Labour Market Rigidity and Economic Efficiency with Non-General Purpose Technical Change

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LABOUR MARKET RIGIDITY AND ECONOMIC EFFICIENCY WITH NON-GENERAL PURPOSE TECHNOLOGICAL CHANGE

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Abstract

The contrasting effects of labour market rigidity on efficiency are investigated in a model where technological change is non-general purpose and different types of skills are available to workers. *Ex ante* efficiency calls for high labour market rigidity, as this favours workers' acquisition of specific skills which have higher productivity in equilibrium. E*x post* efficiency calls for low market rigidity, as this allows more workers to transfer to the innovating sector of the economy. The trade-off between these two mechanisms results in an inverse-U shaped relationship between output and labour market rigidity, which implies that a positive level of labour market rigidity is in general beneficial for the economy.

Keywords: Non-general purpose technology, labour market rigidity, specific and general human capital.
JEL classification: J24, J31, O30

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1 Introduction

Labour market rigidity has been studied extensively over the last decades in relation to the allegedly poor performance of continental Europe labour markets in comparison to that of Anglo-Saxon countries. The various aspects that contribute to make a labour market rigid have been analysed, generally leading to negative conclusions as to their effects[1]. A strand of this literature has focused on the impact of labour market rigidity on labour productivity, reaching similar conclusions. It has been argued that rigidity contributes to keep less productive firms in the market, in addition to generating rents for employed workers at the expense of the unemployed. A reduction in rigidity will thus cause the replacement of less productive firms with more productive ones (Saint-Paul, 2002). This will boost both average productivity and total output, although the consequences for overall employment may be ambiguous. At the industrial level, rigidity may slow down the transfer of workers from declining to dynamic sectors of the economy by increasing reallocation costs, thus holding up economic growth (Hopenhain and Rogerson, 1993).

Even if some voices have been raised against this general view[2], the idea that a reduction in labour market rigidities will engender beneficial effects for the economy has received widespread support among labour market scholars. However, even a superficial look at the reality of the OECD economies shows that this general wisdom is not as clear-cut as it may seem. As commented at greater length in section 2, the presence of a negative relationship between productivity and labour market rigidity does not seem to emerge from the available data. On the contrary, the descriptive evidence shows non-linearities and countries at medium-high levels of rigidity seemingly outperforming others in terms of productivity performance (see section 2: Figure 1).

The aim of this paper is to build a theoretical model addressing the relationship between productivity and labour market rigidity from the angle of technical change and incentives in skills acquisition. The focus is on non-general-purpose technical innovations, which generate a non-obvious trade-off in workers' choice between specific vis-à-vis general skills. In spite of its extreme simplicity, the model is able to generate non-linearities in the relationship between productivity and labour market rigidity, which makes positive levels of rigidity generally *beneficial* for the economy's efficiency.

The model draws on two basic notions. First, the treatment of the institutional features of the labour market is carried out in conjunction with the classic distinction, originally put forward by Becker (1964), between specific and general skills. The former are skills that may mainly be used by a worker in relation to a specific firm, whereas the latter refer to skills that may be transferred across firms. The first mechanism that is analysed is that rigid labour markets should foster workers' incentives to invest in firm-

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[1] Some of the aspects that have been analysed are firing costs (Bentolila and Bertola, 1990), the unemployment benefit system (Layard et al., 1991), the loss of human capital during unemployment spells (Ljungqvist and Sargent, 2002), insider-outsiders relations (Blanchard and Summers, 1987), the inability of systems to adjust either to macroeconomic shocks (Blanchard and Wolfers, 2000) or to microeconomic ones (Gottshalk and Moffitt, 1994).

[2] Atkinson (1999) has objected that the rolling back of the welfare state to which the process of liberalization would lead may in fact decrease labour markets efficiency. Layard and Nickell (1998) conclude that the empirical evidence on the negative impact of labour market rigidity is limited to some institutions, mainly unemployment benefits and strong and uncoordinated unions, but is at best weak for the remaining ones. Others have pointed to the social costs associated with market liberalization (Rodrik, 1997), and have noted that welfare institutions tend to be larger in more open countries, thus underlining their positive function in absorbing macroeconomic shocks (Agell, 1999).

specific rather than general human capital, because of the reduced probability of the worker being dismissed by a firm. The reason is obviously that workers being made redundant will see firm-specific human capital become idle, as that may not be used in other firms[3]. It is clear that, *if there was no need for workers to change their jobs over time*, the situation in which all workers acquired firm-specific skills would maximise total output, as by definition these would permit higher productivity at the firm-level than general skills. Therefore, one consequence of labour market rigidity is that it should lead to higher firm-level productivity, and thus to higher output in the economy.

