Three essays on labour productivity

Lorenzo Piccinini

March 12, 2019

Contents

Introduction

One of the main characteristics of the free-market system has been until now to being able to generate an increase in labour productivity without precedents. According to Maddison (1982) in the one hundred years between 1870 and 1970 the median increase of labour productivity among the sixteen industrialized leader countries was around the 1100%. Even its fiercest critic, Karl Marx, recognized the stunning ability of the capitalist mode of production to increase the productive forces of the economy, i.e. the ability of an economic system to produce things. Many authors have explained this phenomenon with the necessity of the firms to innovate continuously, both inventing new products and finding ways to reduce costs, in order to survive the competition. Already Marx (1867) and Shumpeter (1947) pointed out that innovation and cost reduction is often a matter of life and death for the firms, and this made Baumol (2002) call the free market an "Innovation Machine". Other authors have pointed out the role that the public sector have had (and still have) in stimulating innovation in general, and the development of labour-saving techniques in particular. In recent years, governments around the world have invested billions in stimulating the so called *Industry 4.0*, Italy included[1]. The very term, which is now quit popular but does not have a precise definition, originates from a German government strategy promoting the computerization of production.

Whatever the cause, such impressive increase in labour productivity implies of course a progressive automation of the productive process, meaning an increasing substitution of human labour with automated processes. This phenomenon has cyclically raised concerns and hopes, both within the economic scholars and society in general. Ricardo himself contemplated in the first half of the 19th century the possibility of a fully automated economy, in which only the capitalists would have the right to consume.[2] The Luddite movement in the same years was becoming the eponymous of the fear that the spread of machines would eventually leave the workers out of jobs. In a broad sense, similar worries regarding the decreasing weight of the labour needed for the production process were the basis of Marx's formulation of the theory of the tendency of the rate

[1] *http://www.sviluppoeconomico.gov.it/index.php/it/industria40*

[2] "If machine could do all the work that labour now does, there would be no demand for labour. Nobody would be entitled to consume anything who was not a capitalist, and who could buy or hire a machine" (Works VIII: 399–400), quoted in Kurz, Heinz D., and Neri Salvadori. Classical economics and modern theory: studies in long-period analysis. Routledge, 2005.

of profit to fall due to the ever increasing organic composition of capital.[3] Other great thinkers in the history of economic thought dealt with the subject, with different degrees of optimism: Keynes (1930) predicted a merry future for his grandchildren, finally freed from the burden of manual work and able to spend their time in truly elevating activities; the Nobel price Leontief dedicated his last book to the "Future Impact of Automation on Workers" (1986), considering a variety of scenarios through his input-output techniques. At the end, as already pointed out by Sylos-Labini (1989), the question boils down to the dual effect of productivity over employment: the reduction of labour needed for unit produced, and the (potential) increase of real aggregate demand, and therefore total production. In recent years, characterized by generally higher level of unemployment rates than the ones preceding them, the theme of automation and the possible risks for human jobs has returned popular both in the literature and within the general audience. Among the most influential contributions we can mention Acemoglou, who dealt with the subject in a series of papers in the last few years finding relationship between the automation of certain tasks and the polarization in the labour market (see in particular Acemoglou and Autor, 2011); Frey and Osborne (2013), who predicted that up to 47% of American jobs are at risk of being replaced in the next twenty years; and Brynjolfsson and McAfee (2012,2014), whose work, more educational than scientific sometimes, advocates that it is necessary for workers to develop complementary skills to the machines.

In this work I explore three different aspects regarding the evolution of labour productivity. The three papers which compose my thesis must be considered as independent works, even if connected by a common theme. They can also be seen as a progressive extension of the range of analysis: from a partial equilibrium analysis, passing through a semi-static macroeconomic general equilibrium, to a Dynamic Macrosimulation model with a timespan of 100 years.

In the first paper I investigate the role that a cost-saving technological innovation, as a labour-saving one, would have in a oligopolistic competition framework, when we allow for the possibility that a firm may be excluded from the market as a result of the implementation of the innovation by its rival. More in detail, I consider a a two-stage duopoly game, in which I consider two firms producing an homogeneous good with constant but asymmetric marginal costs. In the first stage they decide, simultaneously and independently, whether implement an innovation at a cost. Such innovation would allow them to produce at a lower marginal cost than both their original costs. In the second period, they compete à la Cournot. As mentioned, I allow for a firm to cause the exclusion of the other from the market trough the decision of innovating. I then present a complete taxonomy of the parameter regions which determine the four possible Nash Equilibria (both innovating, just one innovating, no innovation). I find out that the cost structure has a central role in determining the outcome, and that more often than not starting from an initial situation of disadvantage stimulates innovation, because of the inferior

[3]Such discourse anyway in Marx must be considered within his specific theory of labour-value, and not in "technical" terms.

losses in an innovation war.

In my second paper I increase the range of my analysis, and I explore the consequences of an increase in labour productivity over the general level of wage and employment in a closed economy. The model can be considered an extension of the one presented by Bowles and Boyer (1990), but the wage is here determined though collective bargaining by a single union and a representative of the firms, and not by profit maximization taking in account the incentives' effects over workers' effort, as in the original model. I find out that there are two possible equilibria, one superior to the other both in terms of employment and of wage level. I consider both the case of a "spontaneous" increase in productivity and a "induced" one, consequence of public investments. In both cases the increase in labour productivity has a detrimental effects on both employment and wage in the "bad" equilibrium and a positive one in the "good" one. Moreover, if the government ties his hands trough the commitment to a balanced budget regime, the public investment for incentives to innovation will likely entail a reduction of the general expenditure in welfare.

Finally I consider a system dynamic model with mainly post-Keynesian feature, producing simulations over a long time span. In this case I consider not only the possibility of an increase in labour productivity, but also in energy efficiency, and I investigate the interactions between the two. The main point of the model is that in their decision regarding innovation implementation, firms may face a trade-off between increasing one or the other. Moreover, the emergence of innovations itself may be influenced by endogenous variables, as relative prices of the factors of production. I then consider different scenarios regarding technological trajectories, prices dynamics (energy prices in particular) and government policies in order to analyse the long-term dynamics of employment rate, energy consumption, real wages and production.

As a general conclusion of this work, I can only say that it is difficult to overestimate the importance that the dynamics of the labour productivity has on both an economic system and on the models which try to explain it. With these three papers I hope to have provided some insights on some aspects of such a central economic concept.

Chapter 1

Innovation choice in an asymmetric Cournot model

1.1 Introduction

The aim of this paper is to connect two strands of literature: the one studying the effects of innovation, and the one concerned with asymmetric oligopolies.

I am specifically interested in innovation as a competitive weapon. Despite Marx (1867) and Shumpeter (1947) already pointed out that innovation is often a matter of life and death for a firm, such issue and the extraordinary consequences that it has on the innovation rate in a capitalist economy is rarely the direct subject of research, as noted by Baumol (2002).

Regarding the former strand of literature, Cournot and Bertrand, as known, in their seminal works on non-cooperative oligopolistic competition assume symmetric costs among firms. Such clearly unrealistic assumption has been relaxed by many authors, but usually has been replaced by the assumption that parameters are such that all firms produce positive quantities in equilibrium (see Ledvina, 2011). Among those who do not impose such restriction, Zanchettin (2006) modifies the results by Singh, Nirvikar, and Xavier Vives (1984), showing that, for some parameter regions, industry profits can be higher in a Bertrand duopoly than in a Cournot one; and Ledvina (2011) directly address the issue of the equilibrium number of active firm in four different oligopoly settings: Cournot and Bertrand framework with homogeneous and differentiated goods.

My base model consists in a two-stage duopoly game, in which I consider two firms producing an homogeneous good with constant but asymmetric marginal costs. In the first stage they decide, simultaneously and independently, whether implement an innovation at a cost. Such innovation would allow them to produce at a lower marginal cost than both their original costs. In the second period, they compete *à la* Cournot. The only parameter restriction that I impose is that the size of the market is at least such that both firms produce positive quantities in the case in which no firm implements the innovation. I therefore allow for a firm to cause the exclusion of the other from the market trough the decision of innovating. I then present a complete taxonomy of the parameter regions which determine the four possible Nash Equilibria (both innovating, just one innovating, no innovation).

From the results of the model we can examine the role played by the different parameters in the decision of innovation. It actually appears that in this setting the threat of being excluded is not decisive in the choice of innovation. The initial cost asymmetry plays a much more significant role. Indeed, if I extend the model by allowing for a third firm to enter the competition (increasing the risk of exclusion for the relatively inefficient firm) the parameter region in which the inefficient firm is the only one to innovate shrinks (even if total innovation increases). This contradicts the intuitive result that a greater exposure to the risk of exclusion should increase the incentive for innovation.

The rest of the paper is organized as following: in section 1.2 I present some results concerning asymmetric Cournot competition, which I will use in my model; in section 1.3 I present and solve my two-stage model; finally I draw some conclusions from the result of the model.

1.2 N-firms asymmetric Cournot

Let us assume that there are N potentially active firms producing an homogeneous good and competing *à la* Cournot. The firms employ a CRS technology, and they have asymmetric marginal costs c_i. Without loss of generality, let us assume that $c_1 < c_2 < ... < c_N$. They face a linear demand.

$$P = a - bQ_N$$

where $Q_N \equiv \sum_{i=1}^{N} q_i$ is the total quantity produced. We will soon address the issue of the number of active firms in equilibrium, but let us initially assume that all firms are active. Denote $\mathbb{S} = \{1, 2, .., N\}$ the set of indexes of potential firms. By standard computation it is easy to determine that equilibrium total quantities, price, individual quantities and profits are respectively

$$Q_N^* = \frac{Na - C_N}{b(N+1)} \tag{1.1}$$

$$p^* = \frac{a + C_N}{N+1} \tag{1.2}$$

$$q_i^* = \frac{p(Q_N^*) - c_i}{b} = \frac{(a + C_N^{-i} - Nc_i)}{b(N+1)} \tag{1.3}$$

$$\Pi_i^* = \frac{(a + C_N^{-i} - Nc_i)^2}{b(N+1)^2} \tag{1.4}$$

Where $C_N \equiv \sum_{j \in S} c_j$ and $C_N^{-i} \equiv \sum_{j \in S \setminus i} c_j$

Notice, anyway, that the above vector of individual quantities $\mathbf{q}^*$ may fail to be an equilibrium. This happen because q_i^* depends negatively on individual marginal cost, so it may result negative. In this case the firm would not want to be active.

Consider the power set of $\mathbb{S}$, $P(\mathbb{S})$ and denote σ a generic element of $P(\mathbb{S})$. Denote n_σ the cardinality of the set σ. From the formulas above it is clear that a firm wants to be active in the market if the individual quantity resulting from the optimization process is greater than zero. This happens iff

$$(a + C_\sigma^{-i} - n_\sigma c_i) > 0 \iff a > n_\sigma c_i - C_\sigma^{-i} \tag{1.5}$$

where $C_\sigma^{-i} \equiv \sum_{j \in \sigma \setminus i} c_j$.
Such condition guarantees that both per-unit mark up and individual equilibrium quantities will be positive. We will assume from now on that if a firm is indifferent between being active and staying out of the market, it will decide to stay out.
It is then clear that the number of active firms, for a given cost structure, will increase as the parameter a, which we can interpret as the size of the market, increases.[1]

An equilibrium of the game is a pair $(\mathbf{q}^{*,\sigma}, \sigma)$such that

$$q_i^{*,\sigma} = \begin{cases} \dfrac{(a + C_\sigma^{-i} - n_\sigma c_i)}{b(n_\sigma + 1)} & \text{if } i \in \sigma \\ 0 & \text{if } i \notin \sigma \end{cases}$$

which satisfies the following properties:

i) every firm $i \in \sigma$ wants to be active.
ii) every firm $i \notin \sigma$ does not want to be active.

We will now show that for every value of the parameter a there exist an unique equilibrium in which the n more efficient firms will be active, where $n \in [1, N]$.

Let us first demonstrate the lemma 1.2.1, which states that in equilibrium it cannot be the case that a less efficient firm is active when a more efficient one is not.

Lemma 1.2.1. *Consider the pair $(\mathbf{q}, \sigma)$. If $\exists i \notin \sigma$ s.t. $c_i < c_j$ where $j \in \sigma$, then $(\mathbf{q}, \sigma)$ is not an equilibrium .*

Proof. For $(\mathbf{q}, \sigma)$ to be an equilibrium, all firms in σ must want to be active, included firm j. This means that

$$a > n_\sigma c_j - C_\sigma^{-j} \tag{1.6}$$

[1]Rigorously a it is the highest possible price at which an unit of good can be sold.

Firm i wants to enter if

$$a > (n_\sigma + 1)c_i - C_\sigma^{-j} - c_j \tag{1.7}$$

But since

$$n_\sigma c_j - C_\sigma^{-j} > (n_\sigma + 1)c_i - C_\sigma^{-j} - c_j \iff c_j > c_i \tag{1.8}$$

then

$$a > n_\sigma c_j - C_\sigma^{-j} \Rightarrow a > (n_\sigma + 1)c_i - C_\sigma^{-j} - c_j \tag{1.9}$$

so firm i wants to enter the market, so $(\mathbf{q}, \sigma)$ cannot be an equilibrium.

□

This Lemma tell us that an equilibrium with k active firm must include the k more efficient firms in $\mathbb{S}$. We can then reduce the equilibrium candidates to N possible subset of $\mathbb{S}$: $\{1\}$, $\{1, 2\}$, ... , $\{1, 2, .., N\}$. We can then proceed with Theorem 1.2.2.[2]

Theorem 1.2.2. *If $a > c_1$ then it always exists an unique equilibrium in the game. The unique equilibrium quantities are given by*[3]

$$q_1^{*n^*} = \begin{cases} \dfrac{(a + C_{n^*}^{-i} - n^* c_i)}{b(n^* + 1)} & \text{if } 1 \leq i \leq n^* \\ 0 & \text{if } n^* + 1 \leq i \leq N \end{cases}$$

where n^* is the number of the active firms and it is given by

$$n^* = min\{i \in S : a \leq f(i + 1)\} \tag{1.10}$$

where $f(i) = (\sum_{j=1}^{i} j)c_i - \sum_{j=1}^{i-1} c_j$.

The active firms are the one with indexes from 1 to n^*.

Proof. Existence is guaranteed by the fact that for $a > c_1$ at least firm 1 will want to be active in equilibrium. From 1.2.1 we have restricted the search of the equilibrium to those subset of $\mathbb{S}$ which include the most efficient firms. We proceed then in the following way: we first check if firm 1 wants to be active alone for this value of a. This is the case, since $a > f(1) = c_1$. We then check if firm 2 wants to be active when firm 1 is active. This is the case if $a > f(2) = 2c_2 - c_1$. If such condition is respected, we check if firm 3 wants to be active when 1 and 2 are, which happens if $a > f(3) = 3c_3 - c_1 - c_2$, and so on. We stop when we find that a firm does not wish to partecipate, i.e. $a \leq f(j)$, or when all firm wish to be active, i.e. when $a > f(N)$. This procedure give us the last firm who wishes to be active, that is the n^* of expression 1.10. It is easy to prove that

[2] A similar proof for the case of differentiated Cournot is present in Ledvina(2011).

[3] $C_{-i}^{n^*} \equiv \sum_{i \neq j} c_j$

the situation in which the first n^* firms produce positive quantities is an equilibrium:
i) every firm i s.t. $1 \leq i \leq n^*$ wants to be active.
Denote $\sigma_{n^*} = \{1, .., n^*\}$. Consider any k s.t. $c_k < c_{n^*}$. Then

$$a > f(n^*) = n^* c_{n^*} - \sum_{j \in \sigma_{n^*} \setminus n^*} c_j \Rightarrow a > n^* c_k - \sum_{j \in \sigma_{n^*} \setminus k} c_j \tag{1.11}$$

since

$$n^* c_{n^*} - \sum_{j \in \sigma_{n^*} \setminus n^*} c_j > c_k - \sum_{j \in \sigma_{n^*} \setminus k} c_j \quad for \quad c_{n^*} > c_k \tag{1.12}$$

ii) every firm i s.t. $n^* + 1 \leq i \leq N$ does not want to be active.
Consider any k s.t. $c_k > c_{n^*}$. For $k = n^* + 1$ we have that

$$a < f(n^* + 1) = (n^* + 1) c_{n^*+1} - \sum_{j \in \sigma_{n^*}} c_j \tag{1.13}$$

by definition of n^*.
For any k s.t. $c_k > c_{n^*+1}$ clearly

$$a < (n^* + 1) c_{n^*+1} - \sum_{j \in \sigma_{n^*}} c_j \Rightarrow a < (n^* + 1) c_k - \sum_{j \in \sigma_{n^*}} c_j \tag{1.14}$$

We have then proven that it is an equilibrium. Uniqueness is given by construction. □

1.3 The Model

We model a situation in which two competing firms with asymmetric cost functions are presented with the possibility of an innovation. The two firms, A and B, employ both a CRS technology with, respectively, marginal cost c_1 and c_2 .
We then consider a game with two periods. In the firs period, the two firms decide, simultaneously and independently, whether to implement an innovation which would grant them a marginal cost of $c_0 < c_i, i = 1, 2$. Such innovation would cost the firm an amount F. More formally, each firm chooses an action A_i from the set of actions available to both firm is $\mathbb{A} = \{I, N\}$, where I stands for "innovate" and N for "does not innovate". We can normalize $c_0 = 1$ for simplicity.
In the second period, given the cost structure decided in period one, they compete *à la* Cournot. The product is homogeneous and they face a linear demand.

$$P = a - bQ$$

where Q is the total quantity produced.

The game is solved by backward induction. In the following subsection we analyze the equilibrium of the general case of an homogeneous Cournot setting with asymmetric costs. Then we use this results to study the second period of our game. We then solve the first period by determining at which condition firms decide to innovate.

1.3.1 Second stage

We consider now the second stage of the game presented at the beginning of the section. From the analysis of the previous section we know that, whatever the cost structure resulting from the innovation decision in period one, there exist an unique equilibrium. Moreover, the number and characteristics of the active firms depends on the value of a. Applying condition (1.5), we consider only values of a such that $a > a_1 = 2c_2 - c_1$. In this way if no firm implements the innovation, both firms are active. The reason of this assumption is to represent an initial situation in which two firms with asymmetric costs are competing in a market, and then they are presented with the possibility of an innovation.

At the beginning of period two, the firms may face four possible cost structure[4], depending on the action profiles chosen in period one : $C_I = \{1, 1\}$ if the action profile played was $\{I, I\}$; $C_{II} = \{1, c_2\}$ if it was $\{I, N\}$; $C_{III} = \{c_1, 1\}$ if it was $\{N, I\}$; and $C_{IV} = \{c_1, c_2\}$ if it was $\{N, N\}$. We can determine for each possible cost structure (or, analogously, each possible period one action profile) the number of active firm for each possible value of a. We present the possible situations in Table 1.1. Notice that we have to differentiate two cases: $a_2 = 2c_1 - 1$ is the threshold after which the market is big enough to sustain two firms when the cost structure is C_{III} (only firm B has implemented the innovation), as clear applying condition (1.5). For sufficiently small values of c_1 we have that this threshold lays at the left of a_1. This means that firm A is initially so much more efficient than firm B that firm B does not have the possibility of kicking firm A out of the market for any value of a considered. Precisely, this happens when

$$a_2 < a_1 \iff 2c_1 - 1 < 2c_2 - c_1 \iff c_1 < \frac{1}{3} + \frac{2}{3}c_2 \equiv \gamma_3 \tag{1.15}$$

Table 1.1 shows that firm A can become a monopolist when it is the only one to implement the innovation for sufficiently small market size, i.e., applying condition (1.5), when $a < a_4 = 2c_2 - 1$. Firm B, on the other hand, has the same possibility only if the initial efficiency gap between the two was not too big, i.e. if $c_1 > \gamma_3$.

