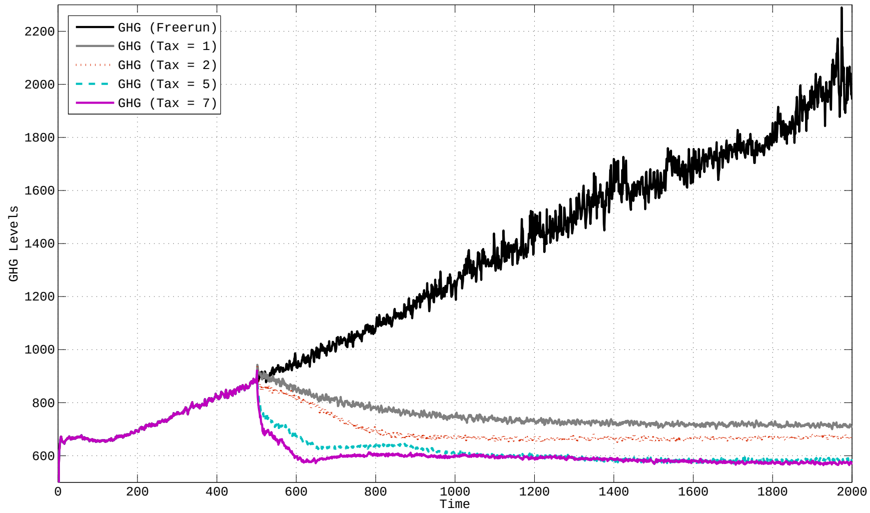


Figure 13: Sectoral levels of pollution (tax = 5 euros)

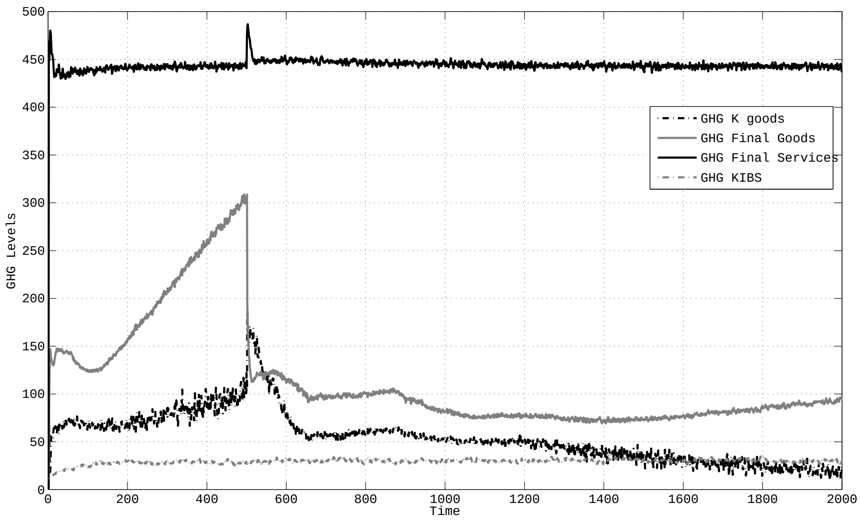


Figure 14: Evolution of GDP in the different scenarios

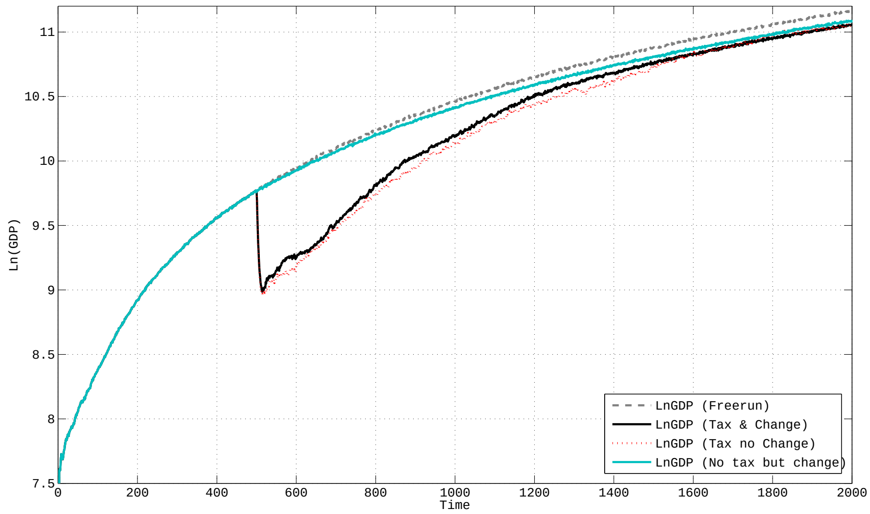


Figure 15: GDP volatility in the scenario with tax but no change in technological trajectory