However, workers do need to change their jobs, mainly in relation to processes of technological progress and structural change taking place in the economy. The second mechanism that the model takes into account is related to the treatment of technological progress. Almost all of the mainstream literature takes technologies to be general purpose (GP), that is, applicable to the whole set of techniques currently available (see e.g. Barro, 1995). General purpose technologies (GPTs) have certainly had a major role in the experience of developed economies over the recent years. Information Technologies are a typical example of GPT given their wide range of applicability across industries and jobs, and the scope of the transformations associated with their implementation is all too clear. However, it is also apparent that technological progress has a strong sector-specific and firm-specific component (see e.g. Petit and Soete, 2001; Metcalfe, 1998; Pavitt, 1984), partly due to the tacit nature of technological knowledge (Nelson and Winter, 1982; Dosi, 1988; Vivarelli, 1995)[4]. In spite of the obvious practical relevance of the idea of non-GPTs, only rarely has this approach been investigated in the theoretical literature, exceptions being the seminal work of Atkinson and Stiglitz (1969), and the model of Violante *et al.* (2002) in their account of wage inequalities within a model of growth.

Taking into account this idea is crucial in the present model because the uneven distribution of non-GPTs innovations across economic sectors call for relevant structural adjustments in the allocation of the workforce for efficiency reasons. Output gains for the economy may be brought about by reallocating workers from those technologies that have failed to innovate into those that have successfully innovated. The distinction between general and specific skills is relevant in this respect, because workers having acquired general skills should have a greater ability to move across sector thanks to the greater transferability of their human capital in comparison with specific skill workers. In this case, greater labour market flexibility should facilitate such workforce cross-sector adjustments, thus engendering productivity gains for the economy.

Therefore, a trade-off arises in the model between what are defined *ex ante* and *ex post* efficiency, where the two concepts of efficiency refer to the time where a non-GP innovation occurs. The former requires more workers to acquire specific skills, as this boosts firm-specific skills and thus raises overall productivity *before* a non-GP innovation takes place. On the other hand, *ex post* efficiency calls for more workers to acquire general skills, as this enables more workers to move to the innovating sector *after* a non-GP innovation has occurred. Consequently, higher labour market rigidity has a positive (negative) effect on *ex ante* (*ex post*) efficiency. The resulting relationship between rigidity

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[3] Firms too will have fewer incentives to impart on-the-job training leading to specific human capital in more slack labour markets, given the higher probability of losing this investment should the worker leave the firm. This model will not take into account the latter aspect, as it will only focus on workers' incentives.

[4] General purpose (GP) and non-general purpose innovations are likely to be interlinked. The introduction of a GPT is likely to generate different paths of technical innovations in different sectors and different firms, thus triggering what are in fact non-GP innovations.

and total output is thus non-linear, and gives rise to an inverse-U shaped pattern, with *ex ante (post)* efficiency being predominant at low (high) values of rigidity.

The existing literature has generally considered these two mechanisms only separately, thus reaching only partial results. Saint-Paul's (2002) is a typical example of a model only taking into account *ex post* efficiency. Studies that have analysed the *ex ante* efficiency link are for instance those of Wasmer (2002), who investigates the structural parameters of the labour market favouring the acquisition of specific as opposed to general skills, so that two different steady states emerge. In his model the acquisition of specific (general) skills is favoured by less (more) changeable environments. Belot *et al.* (2007) use a model with non-contractible specific investments, and show that increasing firing costs may raise welfare by reducing the likelihood of separation and thus prompting the worker to increase her firm-specific effort level. A necessary condition for this to be the case is that the worker can appropriate at least part of the surplus increase produced by increased effort, so their analysis may not extend to labour markets where this condition does not hold. In Ljungqvist and Sargent (2002) a 'laissez-faire' and a 'welfare-state' economy emerge as possible equilibria of their model where the key mechanism is the loss of human capital during unemployment spells. Jovanovic and Nyarko (1996) focus on the trade-off between expanding the knowledge of an existing technology versus opting for a newer technology. Depending on the degree of transferability of one's skills towards the latest technology, a worker may be locked into an old technology although technologies with higher profitability are available in the economy.