From the analysis of the previous section we can determine the profit which a firm earns given any possible cost structure. Denote σ^* the set of active firms, n_σ the cardinality of such set, and $1_{\sigma_*}(i)$ the indicator function assuming value 1 when $i \in \sigma_*$ and zero otherwise. Then we denote by $\Pi(c_i; c_j, \sigma^*)$ the profit that a firm i earns when its marginal cost is c_i and its rival cost is c_j, which is equal to

$$\Pi(c_i; c_j, \sigma^*) = 1_{\sigma_*}(i)\frac{(a + 1_{\sigma_*}(j)c_j - n_\sigma c_i)^2}{b(n_\sigma + 1)^2} \tag{1.16}$$

We can then move to the analysis of the innovation decision, in period one.

[4]We use the convention to present in the cost structure the marginal cost of firm A first: $C = \{c_A, c_B\}$

Table 1.1: Active Firms

Action profiles	$c_1 < \gamma_3$		$c_1 > \gamma_3$		
	$a \in [a_1, a_4]$	$a > a_4$	$a \in [a_1, a_2]$	$a \in [a_2, a_4]$	$a > a_4$
$\{I, I\}$	A, B	A, B	A, B	A, B	A, B
$\{N, I\}$	A, B	A, B	B	A, B	A, B
$\{I, N\}$	A	A, B	A	A	A, B
$\{N, N\}$	A, B	A, B	A, B	A, B	A, B

Where:
$a_1 = 2c_2 - c_1$
$a_2 = 2c_1 - 1$
$a_4 = 2c_2 - 1$

1.3.2 First stage

We need now to determine at which condition each of the possible action profile can be sustained as a Nash equilibrium. From the analysis of the second period we can determine the payoff of the firms as a function of the action profile played, denoted as $U_i(A_A, A_B)$. The payoff function of A is

$$U_A(I, I) = \Pi(1, 1) - F \tag{1.17}$$

$$U_A(N, I) = \begin{cases} 0 & \text{if } c_1 > \gamma_3 \wedge a \in [a_1, a_2] \\ \Pi(c_1, 1) & otherwise \end{cases} \tag{1.18}$$

$$U_A(I, N) = \begin{cases} \Pi(1) - F & \text{if } a \in [a_1, a_4] \\ \Pi(1, c_2) - F & otherwise \end{cases} \tag{1.19}$$

$$U_A(N, N) = \Pi(c_1, c_2) \tag{1.20}$$

The payoff function of B is

$$U_B(I, I) = \Pi(1, 1) - F \tag{1.21}$$

$$U_B(N, I) = \begin{cases} \Pi(1) - F & \text{if } c_1 > \gamma_3 \wedge a \in [a_1, a_2] \\ \Pi(1, c_1) - F & otherwise \end{cases} \tag{1.22}$$

$$U_B(I, N) = \begin{cases} 0 & \text{if } a \in [a_1, a_4] \\ \Pi(c_2, 1) & otherwise \end{cases} \tag{1.23}$$

$$U_B(N, N) = \Pi(c_2, c_1) \tag{1.24}$$

From this functions it is immediate to determine the best response function of the two firms: $B_i(A_j)$, where $i, j = A, B$ and $A_i \in \mathbb{A} = \{I, N\}$. By crossing the best response function we can determine the parameter regions that sustain each possible action profile as a Nash Equilibrium. Indeed the NE action profile will depend on the value of three parameters: the market size, a; the fixed cost F; and the initial cost structure, $\{c_1, c_2\}$. We present a complete taxonomy of all the possible parameter regions and the associated Nash equilibria. In order to do so we distinguish four cases, relative to four intervals of $c_1 \in (1, c_2)$, corresponding to different intensity of initial efficiency gap. Such intervals, found in the intersections of the best responses, are: $c_1 \in (1, \gamma_1]$, $c_1 \in (\gamma_1, \gamma_2]$, $c_1 \in (\gamma_2, \gamma_3]$, and $c_1 \in (\gamma_3, c_2)$.[5] For each interval of c_1 we present a partition of the $a - F$ space into subsets which sustain different equilibria. The boundaries of such regions are the following:[6]

$$F_1 \equiv \Pi(1,1) - \Pi(c_1,1) \tag{1.25}$$
$$F_2 \equiv \Pi(1,1) \tag{1.26}$$
$$F_3 \equiv \Pi(1,1) - \Pi(c_2,1) \tag{1.27}$$
$$F_4 \equiv \Pi(1) - \Pi(c_1,c_2) \tag{1.28}$$
$$F_5 \equiv \Pi(1,c_2) - \Pi(c_1,c_2) \tag{1.29}$$
$$F_6 \equiv \Pi(1,c_1) - \Pi(c_2,c_1) \tag{1.30}$$
$$F_7 \equiv \Pi(1) - \Pi(c_2,c_1) \tag{1.31}$$

Such boundaries are the threshold which determine whether both firms are willing to participate in a specific profile of actions. For the values of the parameters for which they matter, they are all increasing functions of a. Their meaning will be explained in the following subsections.

Very high initial efficiency gap: $c_1 \in (1, \gamma_1]$

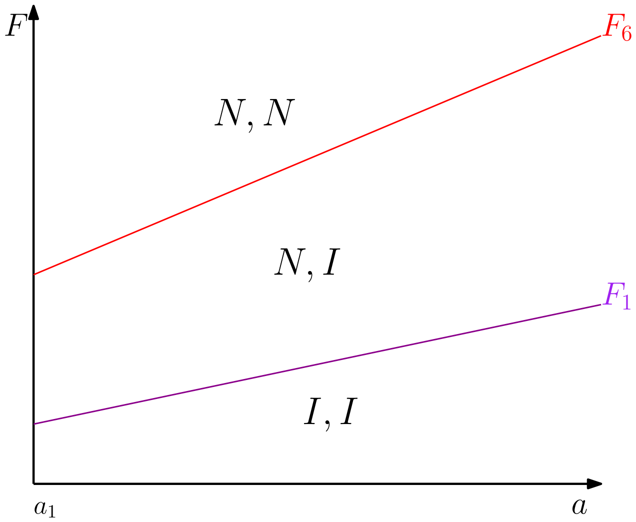
As we can see from Figure 1.1, we have three regions.

For values of F below F_1 the only profile of actions that can be sustained as a NE is the one in which both firms innovate. Firm B would be willing to innovate when firm A innovates, i.e. to sustain $\{I, I\}$, also for higher values of F, given any market size. In fact for $c_1 \in (1, \gamma_1]$ we have that $BR_B(I) = I \iff U_B(I,I) > U_B(I,N) \iff F < F_2$ for $a \in [a_1, a_4]$ and $BR_B(I) = I \iff U_B(I,I) > U_B(I,N) \iff F < F_3$ when $a > a_4$. But firm A is willing to respond to innovation with innovation only when

[5] The values of the cutoff are functions of c_2 and are equal to:
$\gamma_1 = \dfrac{c_2(3-\sqrt{5}) + \sqrt{5} - 1}{2}$, $\gamma_2 = \dfrac{c_2(6 - 2\sqrt{5}) + \sqrt{5}}{6 - \sqrt{5}}$, $\gamma_3 = \dfrac{2}{3}c_2 + \dfrac{1}{3}+$.
It can be proved that if $c_2 > 1$ then $\gamma_1 < \gamma_2 < \gamma_3$ and they are all included in the $(1, c_2)$ interval.

[6] Applying expression 1.16:
$\Pi(c_i, c_j) = \dfrac{(a + c_j - 2c_i)^2}{9b}$, $\Pi(1,1) = \dfrac{(a-1)^2}{9b}$, $\Pi(1) = \dfrac{(a-1)^2}{4b}$, $\Pi(1, c_i) = \dfrac{(a + c_i - 2)^2}{9b}$, $\Pi(c_2, 1) = \dfrac{(a + 1 - 2c_i)^2}{9b}$, where $i = 1, 2$ and $j \neq i$.

Figure 1.1: Very high efficiency gap



$BR_A(I) = I \iff U_A(I,I) > U_A(N,I) \iff F < F_1$, and since $\Pi(1,1) - \Pi(c_1,1) < \Pi(1,1) - \Pi(c_2,1) < \Pi(1,1)$ its constraints are the binding ones.

For values of F greater than F_6, on the other hand, fixed cost are so prohibitive that no firm decides to implement the innovation. In this case it is the cutoff deriving by firm B's best response to be binding. Firm A, in fact, would answer to the decision of not innovating with not innovating already for $F > F_4$ for $a \in [a_1, a_4]$ or for $F > F_5$ for $a > a_4$, two cutoffs both lower than F_6.

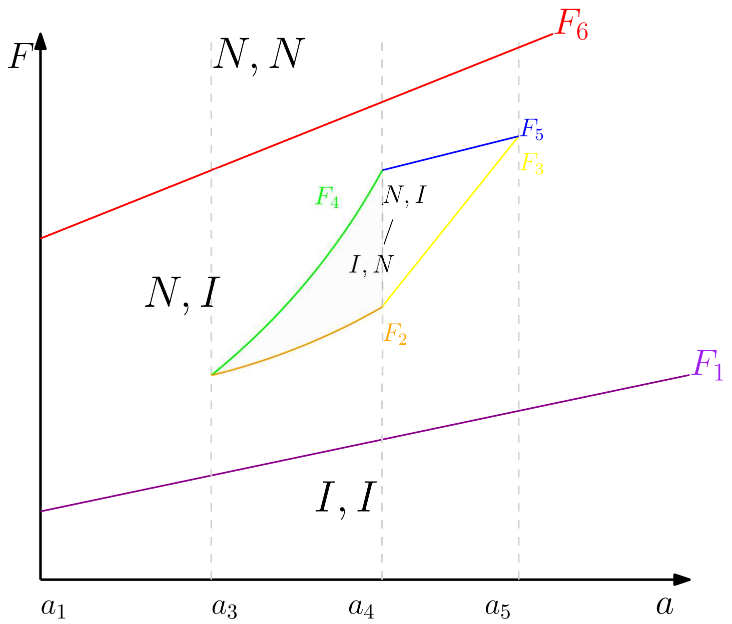
For values of $F \in [F_1, F_6]$ the only NE is the one in which the initially inefficient firm innovates alone. The reason for this is that the initial siituation marginal cost of firm A is quite close to the one it would obtain by implementing the innovation. Therefore its gains from innovation are relatively small. In fact, to sustain $\{I, N\}$ as a NE we need that $U_A(I,N) > U_A(N,N)$, which happens when $F < F_4$, and at the same time that $U_B(I,N) > U_B(I,I)$, which happen when $F > F_2$.[7] But for $c_1 \in (1, \gamma_1]$ we have that $F_2 > F_4$, so that the equilibrium cannot be sustained.

On the other hand, the equilibrium in which B is the only one to innovate is sustained for $F \in [F_1, F_6]$, and for the significant values we have that always $F_1 < F_6$. This is a confirmation of the well known result that inefficient firms have an higher incentive to innovate with respect to efficient ones.

Notice that for a very high initial efficiency gap in equilibrium both firms are always active.

[7]This is true for $a \in [a_1, a_4]$, but the result holds also for $a > a_4$

Figure 1.2: High efficiency gap



High initial efficiency gap: $c_1 \in (\gamma_1, \gamma_2]$

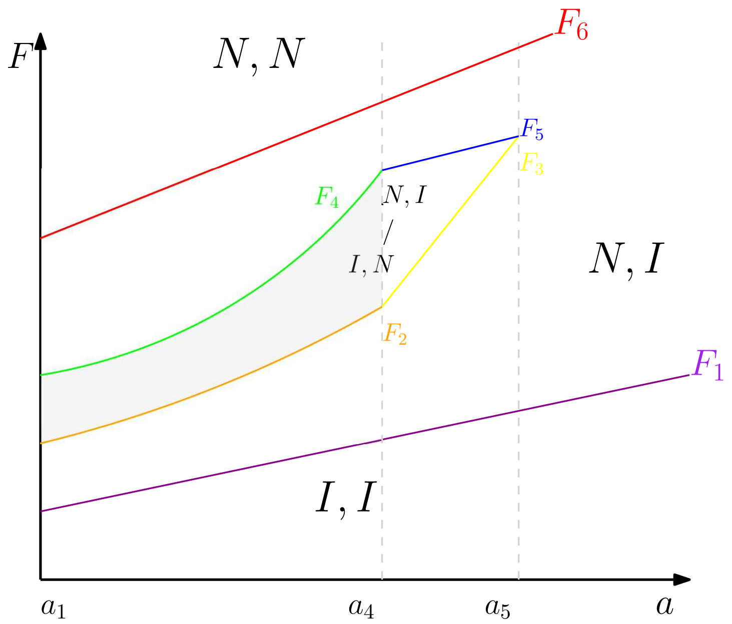
As Figure 1.2 shows, it appears a region in which the equilibrium $\{I, N\}$ is sustainable. Consider first the interval of a between a_1 and a_4. In this interval, if firm A is the only one to innovate, it becomes a monopolist. Here the equilibrium becomes sustainable for a market large enough ($a > a_3$[8]), since the threshold beyond which for firm B is convenient to not innovate when the other innovates, F_2, become lower than the threshold under which for firm A is convenient to innovate when the other does not, F_4.
When a becomes higher than a_4 things change, since firm B cannot be excluded from the market anymore and this changes the significant thresholds. Firm B now wishes to sustain $\{I, N\}$ for $F > F_3$, and firm A for $F < F_5$. Remember that a_4 corresponds to the level of market size for which firm B is indifferent between staying in the market or leaving it, as by applying condition 1.5, since the equilibrium quantity would be just zero (see equation 1.3). For this reason at a_4 we have $F_2 = F_3$ (because $\Pi(c_2, 1) = 0$) and $F_4 = F_5$ (since $\Pi(1) = \Pi(1, c_2)$). But since F_5 has a smaller slope than F_3 there is a level of market size a_5[9] after which $F_5 < F_3$ so that $\{I, N\}$ become no longer sustainable.

Notice that there is a portion of space, highlighted by a light gray background, in which it is sustainable as a NE a profile of actions resulting in the exclusion of a firm. This happens if F is between F_2 and F_4 (so for $a \in [a_2, a_4]$). Indeed, if the profile played is

[8] $a_3 = \dfrac{\sqrt{5} + 2c_2 - 4c_1}{\sqrt{5} - 2}$, which can be proven to be between a_1 and a_4 for $c_1 \in (\gamma_1, \gamma_{2]}$

[9] $a_5 = \dfrac{c_2^2 - c_1^2 + c_1 c_2 - 2c_2 + 1}{c_2 - c_1}$, which can be proven to be greater than a_4 for $c_1 \in [\gamma_1, \gamma_3]$.

Figure 1.3: Low efficiency gap



$\{I, N\}$ firm B cannot earn profits, so it will stay out of production.

Low initial efficiency gap: $c_1 \in (\gamma_2, \gamma_3]$

The only difference between this case, as shown in Figure 1.3 and the previous case is that for this level of c_1 the threshold after which $F_4 > F_2$, a_3, lies at the left of a_1, which is the lowest value of market size which we keep in consideration.

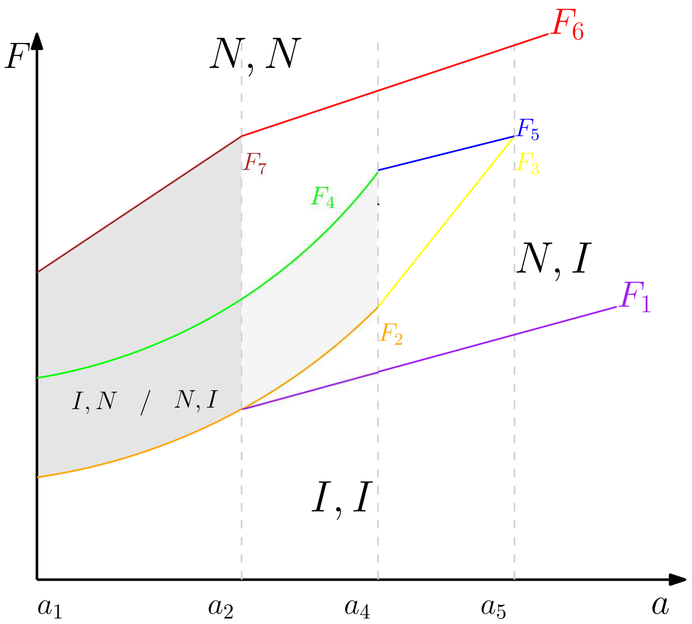
Also in this case the portion of the space between F_2 and F_4 corresponds to a situation of potential monopoly, as before.

Very Low initial efficiency gap: $c_1 \in (\gamma_3, c_2)$

The situation of this last case is depicted in Figure 1.4. When the initial efficiency gap is sufficiently low, both firms have the chance of becoming a monopolist if they are the only one to innovate when the market is small, i.e. when $a < a_2$. This has the consequence that for this interval of a the level of fixed cost under which the A and B wish to sustain $\{I, I\}$ is the same for both firms: F_2. At a_2 firm A is indifferent between staying in or out of the market if B innovates, and for that reason $F_1 = F_2$ and $F_6 = F_7$[10], while for $a > a_2$ firm A cannot be excluded and the analysis becomes analogous to the previous cases.
Notice that for this market size interval there is still a region in which the only NE is the

[10]Since, respectively, $\Pi(c_1, 1) = 0$ and $\Pi(1, c_1) = \Pi(1)$.

Figure 1.4: Very low efficiency gap



one in which firm B is the only one to innovate. This because for firm A becomes convenient to not sustain $\{I, N\}$ (in favour of $\{N, N\}$) for $U_A(I, N) < U_A(N, N) \iff F > F_4$ while firm B decides to not innovate when the other does not innovate for higher values of F, precisely when for $U_B(N, I) < U_B(N, N) \iff F > F_7$. So the lower profits of firm B in the "initial" situation provide to it an higher incentive to innovate.

Differently than in previous cases, we have here a substantial area of the $a - F$ space resulting in a monopoly, i.e. the exclusion of a firm from the market as a consequence of innovation. Indeed for this values of initial efficiency gap also firm A risks to be excluded. Between a_1 and a_2, for every value of $F \in [F_2, F_7]$ the non-innovating firm decides in equilibrium to stay out of the market. Such area, in which there will *surely* be a monopoly, is highlighted by a darker gray as a background. It includes a portion, the one between F_4 and F_7, in which the excluded firm will be the low cost one, and this is the *only* sustainable equilibrium. For greater market size, on the other hand, firm A cannot be excluded, and the analysis is analogous of previous cases: firm A will become a monopolist if we are between F_2 and F_4 (so for $a < a_4$) and the selected equilibrium is $\{I, N\}$.

Extensions

It is possible to modify some of the assumption of the model. We briefly consider two models with one major difference: one considering three possible firms instead of two, and one considering price competition instead of quantity competition.

The model can be expanded to the case of three firms quite easily. In particular I considered the case in which a third firm has the possibility of entering the competition by employing the most efficient resource. This rather complicates the solution, increasing the number of possible cases. Nevertheless it does not modify the overall interpretation of the duopoly case. Regarding the role of the fear of being excluded in the innovation decision, we have actually a quite anti-intuitive result. One may think that the possibility of a third firm entering the market could provide a greater incentive for innovation to the initially inefficient firm, who would be more exposed to exclusion. But this does not happen. Actually the initially inefficient firm has now to "share" with the third firm the portion of the $a-F$ plane in which, in the duopoly case, it was the only one innovating.

Also substituting Cournot competition with Bertrand competition we do not obtain significantly different results. Maintaining the assumption of homogeneous product the Nash Equilibrium in which both firms innovate cannot be sustained anymore. This is obvious, since if both firms innovate they have the same marginal cost, so with price competition they have zero operative profits and they are not willing to pay a positive fixed cost for it. So the only profiles of actions that can be sustained as a NE are those in which just one innovates, and the one in which no firm innovates. And, as in the Cournot case, the initially inefficient firm will innovate alone for a greater portion of the $a - F$ space with respect to its rival.