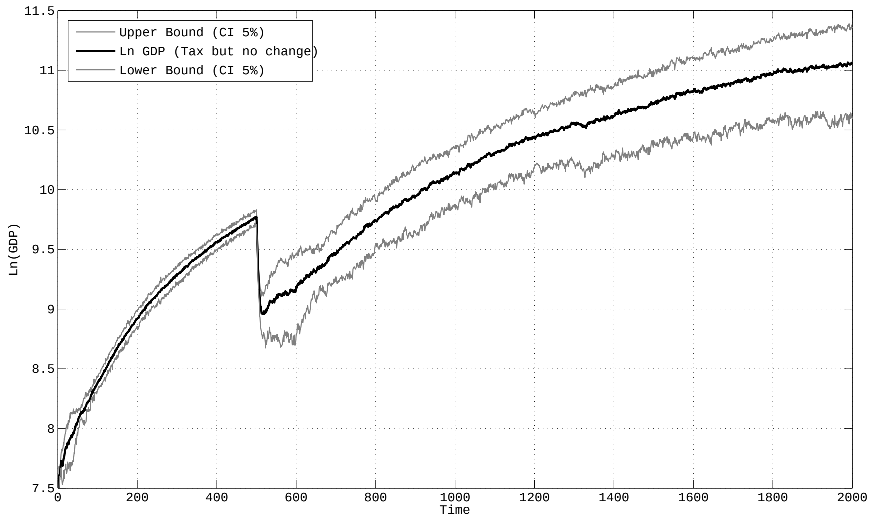
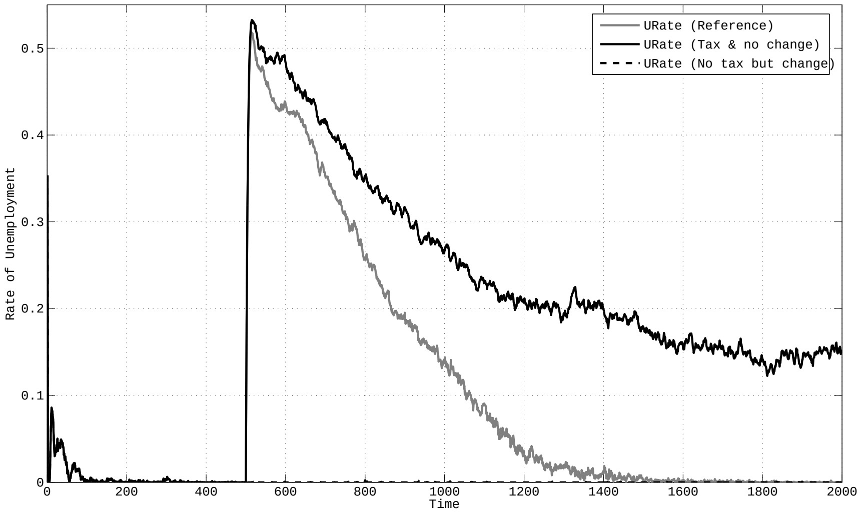
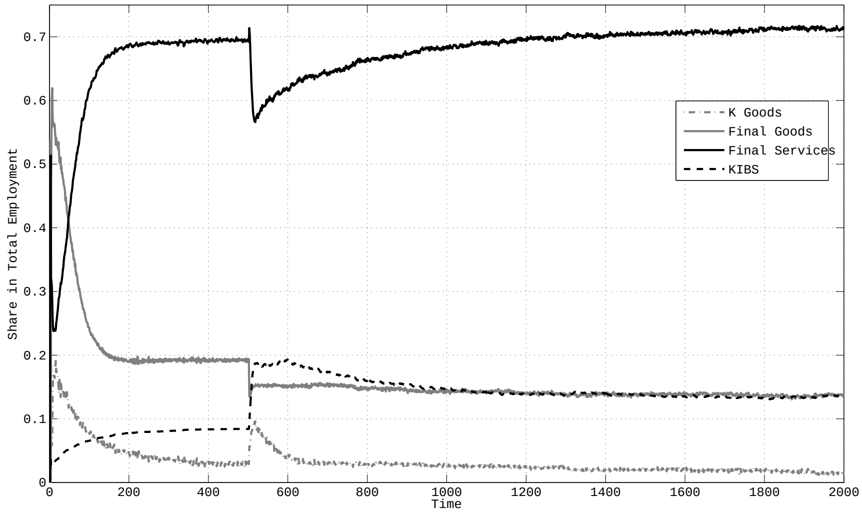
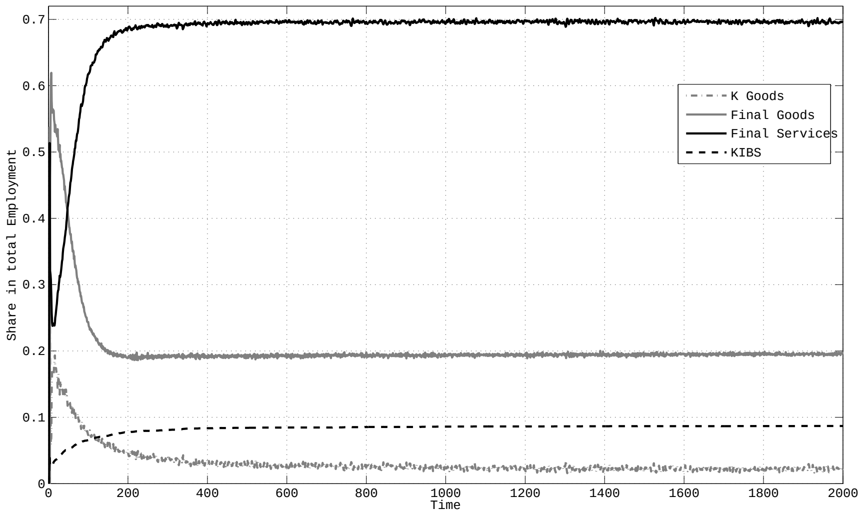


Figure 16: Evolution of the unemployment rate in the different scenarios





(a)



(b)

Figure 17: Sectoral share in employment (a) with tax but with no change in technological trajectory, (b) with no tax but with change in trajectory

Figure 18: Evolution of overall pollution levels in the different scenarios