Unlike these approaches, the present model is capable of taking into account both the *ex ante* and *ex post* efficiency factors in a unified framework, thus offering a more comprehensive – and at the same time simple - interpretative model of reality. Moreover, it innovates on the existing literature by considering workers' choice on their skills in relation to non-GP innovations. The structure of the paper is as follows. Section 2 presents some descriptive evidence over the relation between productivity and labour market rigidity for a sample of OECD economies. Section 3 illustrates the model and puts forward the equilibrium conditions. Section 4 studies the impact of a change in labour market rigidity on the steady state of the economy, and discusses its effects on production. Section 5 concludes and suggests possible extensions of the model

2 Some Descriptive Evidence of the Relation Between Productivity and Market Rigidity

The most commonly used indicator of market rigidity is the OECD Employment Protection Legislation Index (EPLI), which measures various aspects of the costs that a firm has to sustain for workers' layoffs – both for individual and collective dismissals - as well as how easy it is to hire on temporary contracts (OECD, 2004: Chapter 2). Aggregate productivity is calculated as GDP per hour of work. Figure 1a-c report some scatterplots of the mean productivity levels over three different 5-year spells against the EPLI for a sample of OECD economies. These spells are centred around the three years in which the EPLI has been issued by the OECD (1990, 1998, 2003).

Overall, the presence of a negative relation between productivity and market rigidity does not seem to receive support from these data. In the 1988-1992 spell, countries appear to be clustered around two groups with low and high rigidity, but no significant difference in productivity emerges – and, if anything, this favours countries with higher rigidity. In the 1996-2000 spell, the distinction between the two groups become less clear – partly because of the new countries entering the sample - and finding a clear-cut relationship becomes difficult. Most countries with poor productivity performance have relatively high rigidity levels, but at the same time the countries with best productivity levels have middle-high levels of rigidity – i.e. Norway, Belgium, the Netherlands. The same pattern continues during the 2001-2005 spell, with the performance of the set of countries with medium-high rigidity levels even improving with respect to the rest of the group in comparison with the previous spell.

A median spline interpolation of the observations has been added to investigate the presence of non-linearities in the relationship. This curve always reaches it maximum in correspondence of medium-high levels of rigidity, thus confirming the impression gathered above. The peak is particularly pronounced in the most recent spell, whereas a decreasing trend in the first portion of the curve – quite notable in the first spell – points to the fact that very low rigidity may be more productivity-enhancing than medium-low rigidity.

A basic polynomial econometric model has been run with mean labour productivity as dependent variable and the EPLI terms as regressors. Given the paucity of observations, this analysis has no purpose of generality, but it serves as a basic check for the statistical significance of the patterns observed above. The results are shown in Table 1. The analysis conducted shows that the model arrested to the cubic term is the best within the polynomial class, and is able to explain a substantial amount of the overall variance – ranging from 17% for the 1996-2000 spell (Table 1, column 3) to 63% for the 1988-1992 spell (Table 1: column 1). The coefficients of the linear, quadratic, and cubic terms are all significant (Table 1: columns 1, 3, 5). The fact that the signs of the linear and the cubic terms are negative, whereas that of the quadratic term is positive, confirms the decreasing trend in the medium-low portion of the rigidity scale, which is overturned in the medium-high section of the interval. The negative sign of the cubic term highlights the bad performance of countries with high levels of rigidity. This model loses some significance when the level of GDP is controlled for, but the coefficients remain at least weakly significant in all of the three spells (Table 3: columns 2, 4, 6).

Furthermore, countries that liberalised their labour markets do not seem to have improved their performance over time. Figures 2 plots the changes in the labour productivity growth rates between subsequent decades against changes in the EPLI. A negative value for the EPLI variation means that a country's labour market became less rigid according to the OECD indicator. Countries that liberalised their labour markets in the 90's seem in general to have performed *worse* than in the previous decade in terms of productivity growth rates, and less well than countries that did not liberalise (Figure 2a). In particular, the Netherlands, Italy, Denmark, Belgium, and Spain all markedly reduced their labour market rigidity, but their productivity growth rates *dropped* in comparison to the previous decade. That of Germany marginally increased, whereas Sweden is the only case of a clear 'success'. In the 2000-2005 period, fewer countries liberalised, and on a lower scale than in the previous decade. More countries chose to reverse the trend and made their labour markets *more* rigid. Even in this case, the evidence does not support the idea that liberalisation helped improve the productivity performance (Figure 2b).

Although the diagrammatical analysis is at best merely descriptive, and the paucity of observations prevent the generalisability of the econometric analysis, the thesis that lower levels of rigidity conduct to better productivity performance does not appear to be supported by this evidence. Furthermore, the presence of non-linearities and of a peak in the middle-high region of EPLI seems to point to the existence of contrasting forces that may affect the relationship between labour market rigidity and productivity growth. Although the model developed in the next section is too general to be thought of as 'explaining' these stylised facts, its capacity of generating non-linearities supports the view that its underlying mechanisms may indeed be at work in reality.