1.4 Conclusions

The model allow us to reflect upon the different factors that motivate a firm in its innovation choice.

As we have seen, such choice depends on the size of the market, the fixed cost of the innovation, and the initial degree of asymmetry between the firms. We can see that in every possible case, for a given fixed cost, if the market increases both firms will eventually find convenient to innovate. At the same time, for a given market size, if the fixed cost necessary to implement the innovation exceeds a certain threshold both firm will, obviously, abstain from innovating. The most interesting considerations are raised by the analysis of the portion of the market size/fixed cost space in which none of these cases occur. It always exists, indeed, a combination of market and cost structure such that for a firm is convenient to innovate only if its rival does not. In the case of symmetric marginal costs we would have then two identical Nash Equilibria, with just one firm innovating. But with an initial efficiency gap the area in which there is a multiplicity of equilibria shrinks considerably. Indeed in all the analyzed cases we have areas in which the only "asymmetric" action profile that can be sustained as a Nash Equilibrium is the one in which only the initially inefficient firm innovates. This is because the inefficient firm's profits in the initial situation are lower that its rival's, and therefore is willing to prefer the *status quo* to innovating alone in less cases (i.e. for higher values of the fixed cost). The disparity of behaviour appears also when comparing the situation in which a firm would find itself if the rival decided to innovate: the damage for the high cost firm would be in most cases much higher than for the low cost firm, until the extreme case of market exclusion. This reduces further the area in which the action profile "Innovation-Not innovation" is sustainable with respect to the action profile "Not innovation-Innovation". Overall, starting from an initial situation of disadvantage stimulates innovation. We have to notice, nevertheless, that the multiplicity of equilibria does not disappear altogether. There are also cases in which innovation by the leader alone is sustainable as a Nash Equilibrium. This, of course, happens more frequently the smaller the initial efficiency gap is, and in any case disappears as a possibility for large market sizes.

It is interesting to see how there are cases in which a profile of actions which results in a firm being excluded from the market is sustainable as a Nash equilibrium. We have seen that is more common (i.e. it happens for a greater parameter region) that the excluded firm is the high cost firm, as predictable: this situation is sustainable as a NE for a small market size and a relatively small initial efficiency gap. It is more surprising that it exists the possibility that the initially efficient firm result excluded from the market. Moreover this situation, for some parameter configurations, is indeed the only possible Nash equilibrium: when the initial efficiency gap is very small and the market cannot sustain two active firms, if the fixed cost are too high the low cost firm has less to gain from implementing it, and this lack of incentives will result in its exclusion from the market.

It is worth pointing out that the fear of exclusion, as well as the possibility of kicking the rival out, does not play in this framework a significant role *per se*. The choice regarding innovation depends for a firm from a valuation of the payoff that would be earned in the different scenario. In this regard, clearly the risk of being thrown out represent an incentive to innovate. However, the functioning of equilibrium determination does not change in a significant matter when the market size is such to sustain two active firms and whet it is not.

Chapter 2

Industry 4.0 in a balanced budget regime

2.1 Introduction and Literature

This paper investigates the short-term effects of increasing labour productivity given different institutional settings. In particular I investigate the relationship between innovation and government expenditures. Two aspects of this relationship are taken in consideration. First of all, the government can directly affect the rate of innovation. Many governments around the world are investing a massive amount of money into incentives towards the so-called Industry 4.0.[1 2] On the other hand the past ten years have seen, in particular in the Eurozone, the tendency to sustain a public balanced budget. Following the European sovereign debt crisis, many countries implemented harsh austerity measures. Some arrived to the point to write the commitment to balanced budged inside their constitution (Groppi, 2012). Many economists and social movements provided strong arguments against the beneficial effects of austerity[3], but nevertheless to the present day the policies are often maintained. The aim of this paper is to investigate a possible consequence of a balanced budget regime, that is if in such institutional framework public investments towards automation would have detrimental effects on public expenditures, in particular on welfare. Indeed, I separate public expenditures between "automatic stabilizers" [4], in my model represented by unemployment benefits, welfare expenditures, and incentives in innovation. I sustain that the welfare expenditures are considered as residual by the governments, and that there is a good chance they will be cut if the expenditures for incentives for automation are too high, in particular if the short term effects of such innovation is to reduce employment.

[1]For the Italian case see MISE (2018).

[2]The label "Industry 4.0" indicates a variety of innovations, not unanimously defined, but in general we can say that it results in an increase of automation and labour productivity.

[3]See Krugman(2012) or Stiglitz(2014) for two examples among tens by just these two authors.

[4]see Keiser, 1956 for a review of the origin of the concept.

The main inspiration for the model comes from Bowles and Boyer (1988,1990), in particular in the decision of closing the model with a market clearing condition, a stationary condition requiring the absence of excess supply or demand on product markets. Such choice, instead of the relatively more common zero-profit condition, is motivated by the short-term horizon of the model. An other common feature is the modelling of the behaviour of firms when this condition is not satisfied: I follow the Keynesian-Kaleckian tradition on the assumption that firms are actually demand-constrained and do not operate at full capacity, hence being able to freely varying their production positively with the level of excess demand (Kurz, 1992).
There are, nevertheless, significant differences with the work of Bowles and Boyer. First of all, in the choice of the other fundamental equation of the model, the wage-setting equation. In those papers wage was determined optimally and atomistically by the firms, keeping in consideration the wage's effect on the workers' effort, while here I use a different approach: I assume that wage is bargained between the representatives of the workers and the ones of the firms trough Nash Bargaining. This procedure has a long literature backing it, see for example Muthoo (1999). I give the bargaining process also a Marxian flavour by the linking the bargaining power of the workers to the unemployment rate (Marx, 1867). This allows me to determine a wage curve positively related with the level on the employment.
Moreover, Bowles and Boyer' work was focused on the comparison of wage-led and profit-let employment regimes, while I restrain myself to the first one. My focus is, indeed on the consequences of increased labour productivity, a parameter which was explicitly kept constant in Bowles and Boyer. Finally, I am interested in comparing different fiscal framework - the introduction of a balanced budget regime - which implies the introduction of taxation, not considered in the original papers for the sake of simplicity.

The paper is structured as follows. In the first section it is considered the case of an exogenous increase in labour productivity, and analysed the effects over equilibrium wage, unemployment and welfare expenditure both in the case of debt-financed government spending and in the case of a balanced budget regime. In section 2.3, I introduce a public expenditure able to endogenously increase labour productivity and again consider the effect over employment, wage and welfare expenditure in both institutional settings. Section 2.4 concludes.

2.2 Exogenous labor productivity

Let us consider a single commodity economy, where production is carried out by a great number of small firms who jointly express a constant return to scale production function.

$$Q = qh \tag{2.1}$$

Where Q is total production, q is the productivity of labour and h is the amount of homogeneous labour employed (the only input of the economy), normalized such that

$h \in [0, 1]$, so that h indicates actually the rate of employment. In the following section it is studied the case in which the increase in labour productivity is exogenous.

2.2.1 Nash Bargaining

The level of wages is determined trough Nash bargaining between the firms (reunited in an association) and a single union. The firms' pay-off is the aggregate profit, while the union's preferences are represented by a Stone-Geary utility function. Moreover, I consider what Oswald (1982) has called an utilitarian union with risk neutral members, meaning that the union weights at the same way an increase in occupation and an increase in salary:[5] such assumption, quite common in the literature, is not necessary for the results of the paper, but it makes the expression for the optimal wage simpler. The Nash maximand is therefore

$$N = [h(q - w)]^{\beta(h)}[h(w - u)]^{1-\beta(h)} \tag{2.2}$$

Were u is the unemployment benefit, w the hourly wage and $\beta(h)$ indicates the relative bargaining power of the firms. Note that it is a function of the employment rate: the only real requirement for this function would be that $\beta' < 0$, but in order to keep the function simple is set equal to the unemployment rate.

$$\beta(h) = 1 - h \tag{2.3}$$

The bargaining power of the firms is then at its maximum when nobody works, and, on the other hand, the workers are strongest at full employment.
The Nash bargaining condition is simply the derivative of the Nash maximand set equal to zero. The bargained wage is obtained simply solving for w, and it is denoted w_N:

$$w_N = u + (q - u)h \tag{2.4}$$

Workers receive their outside option when their bargaining power is at its lowest, while in full occupation they gain the whole value of production. Notice also that with the given assumptions the wage is a linear function of the occupation rate.[6]
If the economy happens to be outside the negotiated wage, that there will be a tendency to return to it. Formally we could write this assumption by stating that the variation of the wage is directly related to the gap between the negotiated wage and the current wage

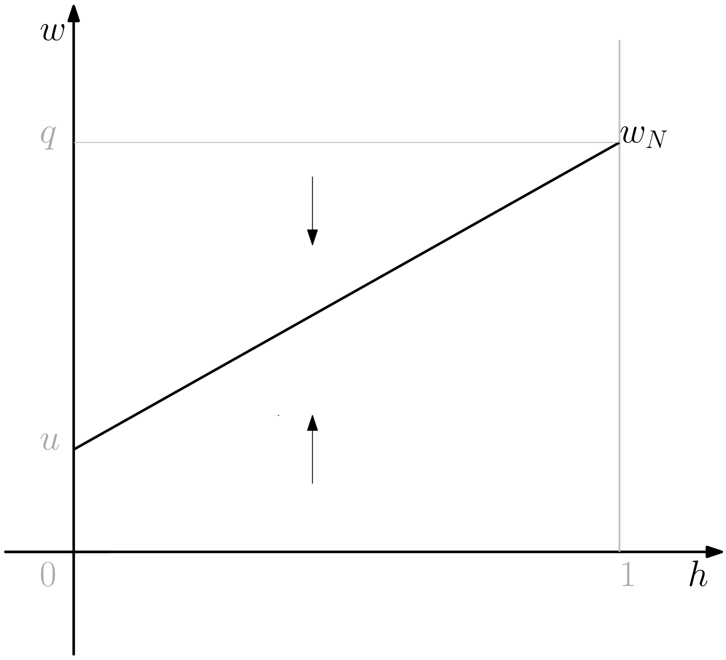
$$\dot{w} = \omega(w_N - w) \tag{2.5}$$

$$\omega' > 0, \omega(0) = 0 \tag{2.6}$$

[5]The more general form would be $U = h(w - u)^{\theta}$, where θ would be the parameter indicating the weight given to the wage opposed to occupation. it would not change the results but it would make the computations messier, so I assume $\theta = 1$

[6]The linearity is a consequence of assuming $\theta = 1$. Considering $\theta \in (0, 1)$ the resulting wage would still be always increasing in h, starting from u and arriving at q when $h = 1$.

Figure 2.1: Bargained wage



This could imply that the bargaining process is not an instantaneous one, but it could take several period, or that there is some kind of inertia (contractual or other) slowing the adaptation process.[7]

Figure 2.1 shows a graphical representation of the curve. The arrows indicates the out of equilibrium adjustment process.

2.2.2 Market Clearing with deficit spending

The other main condition which define the equilibria of the model is the market clearing condition, i.e. the requirement that in the product market aggregate demand needs to be equal to aggregate supply.
The framework used here is analogous to the one of Bowles and Boyer (1990). For the sake of simplicity, net exports are assumed to be zero, and investment are considered to be completely exogenous, and equal to i. Moreover, workers consume all their income, while capitalists save it all.[8] Thus, consumption is equal to wh. Without considering incentives fort innovatin, government spending consists only of unemployment benefits, i.e. $(1-h)u$, and welfare expenses (denoted by g). In this section government spending is fi-

[7] Dynamical and stability analysis are not the focus of this model, which is basically a static one. Therefore the dynamics of the model are carried out solely through phase diagrams and graphical representation, since a more elaborate technical discussion would be of little use in this paper.

[8] Assuming that capitalists would consume a fraction $(1-s)$ of their savings would not affect the results.

nanced through borrowing. Again for the sake of simplicity, I abstract from interest rates.

Total demand is then equal to, using traditional notation

$$D = C + I + G = wh + i + g + u(1 - h) \tag{2.7}$$

The market clearing condition states that total supply (expression 2.1) must be equal to total demand (expression 2.7) or, equivalently, that the Excess Demand function ($DE = D - Q$) must be equal to zero.

$$Q = D \qquad \Rightarrow \qquad qh = wh + i + g + u(1 - h) \tag{2.8}$$

$$DE = 0 \tag{2.9}$$

The market clearing condition is a stationarity condition for h in this model. Outside the locus of the implicit function, firms will either hire more labour (if they are producing less goods that are demanded) or fire workers (if they are producing more that it is demanded). Formally, the rate of change of employment is then

$$\dot{h} = \eta(DE) \tag{2.10}$$

$$\eta' > 0, \eta(0) = 0 \tag{2.11}$$

This dynamics [9] implies both constant return to scale technology and excess capacity of production for the firms, meaning that there is unused capital equipment available which can be employed in order to supply any amount of demand . Firms are then considered generally demand-constrained (Bowles and Boyer, 1988).
From expression 2.8 we can find the level of wage that guarantees that all the goods that are produced are sold, denoted as w_{mc}:

$$w_{mc} = q - \frac{i + g + (1 - h)u}{h} \tag{2.12}$$

This function goes from minus infinite when $h = 0$ to $q - (i + g) < q$ for $h = 1$, with $w'_{mc}(h) > 0$ and $w''_{mc}(h) < 0$in the interval $h \in [0, 1]$.
Figure 2.2 presents a representation of the function $w_{mc}(h)$, where the arrows indicate the dynamic of the economy outside the locus.

Equilibrium

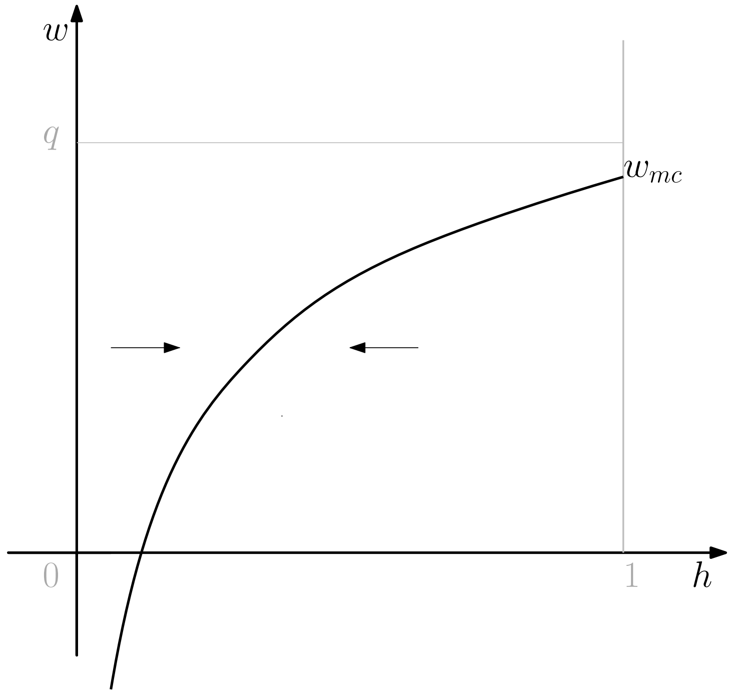
An equilibrium in this model is defined as a pair $e = (h, w)$ such that

- $w > 0$, $h \in [0, 1]$;
- Both the market clearing condition and the Nash bargaining condition are satisfied.

Proposition 2.2.1 states that if the productivity of labour is high enough, there are two equilibria: a "good" one, with high employment and wages, and a "bad" one, with low employment and wage.

[9] See note [7]

Figure 2.2: Market clearing wage



Proposition 2.2.1. *If $q \geq \underline{q}$, there exist two equilibria $e_i = (h_i, w_i)$, $i = 1, 2$ equal to*

$$e_1 = (h_1, w_1) = (\frac{q - \sqrt{\Delta}}{2(q-u)}, \frac{q + 2u - \sqrt{\Delta}}{2})$$
$$e_2 = (h_2, w_2) = (\frac{q + \sqrt{\Delta}}{2(q-u)}, \frac{q + 2u + \sqrt{\Delta}}{2})$$

such that

$$h_1 \leq h_2 \quad , \quad w_1 \leq w_2$$

where $\Delta = (q - 2u)^2 - 4(q-u)(i+g)$ *and* $\underline{q} = 2(u + g + i) + 2\sqrt{(g+i)(u+g+i)}$

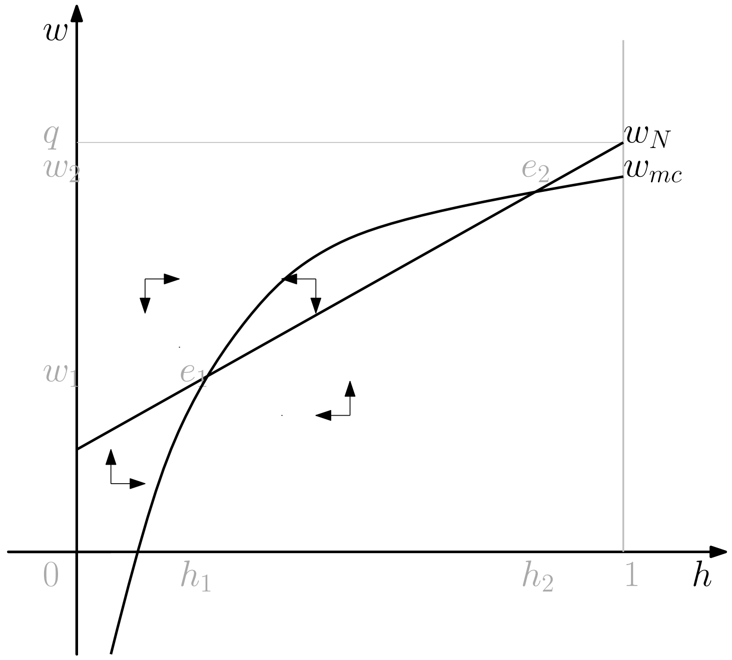
Proof. Appendix □

Figure 2.3 presents a graphical representation of the two equilibria. The arrows indicates the dynamic of the economy outside the equilibria, and show that the "lower" equilibrium is dynamically stable, while the "higher" one isn't. Nevertheless it is a saddle point, so it cannot be dismissed.

Effects of a labor productivity increase

Technological improvement has an effect over the equilibrium level of both occupation and wages. Proposition 2.2.2 shows that an increase in q has a negative effect on both

Figure 2.3: Equilibria



employment and wage if we are in the "bad" equilibrium, and on the contrary a positive effect on both if we are in the "good" equilibrium.

Proposition 2.2.2. *Let us assume that there exist two equilibria* $e_i = (h_i, w_i)$, $i = 1, 2$. *Then*

- $\frac{\delta h_1}{\delta q} < 0, \; \frac{\delta w_1}{\delta q} < 0$
- $\frac{\delta h_2}{\delta q} > 0, \; \frac{\delta w_2}{\delta q} > 0$

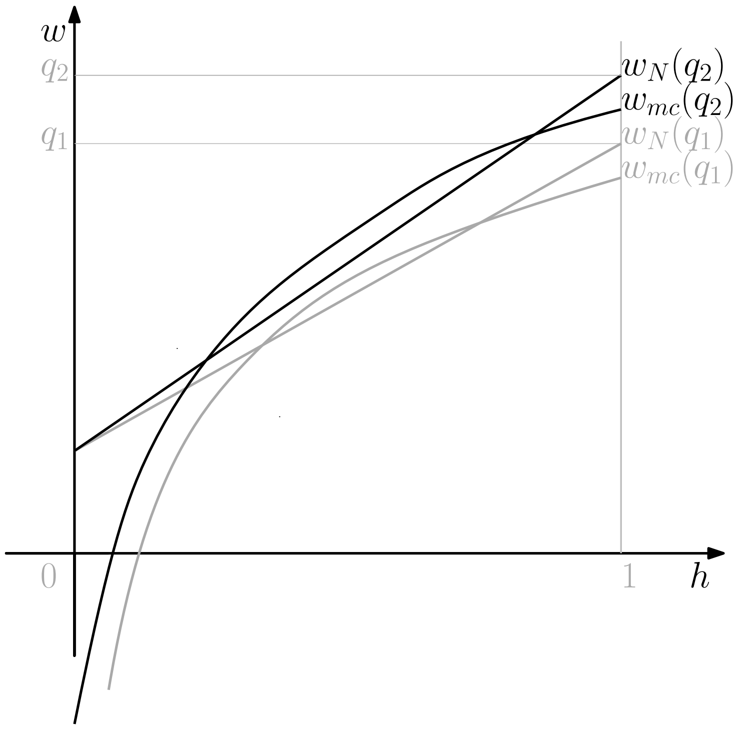
Proof. Appendix □

Figure 2.4 shows two the equilibria for two different level of labour productivity $q_2 > q_1$.