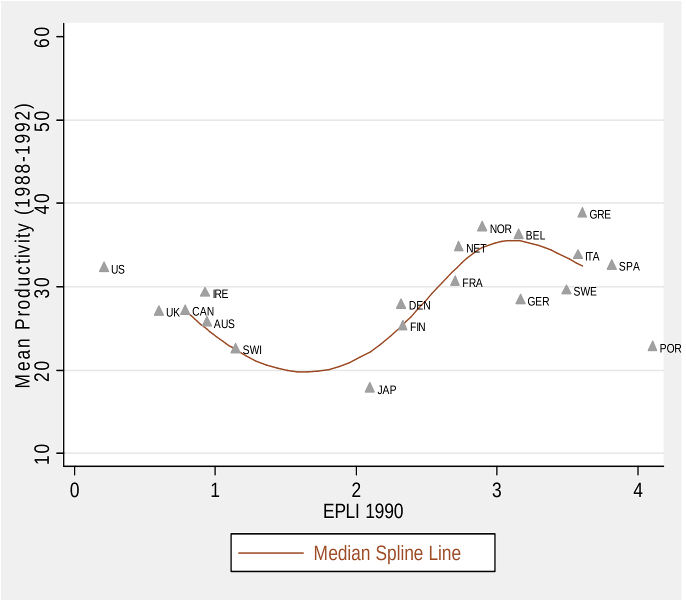

Figure 1a

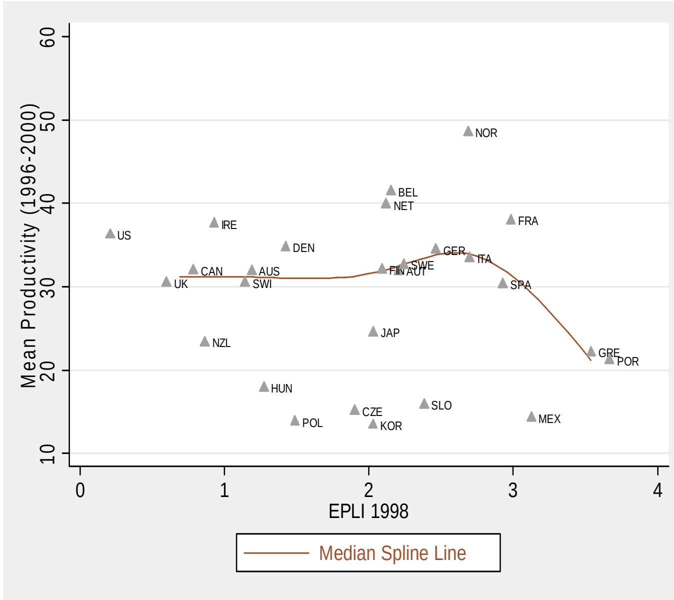

Figure 1b

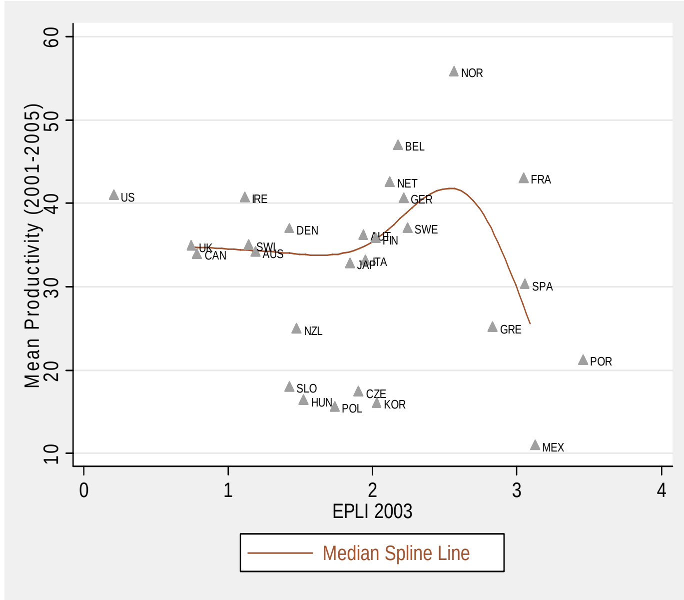

Figure 1c

Figure 1: Labour Productivity and Labour Market Rigidity over Three 5-Year Spells

Sources: Data for productivity are taken from OECD, Statistics Portal. Data for the EPLI are from OECD.stat, v.3.2. Data refer to the Overall EPL, version 1.

Notes: Labour productivity is defined as GDP per hour worked; GDP is Gross Domestic Product expressed in current US Dollars at PPP. Labour input is defined as total hours worked of all persons employed. The data are derived as average hours worked from the OECD Employment Outlook, OECD Annual National Accounts, OECD Labour Force Statistics and national sources, multiplied by the corresponding and consistent measure of employment for each particular country

Dependent variables	Mean Productivity (1988-1992)		Mean Productivity (1996-2000)		Mean Productivity (2001-2005)	
	(1)	(2)	(3)	(4)	(5)	(6)
EPLI – LINEAR TERM	-6.781	-60.89	-34.556	-6.706	-55.165	-65.05
	(1.818)***	(8.639)***	(16.159)**	(-4.971)	(20.474)**	(-34.137)*
EPLI – QUADRATIC TERM	11.538	6.893	23.855	40.238	39.304	45.816
	(2.895)***	(0.905)***	(11.080)**	(-22.995)*	(14.846)**	(-23.801)*
EPLI – CUBIC TERM	-4.838	-4.178	-11.432	-13.038	-19.454	-22.499
	(1.158)***	(0.544)***	(5.205)**	(-7.179)*	(7.345)**	(-11.517)*
GDP		-0.003		-0.001		-0.001
		(0.001)***		-0.001		-0.001
Constant	25.904	25.999	27.371	26.961	31.112	30.547
	(1.726)***	(0.753)***	(2.818)***	(2.887)***	(2.635)***	(2.762)***
Observations	19	19	27	27	27	27
R-squared	0.63	0.77	0.16	0.17	0.21	0.21

Table 1: Econometric Analysis of the Relation Between Productivity and Labour Market Rigidity

Sources: OECD Stats Portal for GDP. See notes to Table 1 for EPL and Productivity.
Notes: Robust standard errors in parentheses; * significant at 10% level ; ** significant at 5% level; *** significant at 1% level.
The EPL variables are derived from the EPL index for the year in the middle of the corresponding spell for the dependent variable. That is, for the regressions having the mean productivity over the 1988-1992 spell as dependent variable, the EPL computed in 1990 has been used to derive the linear, quadratic, and cubic terms of the EPLI. Likewise, GDP is measured in the same year as the EPLI.