2.2.3 Market Clearing with Balanced Budget

Let us consider now the case of a government balanced budget, meaning that every public expenditure must be covered by tax revenues. I consider a single tax on profits, with a fixed rate of t. Moreover, the generic welfare expenditures g (representing expenses for the health system, public housing, public education..) are assumed to be residual: its amount consists of what is left of tax revenues after unemployment benefits (representing

Figure 2.4: Effects of increased labour productivity



automatic stabilizers) are paid. We can then write g as a function of occupation rate and wage.

$$g = th(q - w) - u(1 - h) \tag{2.13}$$

The balanced budget assumption does not affect the bargained wage. It does affect, on the other hand, the level of wage that guarantees market clearing. If the total government expenditures equals total government revenues, the market clearing condition states that investments must equals total private savings, meaning, in this case, after-tax profits.

$$i = (1 - t)h(q - w) \tag{2.14}$$

The market clearing wage with balanced budget becomes then[10]

$$w_{mc}^{bb} = q - \frac{i}{(1 - t)h} \tag{2.15}$$

The analysis of the function does not differ from the previous case, as it does not the behaviour of the economy outside the market clearing locus. Also the main results regarding the equilibrium do not change from the previous case: we have two equilibria, a good one which improves following an increase in productivity and a bad one which

[10]The superscript ^{bb} is used to differentiate the variables in this section from the one in section 2.2.2

worsen after an increase in productivity. Those results are summarized in proposition 2.2.3.

Proposition 2.2.3. *If $q \geq \underline{q}^{bb}$, there exist two equilibria $e_i^{bb} = (h_i^{bb}, w_i^{bb})$, $i = 1, 2$ equal to*

$$e_1^{bb} = (h_1^{bb}, w_1^{bb}) = (\frac{(1-t)(q-u) - \sqrt{\Delta^{bb}}}{2(1-t)(q-u)}, \frac{(1-t)(q+u) - \sqrt{\Delta^{bb}}}{2(1-t)}$$
$$e_2^{bb} = (h_2^{bb}, w_2^{bb}) = \frac{(1-t)(q-u) + \sqrt{\Delta^{bb}}}{2(1-t)(q-u)}, \frac{(1-t)(q+u) + \sqrt{\Delta^{bb}}}{2(1-t)}$$

such that

$$h_1^{bb} \leq h_2^{bb} \quad , \quad w_1^{bb} \leq w_2^{bb}$$

where $\Delta^{bb} = (1-t)^2(q-u)^2 - 4i(1-t)(q-u)$ *and* $\underline{q}^{bb} = u + \dfrac{4i}{(1-t)}$.

Given that such equilibria exist, then

- $\dfrac{\delta h_1^{bb}}{\delta q} < 0$, $\dfrac{\delta w_1^{bb}}{\delta q} < 0$
- $\dfrac{\delta h_2^{bb}}{\delta q} > 0$, $\dfrac{\delta w_2^{bb}}{\delta q} > 0$

Proof. Appendix □

Effects on residual welfare

Clearly if we assume the welfare expenditures to be residual, they become a function of both wages and employment rate. Plugging the equilibrium values into g, it becomes a function of labour productivity. We can show that welfare expenditures are surely positive if the tax rate is high enough. Moreover, it turns out that equilibrium welfare expenditures are positively related to q in the good equilibrium and negatively related to it in the bad equilibrium, as expressed in proposition 2.2.4.

Proposition 2.2.4. *Assume there exist two equilibria $e_i^{bb} = (h_i^{bb}, w_i^{bb})$, and g_1 is the level of residual welfare corresponding to e_1 while g_2 the one relative to e_2.*
For a tax rate $t > \underline{t}$[11]

$$g_1 > 0 \cap g_2 > 0 \tag{2.16}$$

Moreover, for any level of q

$$\frac{\delta g_1}{\delta q} < 0 \quad \frac{\delta g_2}{\delta q} > 0 \tag{2.17}$$

[11] This condition could be re-written as the requirement that the exogenous investments must be high enough (see proof in the Appendix), which would give the proposition a more "Keynesian" flavour. I chose to express it as a requirement over the tax rate because I assume the point of view of the government.

Proof. Appendix □

This is a worrying result. Indeed, introducing a balanced budget regime gives results similar to the deficit spending case regarding the effects of an increase in labour productivity over wages and occupation level, but it causes a reduction of welfare spending in the case of the bad equilibrium, which is actually the properly stable one. It actually implies an increase in welfare spending in the case of the good equilibrium, which nevertheless is a saddle point, as we have seen in the previous section.

2.3 Public incentives to innovation

Up to now we considered technological innovation to be exogenous, something that comes out of nothing, out of human creativity for instance. But most innovations are actually the results of investments in Research and Development, carried out either by private firms or by governments. This paper focuses on public founded R&D. This because I was interested in studying the effects of the massive amount of money that many governments around the world are spending in order to stimulate automation processes, and in particular on the effect of such investment in a balanced budget regime, as the case is in many European countries.
The growth of labour productivity is then endogenized by making it dependent on a fixed investment by the government, denoted R. The relationship between the amount of incentives and labour productivity is described by a simple functional form, which allows to express diminishing marginal returns for the investment in R&D by the government (due to the short-term horizon of the model).[12]

$$q = q_0(1 + \log R) \tag{2.18}$$

The new complete public expenditure becomes then the sum of welfare spending, employment benefits and R&D investments.

$$G = g + u(1 - h) + R \tag{2.19}$$

How does this affect the model? The only point in which the analysis differs from the one carried out up to now is that we have to study the effect over the equilibrium of a new variable, the public investment in R&D, which has the double effect of improving the productivity and increasing public expenditure.
We focus on the case of government balanced budget.[13] The results confirms much of what previously shown: the existence of two equilibria, influenced in an opposite way by an exogenous increase in labour productivity. Moreover, the same specular effect on

[12] I assume $R > 1$ in order to have $\log R > 0$.

[13] I also analysed the case of deficit spending, but I could not determine precisely the sign of the derivatives $\frac{\delta h_i}{\delta R}$, $i = 1, 2$. From some simulation it seems that the effect of R actually reverses sign after a certain amount of investment.

the two equilibria is registered with respect to an increase in public incentives towards automation. Proposition 2.3.1 summarizes those results [14].

Proposition 2.3.1. *If $q \geq \underline{q}_0^R$, there exist two equilibria $e_i^R = (h_i^R, w_i^R)$, $i = 1, 2$ such that*

$$h_1^R \leq h_2^R \quad , \quad w_1^R \leq w_2^R$$

Given that such equilibria exist, the effects of an exogenous increase in productivity is the following:

- $\dfrac{\delta h_1^R}{\delta q_0} < 0, \ \dfrac{\delta w_1^R}{\delta q_0} < 0$
- $\dfrac{\delta h_2^R}{\delta q_0} > 0, \ \dfrac{\delta w_2^R}{\delta q_0} > 0$

Moreover, the effects of an increase in public incentives R are the following

- $\dfrac{\delta h_1}{\delta R} < 0, \ \dfrac{\delta w_1}{\delta R} < 0$
- $\dfrac{\delta h_2}{\delta R} > 0, \ \dfrac{\delta w_2}{\delta R} > 0$

Proof. Appendix □

Le us now analyse the effects on residual welfare. Not surprisingly it turns out that public investments aimed to increase productivity have a detrimental effect on residual welfare when the economy is on the bad equilibrium, as shown in proposition 2.3.2.

Proposition 2.3.2. *Assume there exist two equilibria $e_i^R = (h_i^R, w_i^R)$, and g_1^R is the level of residual welfare corresponding to e_1^R while g_2^R the one relative to e_2^R.*
For a tax rate $t > \underline{t}^R$

$$g_1^R > 0 \cap g_2^R > 0 \tag{2.20}$$

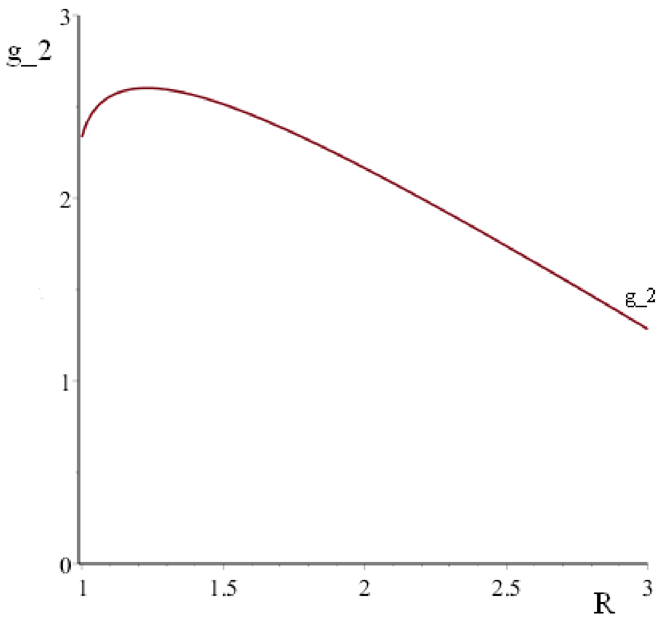
Moreover:

- $\dfrac{\delta g_1^R}{\delta R} < 0$
- *the effect of R over g_2^R can be either negative and positive.*

Proof. Appendix □

I was not able to find analytically a threshold for the change in sign of $\dfrac{\delta g_2^R}{\delta R}$. Nevertheless from numerical simulation it is clear that the effect of public investments on "good equilibrium" welfare expenditures is positive for small values of R, and then become negative, leading eventually them to disappear. Figure 2.5 shows an example.

Figure 2.5: Effects of public investments on g_2^R



Parameter values: $i = 2$; $u = 3$; $q_0 = 30$; $t = 0.7$.

This is a worrisome result: it means that in a balanced budget regime, the government's decision to incentivize an increase in labour productivity will eventually be at the expense of general welfare expenditures, even in the best case scenario.

2.4 Conclusions

The model expresses two different equilibria, one superior to the other in both employment level and wage. The "bad" equilibrium is dynamically stable, but the "good" one may also occur. An exogenous increase in labour productivity is always detrimental for both wages and employment rate if the economy is in the bad equilibrium, and always positive for both if the economy stays in the good equilibrium. This is true both with deficit spending and balanced budget regime. Considering on the other hand a public intervention in stimulating labour productivity, the effects of public investment over wage and employment are ambiguous if the government expenditures are debt-financed, while they mirror the exogenous increase in the balanced budget case. Anyway a consistent expenditure over public incentive towards automation is likely to have a negative effect over the level of welfare expenses. It surely does in the case of the bad equilibrium, in which the direct expenditure over R&D adds up to the increased expense in unemployment benefit. But for level of investment high enough, it does also in the best case scenario, the good equilibrium, in which an increase in labour productivity lowers unemployment, but not enough to compensate for the R&D expenses.

The main contribution of this paper is then to underline a potential contradiction between two public policies which have been strongly advocated by European governments in the last decades: the necessity of government budget stability (and the austerity measures necessary to implement it), and the strategic importance of stimulating automation in the production. The necessary expenses to incentivize the latter may "crowd out" from the government budget the necessary expenses to sustain healthcare, public housing, education etc. This would certainly happen if the short-term effects of the increased automation is a reduction of the active labour force, resulting in an increase in government spending for unemployment benefits, creating a double burden on government budgets. Since there are many reasons, both economic and political, to sustain that this is a negative outcome, this can be considered a further reason to oppose a balanced budget regime.

[14] The superscript ^{R} is used in order to differentiate the variables in this section from the previous ones.

2.5 Appendix

Proof of proposition 2.2.1

Solving $w_N = w_{mc}$ for h and then substituting the solutions back in w_N we obtain the solutions presented in the proposition. In order for the solutions to exist, we have to find the condition such that $\Delta > 0$. Δ is a parabola in q, and is positive for

$$\begin{aligned} q < q_a &\cup q > q_b \\ q_{b,a} &= 2(u+g+i) \pm 2\sqrt{(g+i)(u+g+i)} \end{aligned}$$

It is easily shown that $q_{a,b} > u$.
It is immediate to see that for $\Delta > 0$ one pair of solution expresses both higher wage and occupation rate than the other one. Let us denote the solution such that $h_1 < h_2$ and $w_1 < w_2$.
The solutions by construction respect both the nash bargaining and the market clearing condition. In order to have two equilibria then we just have to find the condition such that they are all positive and $h_{1,2} < 1$.
For $\Delta > 0$ it is immediate to see that $h_2 > 0$ and $w_2 > 0$. Given that $(q - u) > 0$ it is easy to show that this is true also for h_1 and w_1:

$$\begin{aligned} h_1 > 0 &\iff q > \sqrt{(q-2u)^2 - 4(g+i)(q-u)} \\ &\iff q^2 > (q-2u)^2 - 4(g+i)(q-u) \\ &\iff g+i+u > 0 \\ w_1 > 0 &\iff q + 2u > \sqrt{(q-2u)^2 - 4(g+i)(q-u)} \\ &\iff (q+2u)^2 > (q-2u)^2 - 4(g+i)(q-u) \\ &\iff 8qu + 4(g+i)(q-u) > 0 \end{aligned}$$

It is left to show that $h_{1,2} < 1$, which is promptly done. Consider first the case in which $q < 2u \Rightarrow 2u - q > 0$

$$\begin{aligned} h_1 < 1 &\iff \frac{q - \sqrt{\Delta}}{2(q-u)} < 1 \\ &\iff 2u - q < \sqrt{\Delta} \\ &\iff (2u-q)^2 < (q-2u)^2 - 4(g+i)(q-u) \\ &\iff 0 < -4(g+i)(q-u) \Rightarrow FALSE \\ h_2 < 1 &\iff \frac{q + \sqrt{\Delta}}{2(q-u)} < 1 \\ &\iff -(2u-q) > \sqrt{\Delta} \Rightarrow FALSE \end{aligned}$$

Consider then if $2u - q < 0 \Rightarrow q > 2u$

$$\begin{aligned} h_1 < 1 &\iff \frac{q - \sqrt{\Delta}}{2(q-u)} < 1 \\ &\iff 2u - q < \sqrt{\Delta} \Rightarrow TRUE \\ h_2 < 1 &\iff \frac{q + \sqrt{\Delta}}{2(q-u)} < 1 \\ &\iff q - 2u > \sqrt{\Delta} \\ &\iff (q-2u)^2 > (q-2u)^2 - 4(g+i)(q-u) \\ &\iff 0 > -4(g+i)(q-u) \Rightarrow TRUE \end{aligned}$$

So if $q > q_c = 2u$ then both h_1 and h_2 are smaller than one.
It is easy to show that $q_a < q_c < q_b$. Then let us denote $q_b = \underline{q}$ and Proposition 2.2.1 is proven.

Proof of Proposition 2.2.2

Differentiating h_1 and h_2 with respect to q we obtain

$$\begin{aligned} \frac{\delta h_1}{\delta q} &= \frac{-[2q(g+i) + qu - 2(g+i)u - 2u^2] - u\sqrt{\Delta}}{2(q-u)\sqrt{\Delta}} \\ \frac{\delta h_2}{\delta q} &= \frac{2q(g+i) + qu - 2(g+i)u - 2u^2 - u\sqrt{\Delta}}{2(q-u)\sqrt{\Delta}} \end{aligned}$$

It is convenient to notice that $2q(g+i) + qu - 2(g+i)u - 2u^2 > 0$ for $q > \underline{q}$. Then it is immediate to see that

$$\frac{\delta h_1}{\delta q} < 0$$

It is easy to show that, on the other hand $\frac{\delta h_2}{\delta q} > 0$

$$\begin{aligned} \frac{\delta h_2}{\delta q} > 0 &\iff 2q(g+i) + qu - 2(g+i)u - 2u^2 > u\sqrt{\Delta} \\ &\iff [2(g+i)(q-u) + u(q-2u)]^2 > u^2[(q-2u)^2 - 4(g+i)(q-u)] \\ &\iff (g+i)(q-u) + u(q-2u) + u^2 > 0 \end{aligned}$$

which is surely positive since $q > 2u$ for $q > \underline{q}$, as shown in the previous proof.
Differentiating w_1 and w_2 with respect to q we obtain

$$\begin{aligned} \frac{\delta w_1}{\delta q} &= \frac{-[q - 2(g+i+u)] + \sqrt{\Delta}}{2\sqrt{\Delta}} \\ \frac{\delta w_2}{\delta q} &= \frac{q - 2(g+i+u) + \sqrt{\Delta}}{2\sqrt{\Delta}} \end{aligned}$$

It is convenient to notice that for $q > \underline{q}$ we have $q-2(g+i+u) > 0$. It is then immediate to see that $\frac{\delta w_2}{\delta q} > 0$. It is easily show also that $\frac{\delta w_1}{\delta q} < 0$

$$\begin{aligned}
\frac{\delta w_1}{\delta q} < 0 &\iff \sqrt{\Delta} < (q-2u) - 2(g+i) \\
&\iff (q-2u)^2 - 4(g+i)(q-u) < (q-2u)^2 + 4(g+i)^2 - 4(g+i)(q+2u) \\
&\iff 0 < g+u
\end{aligned}$$

So the proof is complete.

Proof of Proposition 2.2.3

The first part of the proof is analogous to the one made for Proposition 2.2.1 where the new significant threshold for q is $\underline{q}^{bb} = u + \frac{4i}{(1-t)}$.
The derivatives of the equilibrium values with respect to q are

$$\frac{\delta h_1}{\delta q} = -\frac{i}{(1-t)\sqrt{\Delta^{bb}}} \qquad \frac{\delta w_1}{\delta q} = -\frac{i(q-u)}{(1-t)\sqrt{\Delta^{bb}}}$$
$$\frac{\delta h_2}{\delta q} = \frac{i}{(1-t)\sqrt{\Delta^{bb}}} \qquad \frac{\delta w_2}{\delta q} = \frac{i(q-u)}{(1-t)\sqrt{\Delta^{bb}}}$$

whose sign is straightforward.

Proof of Proposition 2.2.4

Plugging the equilibrium values into expression 2.13 we obtain

$$g_1 = \frac{(q-u)[2ti - (1-t)u] - u\sqrt{\Delta^{bb}}}{2(1-t)(q-u)} \tag{2.21}$$

$$g_2 = \frac{(q-u)[2ti - (1-t)u] + u\sqrt{\Delta^{bb}}}{2(1-t)(q-u)} \tag{2.22}$$

I show that a sufficient condition for the residual welfare to be positive in both equilibria is that the tax rate t is high enough, precisely that $t > \underline{t} = \frac{u}{u+i}$.[15] Given this condition, it is immediate to see that $g_2 > 0$, and also the second condition is easily proven

$$\begin{aligned}
g_1 > 0 &\iff (q-u)[2ti - (1-t)u] - u\sqrt{\Delta^{bb}} > 0 \\
&\iff (q-u)^2[2ti - (1-t)u]^2 > u^2[(1-t)^2(q-u)^2 - 4i(1-t)(q-u)] \\
&\iff (q-u)t[ti - (1-t)u] + (1-t)u^2 > 0
\end{aligned}$$

[15]Notice that this is a *sufficient* condition for *both* welfare expression to be positive for *any* level of q. It can be shown that for $t \in [\frac{u}{u+2i}, \frac{u}{u+i}]$ g_1 and g_2 are both positive for $(q-u) < \frac{u^2(1-t)}{t[u(1-t)-ti]}$. For $t < \frac{u}{u+2i}$, on the other hand, we have always $g_1 < 0$.

which is true since $ti - (1-t)u > 0$.
The derivatives of g_1 and g_2 with respect to q are

$$\frac{\delta g_1}{\delta q} = -\frac{iu}{(q-u)\sqrt{\Delta^{bb}}}$$
$$\frac{\delta g_1}{\delta q} = \frac{iu}{(q-u)\sqrt{\Delta^{bb}}}$$

whose sign is evident.

Proof of Proposition 2.3.1

The proof for the existence of the two equilibria is analogous to the proof of Proposition 2.2.3, substituting simply $q = q_0(1 + \log R)$.
Also the sign of the derivatives with respect to q_0 is promptly done referring to the same proof, since

$$\frac{\delta h_1^R}{\delta q_0} = (1 + \log R)\frac{\delta h_1}{\delta q} \mid_{q=q_0(1+\log R)}$$

and analogously for $\frac{\delta w_1^R}{\delta q_0}, \frac{\delta h_2^R}{\delta q_0}$ and $\frac{\delta w_2^R}{\delta q_0}$. It is immediate to show then that

$$q_0 = \frac{q}{(1 + \log R)}$$

Finally, also the sign of the derivatives with respect to R can be referred to

$$\frac{\delta h_1^R}{\delta R} = \frac{q_0}{R}\frac{\delta h_1}{\delta q} \mid_{q=q_0(1+\log R)}$$

and analogously for $\frac{\delta w_1^R}{\delta R}, \frac{\delta h_2^R}{\delta R}$ and $\frac{\delta w_2^R}{\delta R}$.

Proof of Proposition 2.3.2

The equilibrium values of welfare expenditures are now equal to

$$g_1^R = \frac{[q_0(1 + \log R) - u][2ti - (1-t)(u + 2R)] - u\sqrt{\Delta^{bb,R}}}{2(1-t)[q_0(1 + \log R - u]} \tag{2.23}$$
$$g_2^R = \frac{[q_0(1 + \log R) - u][2ti - (1-t)(u + 2R)] + u\sqrt{\Delta^{bb,R}}}{2(1-t)[q_0(1 + \log R - u]} \tag{2.24}$$

As for proposition 2.2.4, I show that this values are both positive for a level of tax rate high, enough, precisely for $t > \underline{t}_R = \frac{u+2R}{i+u+2R}$. Given this condition, it is immediate to see that g_2^R. Regarding g_1^R, denote for sake of clarity $\alpha = [q_0(1+\log R) - u]$:

$$\begin{aligned} g_1^R > 0 &\iff \alpha[2ti - (1-t)(u+2R)] - u\sqrt{\Delta^{bb,R}} \\ &\iff \alpha^2[2ti - (1-t)(u+2R)]^2 > u^2[(1-t)^2\alpha^2 - 4i(1-t)\alpha] \\ &\iff \alpha it[ti - (1-t)(u+2R)] + i(1-t)u^2 + \alpha R(1-t)^2(u+R) > 0 \end{aligned}$$

which is surely positive given $t > \underline{t}_R$.[16]
Notice that the condition that the tax rate is high enough can be expressed as a condition over the amount of public investment: indeed R must be low enough in order to guarantee positivity of the residual welfare expenditures, precisely

$$R < \frac{t}{(1-t)}\frac{i}{2} - \frac{u}{2} \tag{2.25}$$

The derivative of g_1 and g_2 with respect to R are

$$\begin{aligned} \frac{\delta g_1^R}{\delta R} &= -\frac{R[q_0(1+\log R) - u]\sqrt{\Delta^{bb,R}} + iq_0 u}{R[q_0(1+\log R]\sqrt{\Delta^{bb,R}}} \\ \frac{\delta g_2^R}{\delta R} &= -\frac{R[q_0(1+\log R) - u]\sqrt{\Delta^{bb,R}} - iq_0 u}{R[q_0(1+\log R]\sqrt{\Delta^{bb,R}}} \end{aligned}$$

The sign of $\frac{\delta g_1^R}{\delta R}$ is straightforward. The fact that $\frac{\delta g_2^R}{\delta R}$ can assume both sign for plausible values of the parameters is easily shown with two numerical examples. Consider the following values of the parameters: $i = 2$; $u = 3$; $q_0 = 30$; $t = 0.7$. Then for $R = 1.2$ we have that $\frac{\delta g_2^R}{\delta R} = 0.122$; and for $R = 2.1$ we have that $\frac{\delta g_2^R}{\delta R} = -0.826$.

[16] As in proposition 2.2.4, this condition is sufficient but not necessary. It can be shown that for $t \in [\frac{u+2R}{2i+u+2R}, \frac{u+R}{i+u+R}]$ we have $g_1^R > 0 \Leftrightarrow q < q^*$, where
$q^* = \frac{(1-t)[R(1-t)(R+u) - ti(u+2R) - u}{(1+\log R[(1-t)^2 R(u+R) - it(1-t)(u+2R) + i^2t^2}$

Chapter 3

Labour productivity and energy efficiency

3.1 Introduction

In the last few years, the issue of automation and its effects on employment have been at the center of the academic and the political debate. There is no agreement regarding the magnitude of the risk of machine replacing humans in the majority of productive activities. The influential paper of Frey an Osborne (2013) predicts that up to 47% of US jobs are at high risk of being automated in the next two decades. Other studies come to more optimistic results: Manyika (2017) presents a variety of scenarios, estimating the number of work activities which could be displaced by 2030 to be between zero and 30%, while the OECD paper by Arntz et al. (2016) make a direct critique of Frey and Osborne methodology, coming to the conclusion that on average 9% of jobs in OECD countries are automatable. Brynjolfsson and McAfee in their recent books *The Second Machine Age* (2014) and *Race Against the Machine*(2012) underline the importance to develop complementary skills with robots in order to avoid structural mass unemployment.
Anyway, economists (and society in general) worrying about the risks of automation is nothing new. The issue arises cyclically in economics, usually (understandably) in periods of recessions. Great economists have dealt with the subject in the past, with different shades of pessimism: for example Keynes (1930) predicted a happy future for "his grandchildren", freed from the burden of manual work, while Leontief, whose last book was on the Future Impact of Automation on Workers (Leontief et al., 1986), considered also more grim scenarios. Ultimately, as already pointed out by Sylos-Labini (1989), the question boils down to the dual effect of productivity over employment: the reduction of labour needed for unit produced, and the potential increase of real aggregate demand, and therefore production. The intrinsic unpredictability of many of the variable involved, technical progress first of all, makes it impossible to predict which effect will prevail, and therefore it makes sense to contemplate even the most pessimistic scenarios.

Overall, anyway, the increase in labour productivity in the last couple of centuries[1] has been a massive phenomenon that, up to now, has shown no significant sign of disappearing. Moreover in the last years the automation process has become the direct aim of a great number of public policies. The German strategy promoting the computerization of manufacturing was at the origin of the nowadays well-known expression of Industry 4.0. Recently, the Italian industrial plan denoted, as well, *Industria 4.0* provided huge incentives to firms investing in automated technologies.[2]

An other worrying issue of the past half century is the depletion of non-renewable sources of energy. Since the famous Hubbler Report (1956) regarding the production of oil, coal and mineral gas, the availability of energy has been at the center of almost every nation's strategic policies. Wars have been (and are still) fought over the access to such resources, which nevertheless inevitably will run out, sooner or later. This has brought in the past decades to an impressive insurgence of research over renewable sources of energy, which nevertheless, at the current state of technologies, are still not as cheap as fossil fuels. The literature on the subject is massive.[3] This is another field in which the complexity of the the subject does not allow for future predictions. Nevertheless it is worth to consider different scenarios, including the one in which we are going to face a long period of increasing energy prices. Such price increase, moreover, may also start well before the so-called "Hubbler peak", as Bardi (2007) shows. Such concerns, beside many others related to more general environmental problems, have led both the private and the public sector to focus on the improvement of energy efficiency in the production process.[4]

The research question behind this paper is about the relationship between these two themes. I want to explore the interaction between the increase in labour productivity (automation process) and in energy efficiency, in a number of different scenarios. Such relationship is often neglected in economic reasoning. For example, it is a well-know fact (even beyond the economic field) that labour productivity in western agricultural sector increased amazingly in the last century. It may come to a surprise for many, on the other hand, to discover that energy efficiency (or "energy productivity") has actually declined, as pointed out by Juan Martinez-Alier (1988). The intuition behind this paper is that, assuming a trade off between investing in labour-saving or energy-saving technologies, different assumption regarding technological trajectories, institutional setting or evolution of relative prices could lead to very different outcomes. For example increasing energy prices could lead to a slow down of the automation process. An intuition of this could come from some stylized facts (without the presumption to find casual relation), as Figures 3.1 and 3.2 below show: in periods with high oil prices we can see a slower

[1] Maddison (1982) calculated a median increase in labour productivity of 1100% in the period 1870-1970 among the 16 industrialized leaders countries

[2] $http://www.sviluppoeconomico.gov.it/index.php/it/industria40$

[3] On this and other issues of the global environment see Stern (2008).

[4] See Stern (2008), Stocker et al. (2015), Hesselbach et al. (2011).

growth of labour productivity.[5]

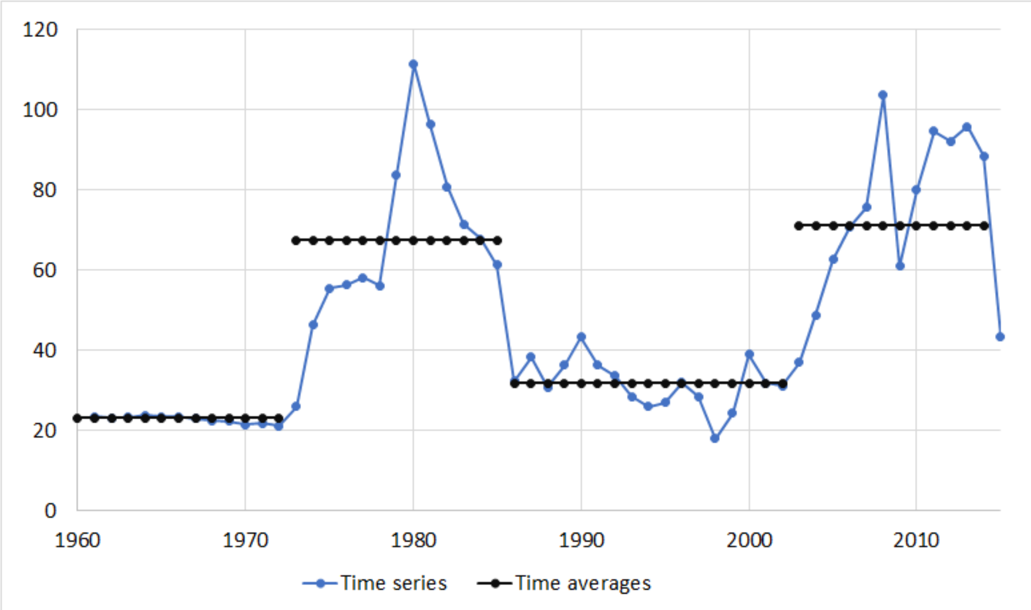


Figure 3.1: Crude oil prices

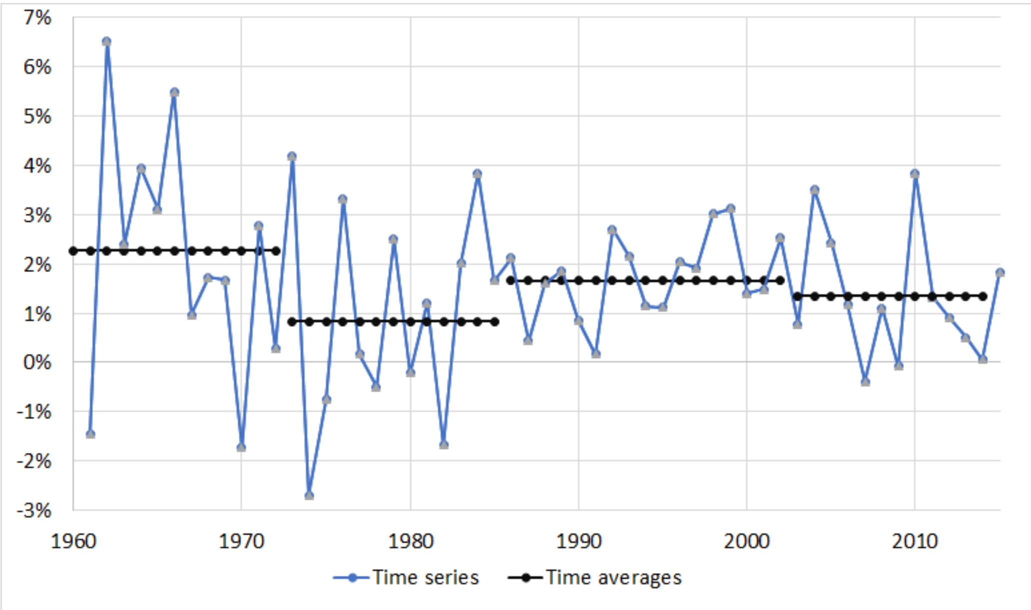


Figure 3.2: Annual labour productivity growth in USA.

[5]Source of data:
FRED (2019) for labour productivity.
$https://inflationdata.com/Inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp$ for oil prices.

To consider productivity increases, of either labour or energy, it means to consider technical change. In economic models, technical change can be of two kinds: autonomous or induced. Technical change is considered to be autonomous when depends mostly of factor exogenous to the model, i.e. government investment or natural human inventiveness. On the other hand, technical change is considered induced when it is influenced by market forces, mostly factor prices. Popp (2002) shows a strong positive correlation between energy prices and the amount of patents on energy-efficiency innovations, and Calel- Dechezlepretre (2013) show a similar relationship between crude oil prices and low-carbon patents. Stern (2008) actually notices that despite the increase in energy prices in the first half of the 2000s the expenditure in energy related R&D did not go up, but finds contingent explanations for this. Brugger and Gehrke (2017) provide a complete review of how the concept of induced technical change was treated by mainstream economics, from its introduction by Hicks in his *Theory of Wages* in the 30s to Samuelson in the 60s and Acemoglu in recent years. The authors criticize the results obtained, because of the difficulties to distinguish properly between induced technical change and factor substitution within the neoclassical framework. Grubb (2002) instead presents a variety of models dealing with technical change, both autonomous and induced. The author is very critical of the literature which makes use of an *Autonomous Energy Efficiency Improvement*, because of the excessive dependence on the initial chosen values and because of the well-established fact that at least partially technical change is influenced by market forces.

On a general level, the model presented is post-Keynesian in its main features. It draws inspiration in many of its features from the EUROGREEN model (D'Alessandro,2017). As the EUROGREEN model, it can be considered an ecological macroeconomic model, placing itself in the strain of literature which is attempting to exploit the synergies between the post-Keynesian tradition and the usually micro-focused ecological economics one. Other related works are Dafermos and al. (2017) or Godin(2013). In order to deal with the complexity of the system I make use of a dynamic macrosimulation approach. The flexibility of this tool allows me to consider a great variety of scenarios and assumptions. Similar works making use of the of system dynamics and macrosimulation tools include Bernardo-D'Alessandro (2016) or Yamaguchi (2014).

In the following section I will present the details of my model. Subsection 3.2.3, dealing with the innovation process and technical change, represents the main novelty of my contribution. In section 3.3 I will presents the results of various simulations, representing both different possible scenarios (different evolution of relative prices or different technological trajectories) and different theoretical assumptions (regarding the endogeneity of technical change or the influence of automation over the bargaining power of workers).

3.2 The Model

3.2.1 Production, Capital and Investment

In the description of the model the time suffixes for the present time are omitted, while a variable correspondent to the previous period has a suffix "$_{-1}$". Moreover, otherwise differently specified, lower case letters indicates real variables, while capital case ones nominal variables.

I consider a closed economy with only two goods: a produced good, which is both a consumption good and a capital good (most of the times referred-to simply as "good") and an extracted good, denoted "energy". I assume that the extraction of energy is costless, and monopolized by a class of capitalists denoted "rentiers". On the other hand, in order to produce the consumption/capital good both energy and labour are needed. Working population is fixed, and equal to n. The labour force is divided between employed, n_E, and unemployed, n_U.

Following post-Keynesian tradition, the output is determined by effective demand: the consumption and investment decisions of households, firms and government determine the amount of consumption/capital goods to be produced. Following traditional notation, output is determined as the sum of total consumption, investment and government (welfare) spending.

$$y = c + i + g \tag{3.1}$$

The amount of produced goods then determines the amount of workers employed and the amount of energy used, according to the following equations

$$n_E = \frac{y}{\overline{\lambda} h} \tag{3.2}$$

$$c_e = \frac{y}{\overline{\eta}} \tag{3.3}$$

where n_e indicates the number of employed workers, h the amount of hours worked per person per year and c_e the amount of energy used in one year. The parameters $\overline{\lambda}$ and $\overline{\eta}$ denote the average productivity of respectively labour and energy, whose determination will be discussed in the following section.

If the good is used as investment, it adds to the stock of productive capital in the industrial sector. Such stock, denoted k, determines the maximum number of goods producible in a year, according to the following equation, where I consider the parameter ξ to be fixed.

$$y_{max} = \xi k \tag{3.4}$$

Anyway it is well known that firms almost never operate at full capacity. The rate of capacity utilization, u, is

$$u = \frac{y}{y_{max}} \tag{3.5}$$

The capital stock depletes every year at a constant rate of δ. On the other hand, increases according to the firms' investment decision. Following Lavoie and Godley (2001), firms determine the desired rate of capital growth (excluding replacement), g_k, according to two factors: the difference between the desired rate of capacity utilization denoted u_n and realized rate of the previous period; and the cash-flow ratio (denoted r) of the industrial sector of the previous period. The cash-flow ratio is the ratio between retained profits, denoted Π_p^R and the nominal value of capital:

$$r = \frac{\Pi_p^R}{Pk} \tag{3.6}$$

The desired rate of growth of capital, and the total amount of investment (including capital replacement) are then

$$g_k = \gamma_1(u_{-1} - u_n) + \gamma_2 r_{-1} \tag{3.7}$$
$$i = max\{g_k + \delta, 0\}k \tag{3.8}$$

3.2.2 Costs, Prices and Profits

Coherently with post-Keynesian price theory, the price of the produced good to be determined by firms, as a mark-up over unit production costs. Unit production costs are determined by the following equation

$$UC = \frac{Wn_E + P_e c_e + \delta Pk}{y} \tag{3.9}$$

where W is the wage and P_e is the price of energy, determined in the world market and so considered exogenous.
Prices are then determined by multiplying a mark-up factor μ to lagged unit cost.

$$P = (1 + \mu)UC_{-1} \tag{3.10}$$

Profits in the industrial sector are then determined by the following equation[6]

$$\Pi_p = Py - (Wn_E + P_e c_e + i_L L) \tag{3.11}$$

Profits earned in one period are then partially distributed as dividends (Π_p^D) and partly retained (Π_p^R) to finance investments

$$\Pi_p^D = \phi \Pi_p \tag{3.12}$$
$$\Pi_p^R = (1 - \phi)\Pi_p \tag{3.13}$$

[6]where L is the quantity of loans and i_L the interest over loans, as explained in section 3.2.7.

where $\phi \in [0, 1]$.