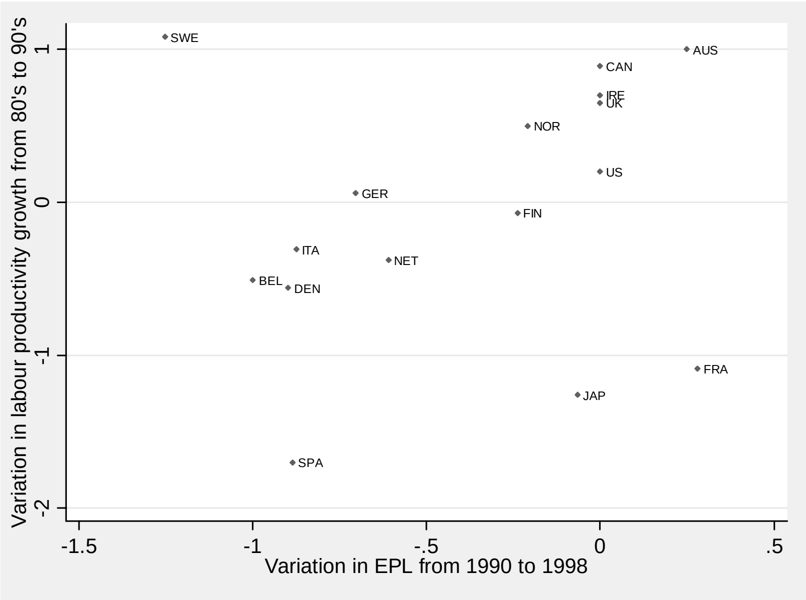

Figure 2a

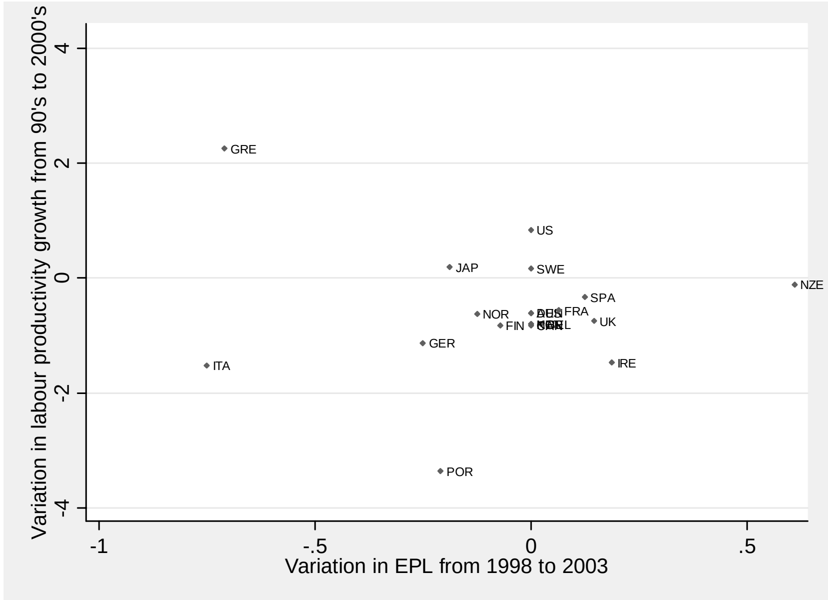

Figure 2b

Figure 2: Labour Market Liberalization and Changes in Labour Productivity Growth

Sources: See Figure 1

3 The Model

3.1 General Features

The model developed basic assumptions are that two different technologies are available to produce a certain commodity, and that technological change is *not* GP. That is, innovations occurring for a technology cannot be used to improve the productivity of the other. I model technological change by assuming that a technical innovation occurs for just one of the two technologies, with even probability for this event to happen. In other words, although there is certainty that an innovation will occur, it is *a priori* unknown for which technology the innovation will take place. The model is static and thus abstracts away from dynamic economies of scale, which may make innovations more or less likely in one of the two sectors depending on the past history of technical progress. Technologies are exactly equivalent prior to the occurrence of the innovation.

Workers of this economy may choose between *specific* and *general* skills. Specific skill workers are highly specialised in the use of one of the two technologies, but little specialised in the other. Conversely, general skill workers do not acquire any technique-specific specialisation, so that their productivity is, *ceteris paribus*, the same in the two techniques. A crucial assumption made is that specific skill workers have to pay a cost before acquiring their technique-specific specialisation. This should be regarded as a payment for the training they receive in the use of the technique in which they become specialised. In turn, the use of specific skill workers makes a certain technology *ceteris paribus* more productive than when general skill workers are employed. This means that *total factor* productivity is higher when specific skill workers are employed. Since it is assumed that returns to scale are decreasing in labour, the same may not necessarily be true for *marginal* productivity. However, as will be demonstrated, the entry cost for specialised workers makes their average wage higher than that of general skill workers in equilibrium. This creates a gap in the marginal productivity of specific and general skill labour that advantages the former. As a result, the marginal productivity of specific skilled labour will in general be higher than that of general skill workers.

Specific skill workers may be seen as the workers 'elite', in that they receive more years of training – or a more intensive educational activity - and are thus better able to boost production in a certain sector. However, a general skill worker is able to transfer her skills across the two technologies more easily than a specific skill worker. For simplicity, I assume that specific skill workers may only be employed in one technology, whereas general skill workers may migrate across the two technologies, up to a transfer cost. Another way to look at this assumption is to think that a specific skill worker executes a specific investment in the firm at which she is hired, which makes it economically unprofitable to switch to the alternative technology. Workers have to choose in which technological sector to locate prior to receiving their training. Being the individual probability of innovation equal to ½, agents are indifferent as to which technological sector to choose, so that they will distribute equally across the two sectors. In this version of the model, it is assumed that managers may not move across sectors.

The timing of the model is described in Figure 3. First, agents decide which technological sector to enter. For the law of large numbers workers will distribute evenly across the two sectors. They then decide whether to acquire technology-specific or general skills. Their type of skill remains fixed thereafter. Once such a choice has been made, a worker joins a firm. Subsequently, workers observe in which technique the innovation has occurred, and general skill workers may decide to migrate towards the alternative sector upon the payment of a transfer cost. At this point, production occurs and wages are paid according to workers' marginal productivity.

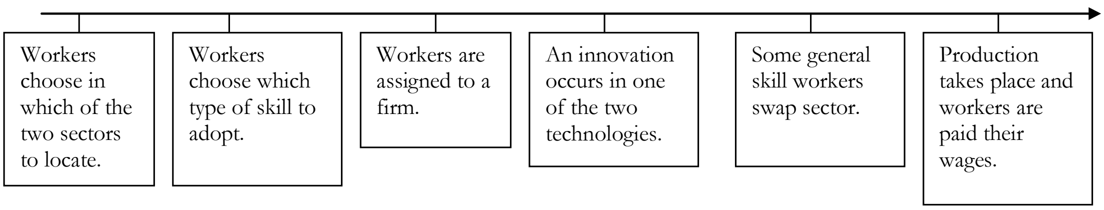

Figure 3: Timing of the Model

We consider the transfer costs that specific skill workers have to sustain to move across sectors as a measure of labour market rigidity. In other words, rigidity is seen in this model as hampering workers' capacity to leave a firm to move to another one. Admittedly, this way of modelling rigidity is fairly general and does not capture all of the more fine-grained aspects associated with labour market rigidity. Even so, we believe that the model captures the most important characteristics of rigidity and that the results we obtain are robust to more detailed specifications.

3.2 Basic Setting

We proceed backwards to illustrate the formal specification of the model. The superscripts *S*, *G* denote whether agents have acquired a specific or a general type of skill, respectively. The subscript *I*, *N* and *M* denote the sectors where workers are located. In particular, *I* stands for innovating sector, *N* for non-innovating sector, and *M* characterises those workers with general skills who migrate from the non-innovating to the innovating sector.

First, let us deal with the innovating sectors. Managers who are active in this sector maximise the following profit function:

$$\pi_I = Y_I^S + Y_I^G - w_I^S l_I^S - w_I^G \left(l_I^G + l_M^G\right) \qquad (1)$$

where the production functions have a Cobb-Douglas form:

$$Y_I^S = A^S (1+\gamma)\left(l_I^S\right)^\alpha \qquad (2)$$

$$Y_I^G = A^G (1+\gamma)\left(l_I^G + l_M^G\right)^\alpha \qquad (3)$$

and where the following set of restrictions apply:

$$
\begin{aligned}
&A^S > A^G \\
&\gamma > 0 \\
&\alpha \in (0,1)
\end{aligned}
\tag{4}
$$

Managers can employ both specific and general skill workers, whose respective contributions to production are additively separable. In particular, it has to be noted that the general skill labour input comprises both workers who were already located in this sector and those who migrate after the innovation takes place. Different wage rates are paid to specific and general skill workers on the basis of their marginal productivity, but the same wage rate is paid to the two categories of general skill workers. Furthermore, output has decreasing returns to scale in labour in both the specific and the general labour input. The 'scarce' factor in the production function is assumed to be managerial competences, as for instance in Rigolini (2004) and Mookherjee and Ray (2003). Specific skill workers are characterised as being more effective in using a certain technology. This is reflected in the fact that total factor productivity of the relative production function is higher than the other ($A^S > A^G$). γ represents the productivity bonus brought about by the innovation. Although specific skill workers may be thought of as being better able to exploit the benefits of an innovation, for simplicity it is assumed that both categories of workers are equally able to reap the innovation bonus. Hence, the productivity bonus is the same in the two sectors.

Maximisation of the profit function with respect to either labour input yields the following optimality conditions:

$$w_I^S = \alpha A^S (1+\gamma)\left(l_I^S\right)^{\alpha-1} \tag{5}$$

$$w_I^G = \alpha A^G (1+\gamma)\left(l_I^G + l_I^M\right)^{\alpha-1} \tag{6}$$

Additionally, it is assumed that the transfer costs for general skill workers moving from the non-innovating to the innovating sector equal a proportion c_T of their wage. Their net wage is then equal to:

$$w_M^G = w_I^G (1 - c_T) \tag{7}$$

c_T is a key parameter of the model because it identifies the economy's level of market rigidity. The main idea is that economies with higher (lower) labour market rigidity will be characterised by higher (lower) transfer costs for workers wanting to leave a firm and join another one. Such costs may be thought of as a penalty that a general skill worker has to pay to her former firm in the non-innovating sector – or to the government - in order to leave that firm and move to a firm in the innovating sector[5]. Although transfer costs may include a variety of costs not directly controlled by a policy-maker - such as costs for geographical relocations, fixed legal costs, *etc* - c_T will be thought of as a variable of

[5] It might appear counter-intuitive that market rigidity engenders a *cost* for a worker, rather than representing a form of protection. However, this characteristic of the model may be easily made more realistic by modelling explicitly managers' choices, and assuming that the transfer cost was paid by the firm rather than by the worker. Even in this case, transfer costs would hinder workers' cross-sector transferability and would reduce the possibility of being re-employed in the innovating sector of the economy. Hence, the same results would be obtained as in the present form of the model.

economic policy, so that it is possible to link explicitly its value to different institutional settings.

Let us now consider the sector that does not innovate. Managers who are active therein will maximise the following profit function:

$$\pi_N = Y_N^S + Y_N^G - w_N^S l_N^S - w_N^G l_N^G \tag{8}$$
$$Y_N^S = A^S \left(l_N^S\right)^\alpha \tag{9}$$
$$Y_N^G = A^G \left(l_N^G\right)^\alpha \tag{10}$$

This is identical to (1) through (3) above but for the absence of the productivity bonus associated with the innovation. l_N^G is the number of general skill workers who do not migrate to the innovating sector. Optimal employment of labour yields the following conditions:

$$w_N^S = \alpha A^S \left(l_N^S\right)^{\alpha-1} \tag{11}$$
$$w_N^G = \alpha A^G \left(l_N^G\right)^{\alpha-1} \tag{12}$$

3.3 The Equilibrium Conditions

Since managers are assumed not to be able to move across sectors, the equilibrium conditions only concern workers' decisions. Overall we have five different categories of workers: specific and general skill workers active in either the innovating or in the non-innovating sector, and general skill workers migrating to the innovating sectors. Five conditions are thus needed to determine labour sectoral allocation and the choice of skills. Equations (5) – (7) and (11)-(12) above set wages accordingly.