As already mentioned, I assume that extracting energy does noes not cost anything to the rentiers. Nevertheless, they do not have the control on the price, P_e, since I consider it to be determined in the world market. I will consider different scenarios regarding the evolution of energy prices. Then the profits of the rentiers are simply

$$\Pi_e = P_e c_e \tag{3.14}$$

I also consider all the profits to be distributed, so

$$\Pi_e^D = \Pi_e \tag{3.15}$$

3.2.3 Technology and Innovation

A fundamental distinction concerning the investment decision of firms is between investments which do not change the technical coefficients and investments which do (Sylos Labini, 1957). Indeed, the two have both different causes and consequences. The first kind derive from the firm's desire to increase their production capacity. It is then strictly related to the evolution of demand (beside, of course, the firms' internal funds availability), it necessarily results in an increased production and employment, and does not imply any kind of technological innovation. Fixed coefficients means that both labour productivity and energy efficiency remain constant in the newly installed plants. On the other hand, investments which do imply new technical coefficients by definition determine a change in either labour productivity or energy efficiency (or both). They are caused by the firms' desire to produce a given desired level of production in the cheapest way possible. They are, then, strongly dependent on the evolution of relative prices. They do not necessarily result in an increase in employment: if investments induce a significant increase in labour productivity (i.e. automation) they can actually reduce it. I deal with this distinction in the model by separating the decision concerning the *amount* of investment, i.e. the decision regarding the desired production capacity (determined by the equation for i in the previous section) from the decision concerning which *technology* should be installed in the new plants.

Every period new technical coefficient are determined randomly, corresponding an increase in productivity of labour, or energy, or both, or neither. Then firms decide which technology will be incorporated into the newly acquired machinery, bought on order to replace old machinery or in order to increase production. Firms will choose each year the technology which will allow them to minimize the unit cost of production, given the current wages and energy prices. Since it is not possible to substitute the whole stock of capital at once, this decision process creates a path dependence: the direction of technical change is influenced by prices evolution, even considering a fixed probability distribution behind the innovation process. We may call it *semi-induced* technical change. I will consider in subsection 3.3.3 a specification in which the probability distribution itself is influenced by the evolution of relative prices, making the technical change purely induced.

Since the new technologies will be installed only in new equipment, and not in the whole stock of capital, the amount of labour and energy demanded will be determined by a variety of technologies operating at the same time. The significant variable are then the *average* productivities of labour and energy, computed in the following way

$$\overline{\lambda} = \frac{\lambda i + \overline{\lambda}_{-1}k - \delta\overline{\lambda}_{-2}k}{k} \tag{3.16}$$

$$\overline{\eta} = \frac{\eta i + \overline{\eta}_{-1}k - \delta\overline{\eta}_{-2}k}{k} \tag{3.17}$$

The technologies among which firms choose depend on the process of innovation. The determinants of innovation are, for the moment, left as exogenous. Nevertheless we must consider all the possible sets of coefficients available each period. It may be the case, indeed, that a new machinery includes improvements both regarding labour productivity and energy efficiency. But at the same time, it often happens that only one of the two increases, the other remaining constant or even lowering. Moreover, there could be no technological improvement available in a particular year.

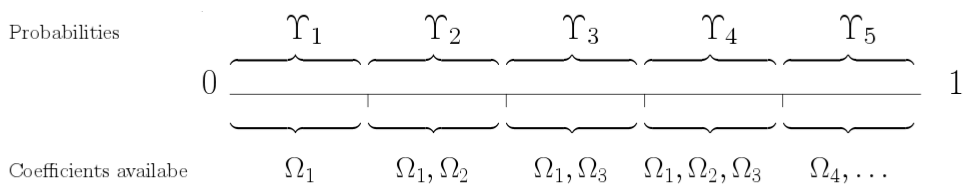
I consider then that each year there are at most four possible set of coefficients among which the firms may choose, denoted with $\Omega_i, i = \{1, 2, 3, 4\}$.

	λ	η
Ω_1	$\lambda_{\Omega_1} = \lambda_{t-1}$	$\eta_{\Omega_1} = \eta_{t-1}$
Ω_2	$\lambda_{\Omega_2} = \lambda_{t-1} + \Delta\lambda$	$\eta_{\Omega_2} = \eta_{t-1} - \delta\eta$
Ω_3	$\lambda_{\Omega_3} = \lambda_{t-1} - \delta\lambda$	$\eta_{\Omega_3} = \eta_{t-1} + \Delta\eta$
Ω_4	$\lambda_{\Omega_4} = \lambda_{t-1} + \Delta\lambda$	$\eta_{\Omega_4} = \eta_{t-1} + \Delta\eta$

The values of the productivities' increase ($\Delta\lambda$ and $\Delta\eta$) or decrease ($\delta\lambda$ and $\delta\eta$) can be modelled in different ways: they can be constant, can be random variables, can follow a determined path.[7]

Apart from Ω_1, which consist in the technology currently used and which can always be replicated, not necessarily the other set of coefficients are available each period, i.e. not necessarily there have been advances concerning energy efficiency or automation of production process in industrial plants. $\Omega_2, \Omega_3, \Omega_4$ are assumed to have positive (non independent) probabilities to be available. Clearly Ω_4 will always be preferable to the other three, so if it is available it will always be chosen. Actually the significant cases can be reduced to five: only Ω_1 is available (probability Υ_1 to occur); Ω_1 and Ω_2 are available (probability Υ_2); Ω_1 and Ω_3 are available (probability Υ_3); Ω_1 and both Ω_2 and Ω_3 are available (probability Υ_4); and Ω_4 is available, and will be chosen (probability Υ_5).

[7]In my simulation I usually use a fixed value for $\Delta\lambda$ and $\Delta\eta$ and a random one for $\delta\lambda$ and $\delta\eta$: with a certain probability they are zero (meaning that only one of the coefficients increases, while the other stays constant) and otherwise they assume a fixed positive value.



The probabilities of the different states of the world can be exogenously determined or can be made dependent to economic variables, as we will see in section 3.3. Let us denote with Ω the set of the index of the technologies available in the current period, where clearly $\Sigma \subseteq \{\Omega_1, \Omega_2, \Omega_3, \Omega_4\}$. Once that the firms know which sets of technical coefficient are available, they decide to implement the technology which allow them to produce at the lower cost. This means that they compute the (hypothetical) average productivity of labour / energy efficiency on the basis of the (already decided) amount of today's investment, so according to the equations

$$\overline{\lambda}_x = \frac{\lambda_x i + \overline{\lambda} k - \delta \overline{\lambda}_{-1} k}{k - \delta k + i} \qquad x \in \Omega \tag{3.18}$$

$$\overline{\eta}_x = \frac{\eta_x i + \overline{\eta} k - \delta \overline{\eta}_{-1} k}{k - \delta k + i} \qquad x \in \Omega \tag{3.19}$$

From this they can compute the (hypothetical) energy consumption and employment that would result from the use of the different technologies, and therefore the possible unit costs of the following period, for each available set of coefficients: $UC_x \quad x \in \Omega$, computed as in equation (3.9). The technology implemented in today's investment will be the one resulting in the lower unit cost. This choice will clearly depend on the differences among coefficients but also on the relative prices between labour and energy. Moreover different technological trajectories (values of $\Delta\lambda$,$\Delta\eta$, $\delta\lambda$, $\delta\eta$) or different probability distributions of the innovation process will affect the results. I will examine a number of scenarios in section 3.3.

3.2.4 Labour Market

Equation 3.2 above shows that the amount of people employed is determined by the level of demand and the average labour productivity in the economy. The evolution of wages, on the other hand, is the result of collective bargaining between workers and capitalists. I consider three factors influencing the variation of wages: the variation in the unemployment rate ($\Delta \upsilon$), the inflation rate (π) and the growth of labour productivity (g_λ). The equation for wage is then

$$W = (1 + \omega_1 g_\lambda - \omega_2 \Delta \upsilon + \omega_3 \pi) W_{-1} \tag{3.20}$$

Where ω_1, ω_2 and ω_3 are positive parameters.

It has been advocated that the progress of automation actually reduces the bargaining power of the workers, by reducing the control they have over the production process (see Braverman, 1974). This can be modelled making the coefficient linking the growth of wage and the growth of labour productivity dependent on the growth of labour productivity itself, i.e.

$$\omega_1 = (1 - \iota g_\lambda)\omega_{1,-1} \tag{3.21}$$

In most analysis we'll consider $\iota = 0$, but I will also investigate the effects of positive values.

3.2.5 Households' Consumption

I consider five categories of households, divided in two social classes. Workers are divided between employed and unemployed, and I consider three kinds of capitalist: industrials (who own the capital in the productive sector), bankers (who own the banks) and rentiers (who own the right to extract energy). Employed workers receive a wage, while unemployed collect a benefit and capitalist earn profits. All categories of households also receive income from interests over deposits, which I model as tax-free.[8] The equations for the disposable income are then

$$Y_E = (1-t)n_E W + i_D D_E \tag{3.22}$$
$$Y_U = (1-t)n_U UB + i_D D_U \tag{3.23}$$
$$Y_{CA} = (1-\tau)(\Pi_p^D + \Pi_b^D + \Pi_e^D) + i_D D_{CA} \tag{3.24}$$

Where the suffixes $\{E, U, CA\}$ indicate respectively employed, unemployed and capitalists, D_i the deposits, i_D the interests over deposits, UB the unemployment benefit, $\Pi_p^D, \Pi_b^D, \Pi_e^D$ are total distributed profits respectively from the industrial, financial and energy sectors, t and τ the tax rates. Notice that while it is of interest to distinguish between workers employed and unemployed, I consider the number of capitalists to be fixed and relatively small, so I consider the capitalist class only in the aggregate.

The level of consumption depends both on income and wealth. For the workers the wealth consists only in the value of their deposits, while for the capitalists (denoted V) is the sum of the value of deposits and of the net worth of the firms, denoted NW, equal to the difference between the value of capital and the total amount of loans:

$$V = D_{CA} + NW = D_{CA} + Pk - L \tag{3.25}$$

Following the Kalckian tradition I assume that, in general, workers have an higher propensity to consume that capitalists. Moreover I consider unemployed workers to have an higher propensity to consume than employed ones. On the other hand, I do not distinguish between the consumption habits of the different kinds of capitalists. In the model I consider consumption decision to be based on *expected* income and wealth, which for

[8] The amount of deposits over which a category earn interests needs adjusting, see the Appendix.

simplicity I consider to be the previous period values, in order to represent the well known inertia of consumption decisions. The consumption equations are then

$$C_i = \alpha_{Y,i}Y_{i,-1} + \alpha_{D,i}D_{i,-1} \qquad i = \{E, U\} \tag{3.26}$$

$$C_{CA} = \alpha_{Y,CA}Y_{CA,-1} + \alpha_{D,CA}V \tag{3.27}$$

where C_i indicates aggregate nominal consumption, $\alpha_{Y,i}$ and $\alpha_{D,i}$ are the propensities to consume out of income and out of wealth. The value of the coefficients are taken from EUROGREEN[9], and are summarized in table 3.1.

Table 3.1: Propensities to consume

	Employed	Unemployed	Capitalists
Propensity to consume out of income ($\alpha_{Y,i}$)	0.86	0.95	0.73
Propensity to consume out of wealth ($\alpha_{D,i}$)	0.065	0.075	0.05

Total consumption is then simply the sum of the consumption of all households, and real consumption (in consumption/capital good terms) is obviously nominal consumption divided for the price.

$$C = C_E + C_U + C_{CA} \tag{3.28}$$

$$c = \frac{C}{P} \tag{3.29}$$

3.2.6 Government

Total nominal government spending is given by the sum of nominal value of welfare expenses (g), unemployment benefits expenses and interests over national debt (B)

$$G = Pg + UBn_U + i_B B \tag{3.30}$$

The nominal value of unemployment benefit is determined as a fraction β of current wage: $UB = \beta W$, $\beta \in [0, 1]$.

Total government revenues are the sum of revenues from taxation over wage and profits

$$T = t(Wn_E + UBn_U) + \tau(\Pi_p^D + \Pi_b^R + \Pi_e^D) \tag{3.31}$$

The government funds its deficit by selling a single type of bond, which is bought exclusively by banks. The annual variation of government debt is then

$$\Delta B = G - T \tag{3.32}$$

[9]Except for $\alpha_{D,U}$, set equal to 0.075 in order to be greater than $\alpha_{D,E}$.

3.2.7 Financial Sector

Whatever is not consumed in one period adds to the amount of deposits held by households. This means that annual deposit variation is equal to[10]

$$\Delta D_i = Y_i - C_i \qquad i = \{E, U, CA\} \tag{3.33}$$

Banks, as I have said, purchase government bonds and earn interests from it. Moreover, they concede loans to firms. Firms finance investments primarily through their internal funds, Π_p^R, and if this is not sufficient they borrow the difference from the banks. If, on the other hand, the value of desired investment is smaller than retained profits, they will use the difference to reduce their stock of loans. The annual variation of loans will then be

$$\Delta L = Pi - \Pi_p^R \tag{3.34}$$

The profits of bank will then be

$$\Pi_b = i_B B + i_L L - i_D (D_{CA} + D_E + D_{U)} \tag{3.35}$$

Where i_B,i_L and i_D are respectively the interests on bonds, loans and deposits.
Banks fully distribute the profits, so

$$\Pi_b^D = \Pi_b \tag{3.36}$$

3.3 Results

In this section I present the results from a variety of scenarios. In subsections 3.3.1 and 3.3.2 I will consider the case in which the probability distribution of the technological innovation available to firms is exogenous. I first analyse the consequences of assuming different technological trajectories. Then I will compare different probability distributions of the random variable determining the innovation process, which can be interpreted as different public policies. Finally I present the effects of increasing energy prices over employment and the rapidity of the automation process .
I then present a specification of the model in which the automation process decreases the bargaining power of workers, and show how this could create a gap between wage and productivity increases.
In the subsection 3.3.3 I consider a specification in which the evolution of relative prices affect the probability distribution of the available innovations. I compare the results obtained with the ones resulting from a fixed probability distribution for the innovation process, and I analyse again the effects of different public policies and energy price dynamics.

[10]The determination of the deposit variation for household require some adjustments because of the division between employed and unemployed. The argument is explained in detail in the Appendix.

3.3.1 Exogenous innovation

Let us first assume that the probabilities connected to the availability of the various technological innovations are exogenously given, and do not change during the simulation. This is an unrealistic assumption, since it is widely recognized that innovation is at least partly induced by relative prices, which will be abandoned in the next section.

I will consider a baseline scenario with the following probabilities: $\Upsilon_1 = 0.1$, $\Upsilon_2 = 0.2$, $\Upsilon_3 = 0.2$, $\Upsilon_4 = 0.4$,$\Upsilon_5 = 0.1$. This means that both the case in which only a labour-saving and an energy-saving innovations are available have the same probabilities (0.2); also the no-innovation case and the case in which an innovation allows both an improvement in labour productivity and in energy efficiency have the same, lower probability (0.1); and finally there is a probability of 0.4 that firms have to choose between an "automated" and a "green" new machinery.

Technological trajectories

Beside the probability distribution, results are also influenced by the kind of technological trajectory assumed. I consider two cases.

In the first case I assume that if an increase in productivity is available, it augments the current level of a fixed amount, the same every year. This specification corresponds to the hypothesis that technological improvement expresses a kind of "diminishing returns": indeed the relative increase is progressively smaller. On the other hand, it is possible that the price to pay for a set of coefficients resulting in an increase in productivity in one of the two factors is a reduction of the productivity of the other factor. I consider that in most cases (90%) the productivity of the not-improving input remains constant, and in the remaining cases it reduces of, again, a fixed amount. In particular I set the variables from table 3.2.3 with the following values:

$$\Delta\lambda = \Delta\eta = 5 \tag{3.37}$$

$$\delta\lambda = \delta\eta = \begin{cases} 0 & \textit{with probability} \quad 90\% \\ 2 & \textit{otherwise} \end{cases} \tag{3.38}$$

An alternative is to consider a more optimistic case, in which the possible increase in productivity is a fixed percentage of the level reached up to that moment. This means that the absolute value of the "steps" of the productivities are increasing the more advanced the original technology is. Also for the possible reduction (in case it occurred) I consider a fixed proportion of the actual level. In particular I decided to set the variable from table 3.2.3 with the following values:

$$\Delta\lambda = 0.03\lambda \tag{3.39}$$

$$\delta\lambda = \begin{cases} 0 & with \quad probability \quad 90\% \\ 0.01\lambda & otherwise \end{cases} \tag{3.40}$$

$$\Delta\eta = 0.03\eta \tag{3.41}$$

$$\delta\eta = \begin{cases} 0 & with \quad probability \quad 90\% \\ 0.01\eta & otherwise \end{cases} \tag{3.42}$$

Figure 3.3 shows the differences in the evolution of labour and energy productivities. With the given values we can see that the rapidity of innovation is much slower with proportional increase, which nevertheless exhibits increasing returns. It is interesting to notice how the implementation of energy-saving techniques is sensitive to the technological trajectories assumed: with proportional increases in productivity is much less convenient than with fixed increases.

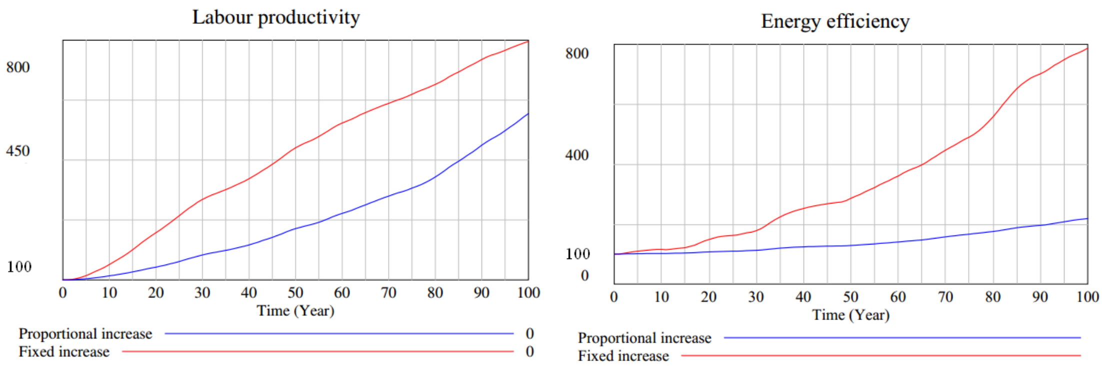


Figure 3.3: Evolution of labour productivity and energy efficiency with fixed and proportional increases.

Public incentives

Changing the probability distribution of the available coefficients can have strong effects on the economy as a whole. We could interpret such exogenous changes as public policies, aimed to incentive either one kind of innovation or the other. For example we can interpret an increase in the probability Υ_2 (in which only labour-saving innovations are available) as public founding to "Industry 4.0". Analogously we can see an increase in probability Υ_3 (in which only energy-saving innovations are available) as "environmentalist" incentives, aimed to reduce the consumption of energy. Anyway also alternative interpretation of the change in the distribution are possible: for example they could represent different countries, with different institutional setting or technological tradition.

I consider two different scenarios: one denoted "Automation incentives" with probabilities $\Upsilon_1 = 0.1$ (stable), $\Upsilon_2 = 0.4$ (increased), $\Upsilon_3 = 0.1$ (decreased), $\Upsilon_4 = 0.3$

(decreased),$\Upsilon_5 = 0.1$ (stable); and one denoted "Green incentives" with probabilities $\Upsilon_1 = 0.1$ (stable), $\Upsilon_2 = 0.1$ (decreased), $\Upsilon_3 = 0.4$ (increased), $\Upsilon_4 = 0.3$ (decreased),$\Upsilon_5 = 0.1$ (stable). I assume a proportional increase in productivity.
Figure 3.4 shows the effects of this changes over the evolution of the input productivities, the level of employment and the consumption of energy. We can clearly see that incentives to automation has a negative effect on the level of employment, and at the same time increases the consumption of energy. At the same time it has a positive effect on real wages, which are indexed for increase in productivity, resulting in greater demand (and production). At the contrary, green incentives strongly reduces the consumption of energy, and also slows down the automation process, resulting in higher employment. Anyway the increase in the number of jobs do not compensate for the lower salaries, resulting in lower demand and slower growth.

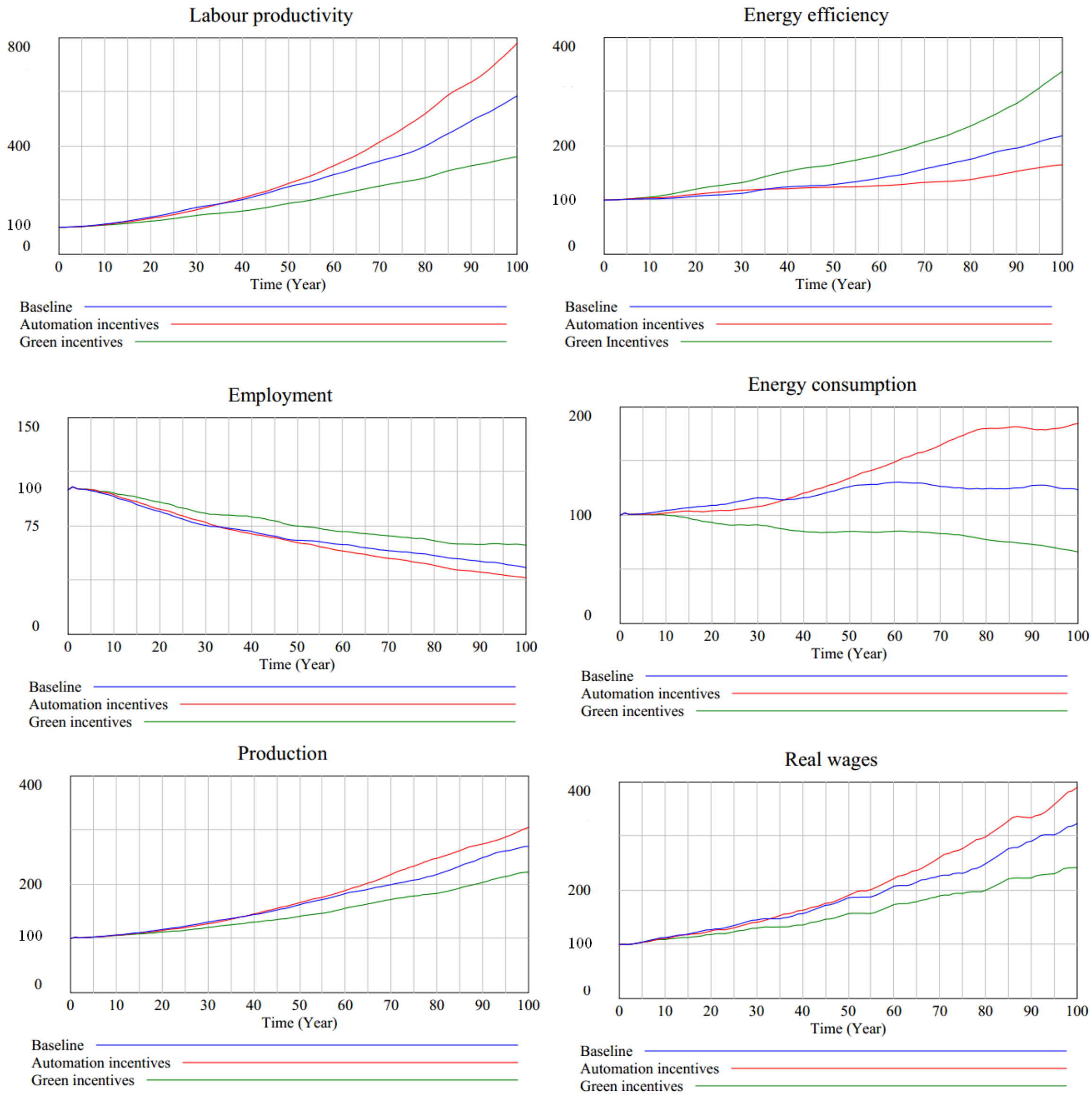


Figure 3.4: Evolution of labour productivity, energy efficiency, employment, energy consumption, production and real wages with different incentive regimes.

Increasing energy prices

Even if the probabilities of the availability of new technological advancements are fixed in this specification, this does not mean that relative prices do not have an influence on the technological path of the economy. Indeed, since firms have often the choice between increasing their labour productivity at the expense of energy efficiency or viceversa (and always the choice to maintain the currently employed coefficients), different scenarios regarding the evolution of real wages or energy prices can strongly affect the outcomes of the simulation. For this reason we may speak of *semi-induced* technological change.

I consider the energy prices to be set exogenously, on the international market. In Figure 3.5 I compare the evolution of labour productivity, energy efficiency, employment and energy consumption in two different scenarios: in the first the international price of energy remain constant, while in the second in increases at an increasing rate.[11]

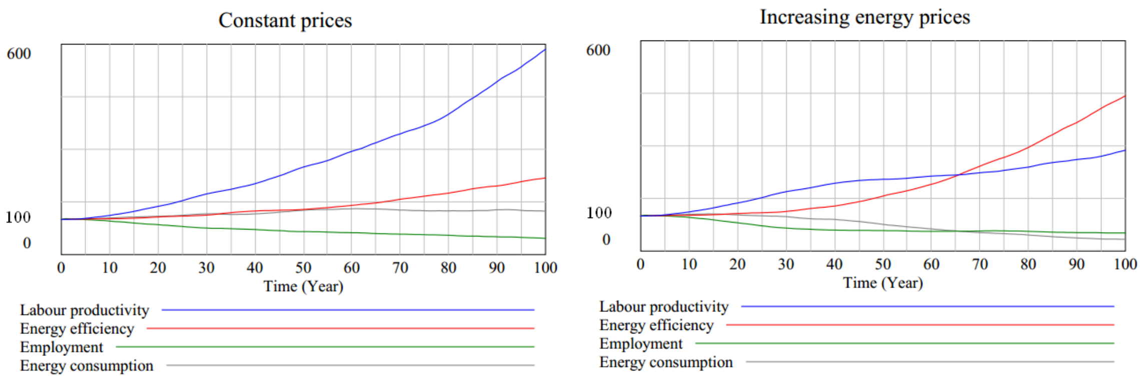


Figure 3.5: Evolution of labour productivity, energy efficiency, employment and energy consumption with different dynamics of energy prices.

It is clear that increasing energy prices has a clear-cut effect of both labour productivity and energy efficiency. In fact it makes much more convenient for firms to implement energy saving investments, which has as a consequence a significant reduction in the consumption of energy. Anyway, the effects on employment are quite ambiguous. Indeed increasing energy prices have two contradictory effects on the number of people employed. On the one hand it disincentives automation, slowing down the expulsion of labour force from the production process. On the other hand it has, predictably, inflationary effects, which reduces aggregate demand and therefore the level of employment. Which effect will prevail depends on many factors, including the choice of technological trajectory. In Figure 3.6 I compare the different effects of increasing energy prices on employment with fixed or proportional productivity increases. In order to exasperate the trade-off between the two kind of investments, I consider a scenario in which the firms have always to choose between keeping the current technology, implementing the technology which will allow less use of labour at the expense of energy efficiency or, on the other hand, the technology which will increase energy efficiency but at the cost of using more labour. This means to set $\Upsilon_1 = \Upsilon_2 = \Upsilon_3 = \Upsilon_5 = 0, \Upsilon_4 = 1$.

[11] I still consider the case of proportional increase in productivity, with the probability distribution used in the baseline case of before.

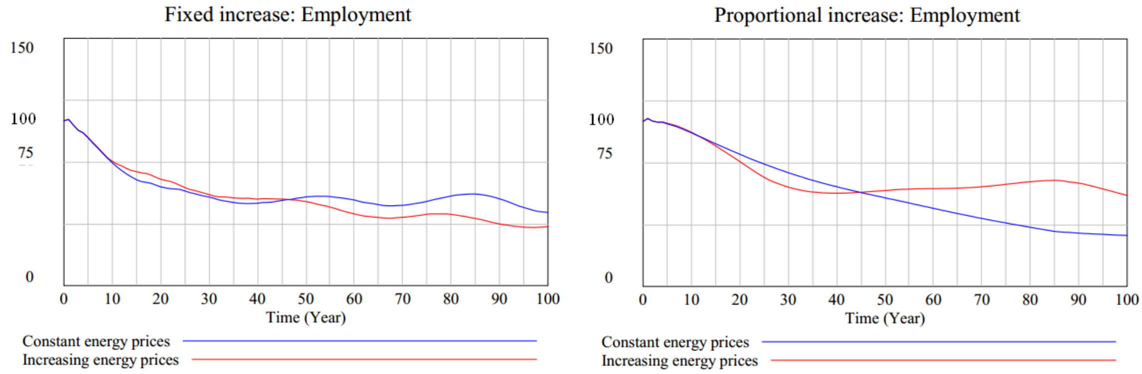


Figure 3.6: Comparison of the effects of increasing energy prices on employment with different technological trajectories.

As we can see in the first case (fixed increases) the positive effect on employment weakly prevails at the beginning, then as the increases become relatively smaller, the lack of demand become stronger. The opposite happens in the proportional increase case: here, as technology improves at a constant rate, energy saving become increasingly convenient, slowing much more the automation process. This leads to substantially higher levels of employment in the long run.

3.3.2 Decreasing bargaining power

As mentioned in section 3.2.4 it is possible investigate how the outcomes changes if I consider that the bargaining power of the workers, in determining the annual salary, is affected by the implementation of a more automated technology. I assume that the more automated the implants are, the less control workers have over the production process, and therefore the smaller their bargaining power is. The coefficient which most represents bargaining power in the model is the one linking the increase in labour productivity to the increase in nominal wage. I start to consider a situation in which such coefficient is equal to one, meaning that all the gains of increased labour productivity go to the workers. I compare then a scenario in which the coefficient remains constant with a scenario in which it decreases as automation increases. The difference between the two cases can be interpreted as different institutional contexts: in the first one the bargaining power of the worker is actively preserved by either the government and/or very strong and conflictual unions, in the second one much less.

Figure 3.7 shows the effects on the different trends of real wages and productivity of labour of setting coefficient from equation (3.21) $\iota = 0$ or $\iota = 0.2$. While with the institutional framework in which workers' bargaining power remain constant the increase in real wages and labour productivity follows an almost identical path, in the second case the advance of automation causes a widening gap between the two.

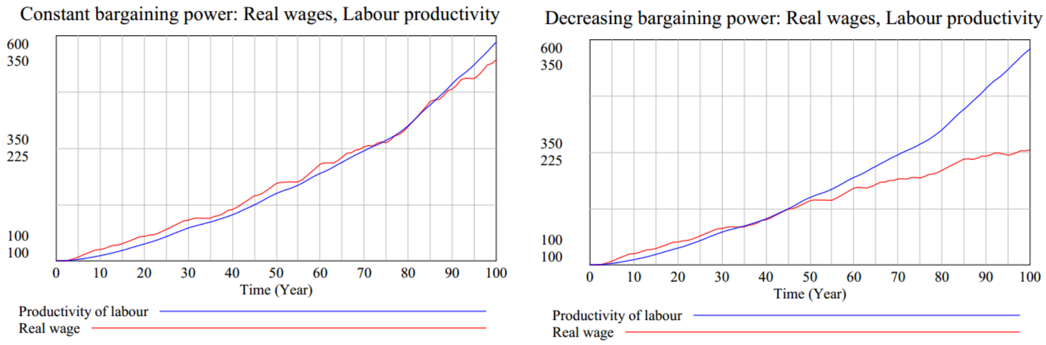


Figure 3.7: Evolution of labour productivity and real wages with or without decreasing bargaining power of the workers.

The loss of bargaining power due to the loss of control over the productive process may concur to explain the actually observed discrepancy between workers' retribution and productivity- see Figure 3.8 or, for a more complete analysis Baker (2007). Bosworth, Barry, Perry, and Shapiro (1994) discuss this "puzzle", since, according to traditional Neoclassical growth theory, growth of labour retribution (which always equals s labour marginal productivity) should, in the long run, equal also the growth of average labour productivity- they do not, anyway, consider the effect of bargaining power. Cooper et al. (2015) discuss instead the role of the erosion of collective bargaining, while Bowles consider the effects of new machinery/technology in the employer-employee relationship- in that case the ability of the employer to control the employee.

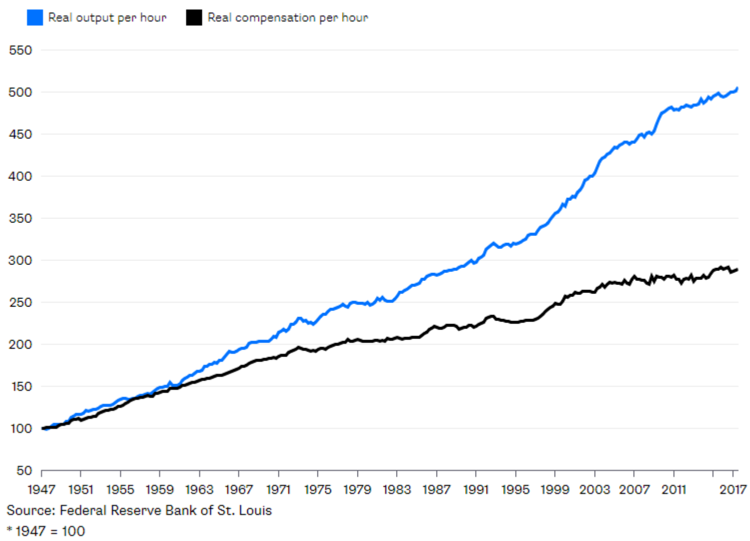


Figure 3.8

3.3.3 Endogenous innovation

In the previous subsection assumed the probability distribution of the available technology improvements to be exogenous. I was able to compare different scenarios resulting from different distribution, but the probability of a technical coefficient to be among the firms' choice was not influenced by other variables in the model. Nevertheless there is a big literature which says that in reality this is not the case, and that technical change is indeed *endogenously* determined. Such literature advocates that the direction of the research in influenced by economic variables, in particular variation of input prices. The rationale behind this is that scientists, either in the public sector or in R&D departments, would have greater incentives to try to develop a technology which would allow a saving of the input whose price is growing faster. For example Popp (2002) finds that energy prices have a strong, positive impact on the number of patents for energy efficient innovations (he considers US patents data between 1970 and 1994).

In the previous section the *path* of technical change was already, as I have shown, influenced by the evolution of prices. This was because I assumed in that case that firms had each period the possibility to choose among either labour-saving or energy-saving technologies. Relative prices influenced then the number of times firms chose one or the other, changing, also drastically, the technological path of the economy. We may talk about *semi-induced* technical change, where the "semi" comes from the fact that the priced did not influence the innovative process *per se*, just the success that an innovation would have.

It is nevertheless possible to modify the model in order to account for a direct influence of prices over our representation of innovation. I assign to each one of the five probabilities corresponding to the five possible state of the world (no innovation, only labour-saving, only energy-saving, both, innovation increasing both productivities:), $\Upsilon_i, i = \{1, 2, 3, 4, 5\}$, a weight variable denoted $\Delta_i, i = \{1, 2, 3, 4, 5\}$ such that

$$\Upsilon_i = \frac{\Delta_i}{\Sigma_{j=1}^5 \Delta_j} \tag{3.43}$$

It is easy to show that the probability of a state is positively related with its own weight, but at a diminishing rate, and negatively related to an other state's weight, also at a diminishing rate.
The weight can be dependent on some variables. In particular consider the variable

$$\chi = \frac{TC_{en}}{TC_l} \tag{3.44}$$

which is simply the ratio between the share of the total cost given by energy expenses (TC_{en}) and the one given by wages (TC_l). Such variable depends clearly on the evolution of the input prices (energy prices and wages) but also on the evolution of the average productivity of the same inputs.

I assume that if this ratio increases (i.e. energy become a larger share of the costs) scientist will tend to develop "greener" technologies, and so it will increase the weight (and the probability) of the state of the world in which only energy-saving innovations are available (i.e. Υ_3 increases); at the contrary, if χ decreases the incentives to create more automated implants will increase, and so Υ_2 will go up.
In particular i set

$$\Delta_2 = \Delta_{2,-1}\{1 + \kappa_0^{\Delta_2} - \kappa_1^{\Delta_2} g_\chi[1 - I(g_\chi > 0)]\} \tag{3.45}$$

$$\Delta_3 = \Delta_{3,-1}\{1 + \kappa_0^{\Delta_3} + \kappa_1^{\Delta_3} g_\chi I(g_\chi > 0)\} \tag{3.46}$$

where g_χ is the percentage variation of χ, $I(g_\chi > 0)$ is an indicator function assuming value 1 if $g_\chi > 0$ and 0 otherwise, $\kappa_1^{\Delta_i}$ $(i = 2, 3)$ are the (positive) coefficients linking the growth of the weights with the growth of χ and $\kappa_0^{\Delta_i}$ $(i = 2, 3)$ are policy variables.

In the Figure 3.9 I compare the evolution of labour productivity, energy efficiency, employment and energy consumption assuming exogenous (semi-endogenous) innovation (left) and endogenous innovation (right). We can see that labour productivity grows much slower in the endogenous case, and the opposite happens to energy efficiency. The reason for that can be seen in Figure 3.10: the share of the total cost used for energy expenses, after an initial short period, starts to grow steadily relatively to the labour share. This pushes up the probability that the only possible innovation would be the energy-saving one, pushing up energy efficiency and down automation.

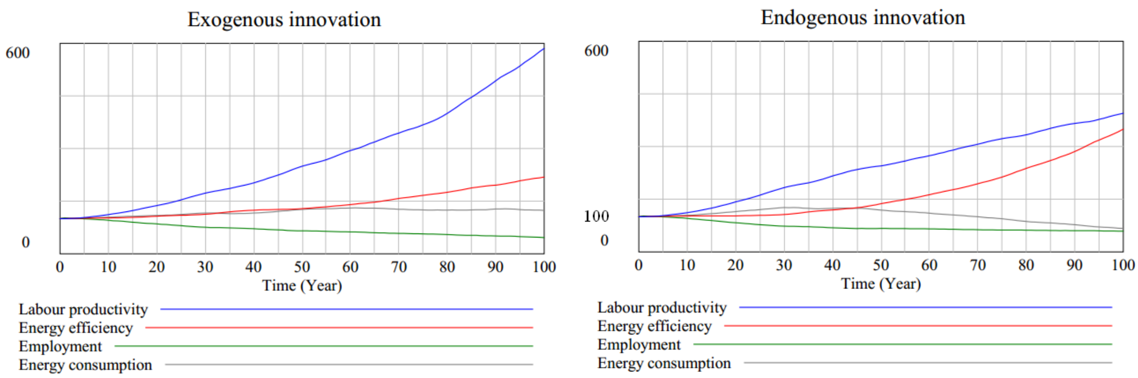


Figure 3.9: Evolution of labour productivity, energy efficiency, employment and energy consumption with exogenous and endogenous innovation.

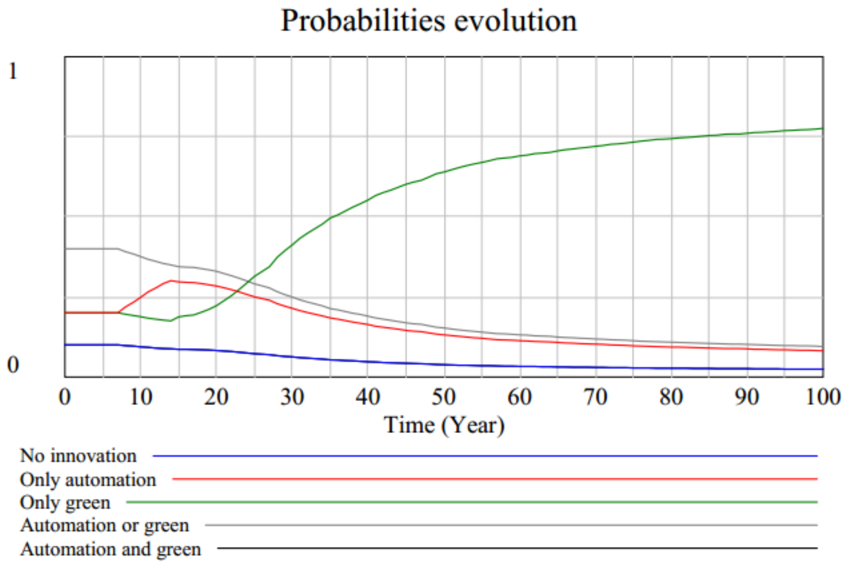


Figure 3.10

We can now replicate the scenarios we analysed in the exogenous case, and see how the endogeneity affects the results

Increasing energy prices

Figure 3.11 shows how the endogeneity assumption influences the effects of increasing energy prices over employment level. I assume proportional increase. In both cases (with constant and increasing relative prices) the level of employment is higher than in the exogenous case. In general we can say that endogeneity strengthen the positive effect that increasing energy prices have over employment: contrary to the case depicted in Figure 3.6, here the level of employment with increasing energy prices is always higher than in the constant prices case. This is due to the strong effect of the change in relative prices over the probability that only energy-saving technologies are available, as depicted in Figure 3.12. We can see, anyway, that actually after an initial period the probability Υ_3 tends to decrease: this is because the fast increase in energy productivity actually has the effect of reducing the share of costs paid for energy expenses. This effect, nevertheless, is not sufficiently strong.

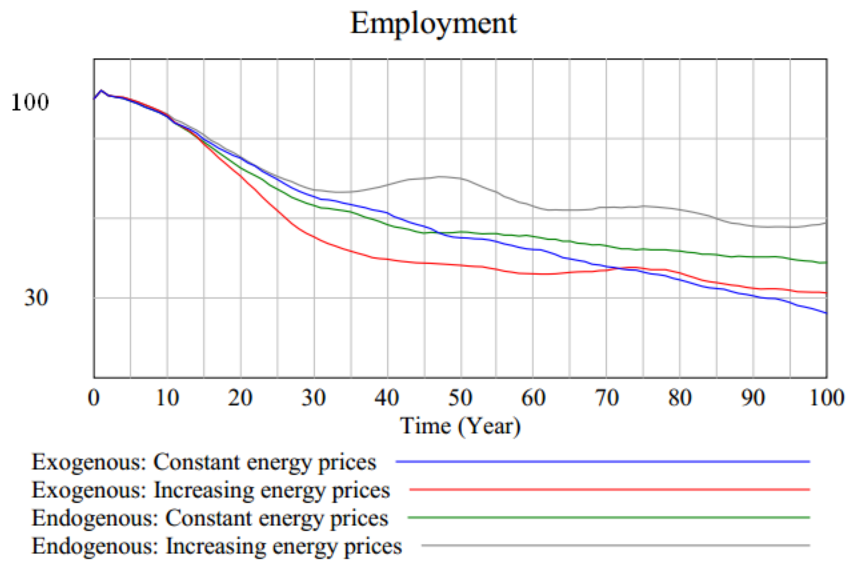


Figure 3.11: Comparison of the effects of increasing energy prices on employment with exogenous and endogenous innovation.

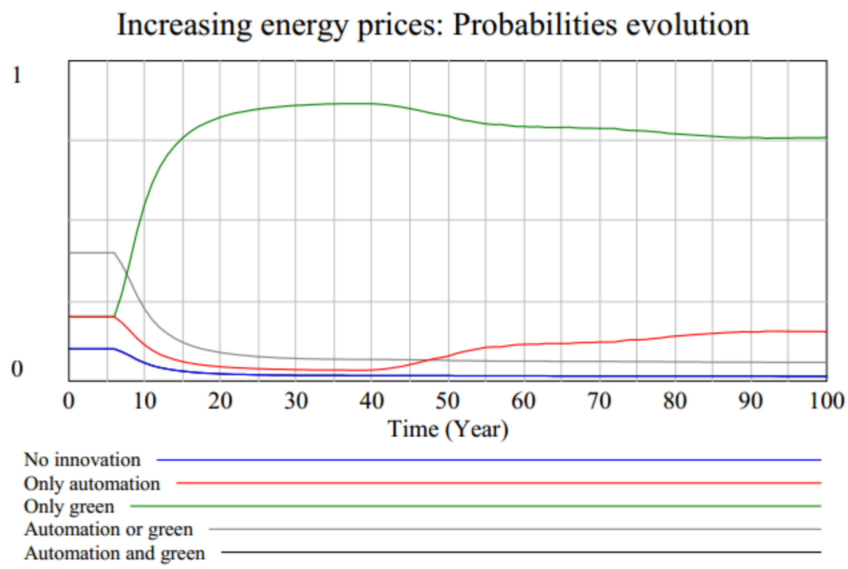


Figure 3.12: Evolution of probabilities with increasing energy prices

Public policies

Le us consider now the effects of possible public incentives towards either automation or green technologies. In this specification this is modelled by setting a positive value for the coefficients $\kappa_0^{\Delta_i}$ $(i = 2, 3)$. The results obtained in the exogenous case in section 3.4 are confirmed: incentives towards automated technologies strongly affect negatively the level of employment, while "green" incentives do the opposite, as seen in Figure 3.13. Again, these effects are stronger than in the previously examined case.

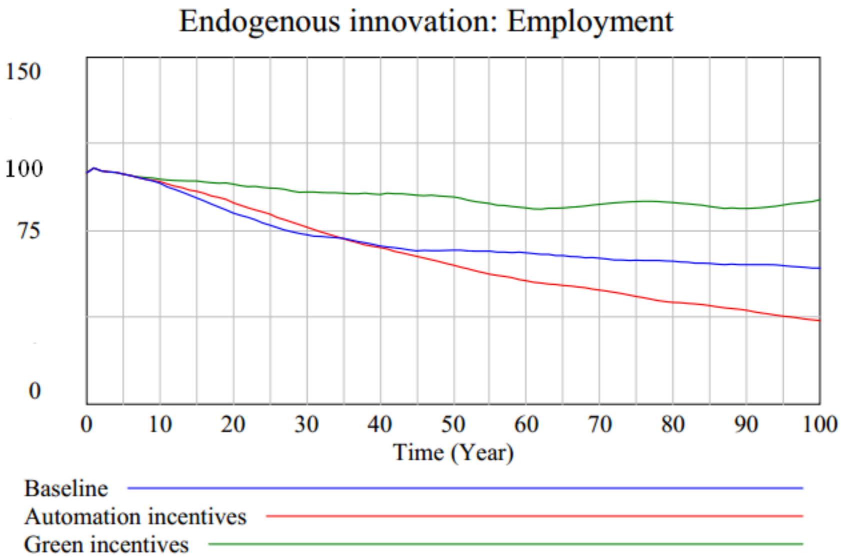


Figure 3.13: Evolution of labour productivity, energy efficiency, employment and energy consumption with different incentive regimes.

3.4 Conclusions

In this paper I investigated the relationship between the increase in productivity of labour and in energy efficiency. The main point that I wanted to underline is that it is adequate to consider the two in conjunction, since their interaction can affect significantly the main economic variables. Assuming that firms may face a trade-off in their investment decisions between improving either one or the other, I explored how this decision may be influenced by a variety of hypothesis regarding possible future scenarios or different theoretical assumptions, and how this would affect the economy in the whole.
The simulations show that public policies may have a great impact in the technological path of the economy. In particular, we have seen that incentives to automation (without other measures of demand stimulus) may have negative effects both on the level of employment, which would decrease, and on the consumption of energy, which would increase, resulting in ecological damage. On the other hand, "green" incentives would both reduce the consumption of energy, by stimulating energy efficiency, and increase the employment, by slowing the automation process. Nevertheless, this would result in a slower growth, given by lower real salaries (which I assumed to be linked to labour productivity). The effect of both cases are strengthen if I assume that the innovation process is induced, i.e. linked to the relative weight that the two inputs have on total

production costs.
I have also analysed the double effect that an increase in energy prices would have on the general level of employment: on one side would reduce it, because it would tamper demand, on the other it would push it up, since it would slow down automation in favour of increased energy efficiency. The final effect would depend on the assumptions made on the technological trajectories of the economy.

The flexibility of the model allows for the analysis of a great variety of different scenarios. Its structure also allows the possibility of future extensions. One of the main limitations of the model is the over-simplified productive sector, which should comprehend more inter-connected sectors. In particular the energy sector should be modelled with greater detail, and the energy price should be determined endogenously in order to have an analysis of a world system. This is left for future efforts.

Appendix: Deposits adjustments

Since workers' deposits are divided between the one belonging to employed and the one belonging to unemployed, some adjustments are needed regarding the flow of deposits. Indeed, since we have every year a number of people who change occupational status, I have to account for the change of denomination of their deposit (from D_U to D_E of vice versa). This is simply done by the use of the variable D in the following way

$$Inflow(D_E) = Y_E + D \tag{3.47}$$

$$Inflow(D_U) = Y_U - D \tag{3.48}$$

where

$$D = \begin{cases} (n_E - n_{E,-1}) \dfrac{D_U}{N_{U,-1}} & if \quad n_E > n_{E,-1} \\ (n_E - n_{E,-1}) \dfrac{D_E}{N_{E,-1}} & if \quad n_E \leq n_{E,-1} \end{cases}$$

At the same time I have to make adjustments also for the annual outflows of deposits. Indeed we have to remember that consumption decisions are made at the beginning of the year on the basis of the previous year's income. From this decisions derives the aggregate demand, and then the employment level, and so the income perceived by workers. The deposit variation, nevertheless, is computed at the end of the year. It is as if the workers could buy the desired good at the beginning of the period with a credit card, and the value of the good would actually be withdrawn by their current account at the end of the period, when they receive their wage/benefit. Anyway, since a worker may have changed occupational status during the year, I have to make sure that her consumption is withdrawn from the right current account. This is done determining the deposit outflows in the following way.

If $n_E > n_{E,-1}$

$$Outflow(D_E) = n_{E,-1}\frac{C_E}{n_{E,-1}} + (n_E - n_{E,-1})\frac{C_U}{n_{U,-1}} \tag{3.49}$$

$$Outflow(D_U) = n_U\frac{C_U}{n_{U,-1}} \tag{3.50}$$

If $n_E \leq n_{E,-1}$

$$Outflow(D_E) = n_E\frac{C_E}{n_{E,-1}} \tag{3.51}$$

$$Outflow(D_U) = n_{U,-1}\frac{C_U}{n_{U,-1}} + (n_U - n_{U,-1})\frac{C_E}{n_{E,-1}} \tag{3.52}$$

Finally, I have to account for interest rates payment. Indeed an individual receives a rent on the basis of the amount of her deposit in the previous year. But in the current year he may have changed occupational status. This is fixed in the following way: denote DF_i,$i = \{E, U\}$ the amount of deposits on which the two kinds of workers receive the interests over. This variable assume the value If $n_E > n_{E,-1}$

$$DF_E = D_E + D \tag{3.53}$$

$$DF_U = \frac{n_U}{n^{U,-1}}D_U \tag{3.54}$$

If $n_E \leq n_{E,-1}$

$$DF_E = \frac{n_E}{n_{E,-1}}D_E \tag{3.55}$$

$$DF_U = D_U - D \tag{3.56}$$

Bibliography

Acemoglu, Daron, and David Autor. "Skills, tasks and technologies: Implications for employment and earnings." Handbook of labor economics. Vol. 4. Elsevier, 2011. 1043-1171.

Apostolos, Fysikopoulos, et al. "Energy efficiency of manufacturing processes: a critical review." Procedia CIRP 7 (2013): 628-633.

Arntz, Melanie, Terry Gregory, and Ulrich Zierahn. "The risk of automation for jobs in OECD countries: A comparative analysis." OECD Social, Employment, and Migration Working Papers 189 (2016): 0-1.

Baker, Dean. "The productivity to paycheck gap: what the data show." Washington, DC: Center for Economic and Policy Research (2007).

Bardi, Ugo. "Energy prices and resource depletion: lessons from the case of whaling in the nineteenth century." Energy Sources, Part B 2.3 (2007): 297-304.

Bassi, Andrea M., Joel S. Yudken, and Matthias Ruth. "Climate policy impacts on the competitiveness of energy-intensive manufacturing sectors." Energy Policy 37.8 (2009): 3052-3060.

Baumol, William J. "Productivity growth, convergence, and welfare: what the long-run data show." The American Economic Review (1986): 1072-1085.

Baumol, William J. *The free-market innovation machine: Analyzing the growth miracle of capitalism.* Princeton university press, 2002.

Bernardo, Giovanni, and Simone D'Alessandro. "Systems-dynamic analysis of employment and inequality impacts of low-carbon investments." Environmental Innovation and Societal Transitions 21 (2016): 123-144.

Bosworth, Barry, George L. Perry, and Matthew D. Shapiro. "Productivity and real wages: is there a puzzle?." Brookings Papers on Economic Activity 1994.1 (1994): 317-

344.

Bowles, Samuel. Microeconomics: behavior, institutions, and evolution. Princeton University Press, 2009.

Bowles, Samuel, and Robert Boyer. "Labor discipline and aggregate demand: a macroeconomic model." The American Economic Review 78.2 (1988): 395-400.

Bowles, Samuel, and Robert Boyer. "A wage-led employment regime: Income distribution, labour discipline, and aggregate demand in welfare capitalism." The Golden Age of Capitalism. Oxford: Clarendon (1990).

Braveman, Harry. "Labor and monopoly capital." New York: Monthly (1974).

Brown, Stephen PA, and Mine K. Yücel. "Energy prices and aggregate economic activity: an interpretative survey." The Quarterly Review of Economics and Finance 42.2 (2002): 193-208.

Brynjolfsson, Erik, and Andrew McAfee. "The second machine age: Work, progress, and prosperity in a time of brilliant technologies." WW Norton & Company, 2014.

Brynjolfsson, Erik, and Andrew McAfee. "Race against the machine: How the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy." Brynjolfsson and McAfee, 2012.

Brugger, Florian, and Christian Gehrke. "The neoclassical approach to induced technical change: From Hicks to Acemoglu." Metroeconomica 68.4 (2017): 730-776.

Calel, Raphael, and Antoine Dechezlepretre. "Environmental policy and directed technological change: evidence from the European carbon market." Review of economics and statistics 98.1 (2016): 173-191.

Cooper, David, and Lawrence Mishel. "The erosion of collective bargaining has widened the gap between productivity and pay." Economic Policy Institute, Washington, DC. (2015).

Dafermos, Yannis, Maria Nikolaidi, and Giorgos Galanis. "A stock-flow-fund ecological macroeconomic model." Ecological Economics 131 (2017): 191-207.

D'Alessandro, Simone. "Modello di Macroeconomia Ecologica per la Transizione Energetica (2METE): Scenari alternativi per la sostenibilità ecologica e." (2017).

Frey, Carl Benedikt, and Michael A. Osborne. "The future of employment: how susceptible are jobs to computerisation?." Technological Forecasting and Social Change 114 (2017): 254-280.

Groppi, Tania. The Impact of the Financial Crisis on the Italian Written Constitution. 2012.

Godin, Antoine. "Green Jobs for full employment, a Stock Flow Consistent analysis." Employment Guarantee Schemes. Palgrave Macmillan, New York, 2013. 7-46.

Grubb, Michael, and J. Kohler. "Induced technical change: Evidence and implications for energy-environmental modelling and policy." No. 0031. Faculty of Economics, University of Cambridge, 2000.

Hesselbach et Al., "A Practical Guide to Energy Efficiency in Production Processes", printed by Werbedruck Schreckhase, Spangenberg for the Hessian Ministry of Economics, Transport, Urban and Regional Development, 2011

Hubbert, M. King. "Nuclear energy and the fossil fuel." Drilling and production practice. American Petroleum Institute, 1956.

Jackson, Tim, Peter Victor, and Asjad Naqvi. "Towards a stock-flow consistent ecological macroeconomics." No. 114. WWWforEurope Working Paper, 2016.

Keiser, Norman F. "The Development of the Concept of “Automatic Stabilizers”." The Journal of Finance 11.4 (1956): 422-441.

Keynes, John Maynard. "Economic possibilities for our grandchildren (1930)." Essays in persuasion (1933): 358-73.

Krugman, Paul, and Richard Layard. "A manifesto for economic sense." Financial Times 27 (2012).

Kurz, Heinz D. "Accumulation, effective demand and income distribution." Beyond the Steady State. Palgrave Macmillan, London, 1992. 73-95.

Lavoie, Marc, and Wynne Godley. "Kaleckian models of growth in a coherent stock-flow monetary framework: a Kaldorian view." Journal of Post Keynesian Economics 24.2 (2001): 277-311.

Ledvina, Andrew Fabian, and Ronnie Sircar. *Bertrand and Cournot competition under asymmetric costs: number of active firms in equilibrium.* (2011).

Leontief, Wassily W., Wassily Leontief, and Faye Duchin. "The future impact of automation on workers." New York: Oxford University Press, 1986.

Maddison, Angus. "Phases of capitalist development." Vol. 40. Oxford: Oxford University Press, 1982.

Manyika, James, et al. "Jobs Lost, Jobs Gained: workforce transitions in a time of automation." McKinsey Global Institute (2017).

Martinez-Alier, Juan. "Ecological economics and eco-socialism." Capitalism Nature Socialism 1.2 (1988): 109-122.

Marx, Karl. "Capital, volume I." (1867).

Marx, *Karl. Capital: a critique of political economy; vol III the process of capitalist production as a whole*, 1867.

MISE-Ministero dello sviluppo economico (2018). "La diffusione delle imprese 4.0 e le politiche: evidenze 2017." Available at: URL http://www.sviluppoeconomico.gov.it/images/stories/documen
MiSE-MetI40.pdf(2018-09-07).

Muthoo, Abhinay. Bargaining theory with applications. Cambridge University Press, 1999.

Organization for Economic Co-operation and Development, Early Estimate of Quarterly ULC Indicators: Total Labor Productivity for the United States [ULQELP01USQ657S], retrieved from FRED, Federal Reserve Bank of St. Louis;
https://fred.stlouisfed.org/series/ULQELP01USQ657S, January 26, 2019.

Oswald, Andrew J. "The microeconomic theory of the trade union." The Economic Journal 92.367 (1982): 576-595.

Pindyck, Robert S. "The long-run evolution of energy prices." The Energy Journal (1999): 1-27.

Popp, David. "Induced innovation and energy prices." American economic review 92.1 (2002): 160-180.

Schumpeter, Joseph A. *Capitalism, socialism and democracy* Routledge, 2013.

Singh, Nirvikar, and Xavier Vives. *Price and quantity competition in a differentiated duopoly.* The RAND Journal of Economics (1984): 546-554.

Stern, Nicholas. "The economics of climate change." American Economic Review 98.2

(2008): 1-37.

Stiglitz, Joseph E. "Europe's austerity zombies." Project Syndicate, September 26 (2014).

Stocker et Al., "The interaction of resource and labour productivity", on behalf of the European Commission, 2015

Sylos Labini, Paolo. "Oligopolio e progresso tecnico." (1957).

Sylos-Labini, Paolo. Nuove tecnologie e disoccupazione. Bari: Laterza, 1989.

Yamaguchi, Kaoru. "Money and Macroeconomic Dynamics." Awaji Island, Japan: Japan Future Research Center (2014).

Zanchettin, Piercarlo. *Differentiated duopoly with asymmetric costs.* Journal of Economics & Management Strategy 15.4 (2006): 999-1015.