Firstly, conditions (13) and (14) are direct consequences of the way the model has been constructed:

$$l_I^S = l_N^S \tag{13}$$
$$l_I^G = l_N^G + l_I^M \tag{14}$$

Each condition requires the distribution of workers across the two technological sectors to be even. The reason is that workers have to choose a sector before the innovation occurs, and each sector looks equally profitable to both specific and general skill workers. Condition (15) requires the number of workers employed be equal to the total supply of labour L.

$$l_I^S + l_N^S + l_I^G + l_I^M + l_N^G = L \tag{15}$$

Full employment is assumed, so that (15) is always satisfied. Condition (16) requires general skill workers who are located in the non-innovating sector to be indifferent between migrating to the alternative sector and remaining in the current sector:

$$w_M^G = w_N^G \tag{16}$$

Were w_M^G greater than w_N^G, then more general skill workers would have an incentive to move to the innovating sector. Were the opposite true, some workers who had migrated to the innovating sector would in fact be better off in the non-innovating sector.

The final condition concerns which type of skill to acquire. A specific skill worker has a probability equal to ½ of earning a wage in either the innovating or in the non-innovating sector, so that her expected wage, denoted with $\tilde{w}^S$, amounts to:

$$\tilde{w}^S = \frac{1}{2}\left(w_I^S + w_N^S\right)\left(1 - c_S\right) \qquad (17)$$

c_S is the training cost that specific skill workers have to pay in order to acquire their specialisation. It is assumed to be a portion of the expected wage that will be earned once employed. Similarly, a general skill worker's average wage is equal to:

$$\tilde{w}^G = \frac{1}{2}\left(w_I^G + w_N^G\right) \qquad (18)$$

(18) makes use of condition (16) above in that a worker who is originally located in the non-innovating sector earns the same wage whether she moves to the alternative sector or remains in the non-innovating sector. Moreover, it is assumed that no additional cost is required to acquire this type of skill, unlike specific skill workers.

Condition (19) requires the expected wage of specific and non-specific skill workers to be equal to one another:

$$\tilde{w}^S = \tilde{w}^G \qquad (19)$$

A steady state of the system is defined as the set of wage rates and labour allocations that satisfies the system of 10 equations given by (5) – (7), (11)-(16) and (19).

3.4 Efficiency and First Best

The normative criterion that will be deployed for the analysis of efficiency is unconstrained maximisation of expected output. Unlike Saint-Paul (2002), the focus of this paper is not on the political economy aspects of labour market institutions. Hence, notions such as Pareto-efficiency – which would require the various labour categories to benefit from institutional changes - are not desirable. Moreover, given the relatively high number of categories, Pareto-efficiency may be too weak a concept to discriminate among allocations.

Output maximisation is unconstrained because both transfer costs and skill upgrade costs are assumed to be revenues for some other agents who are part of the economic system, whose welfare is worth taking into account by the policy-maker. Consequently, the relative costs and benefits cancel out in the policy-maker's objective function. For instance, the costs for the acquisition of specific skills may be thought of as being paid to some other specific skill worker or to the manager of the firm through on-the-job training. Cross-sector transfer costs are considered as instruments of economic policy, alike fiscal revenues for the government, which are redistributed in some forms to the agents after their collection. The maximisation is on 'expected' output because it is assumed that the policy-maker is subject to the same informational constraints outlined in section 3.2. That is, she knows that an innovation will occur with equal probability in one of the two sectors of the economy, but she cannot know *ex ante* in which sector the innovation will occur. This implies that conditions (13), (14), and (15), relative to the *ex ante* allocation of labour across sector, will act as constraints for the policy-maker's maximisation problem. The equilibrium conditions (16) and (19) relative to workers' incentives to move across sectors do not instead act as constraints, as an increase in total output may derive from the violation of these conditions.

More formally, once the three constraints (13), (14), (15) are substituted into the policy-maker's objective function, it looks as follows:

$$\max_{l_I^G, l_M^G} \left\{ A^S(1+\gamma)\left(L/2 - l_I^G\right)^\alpha + A^S\left(L/2 - l_I^G\right)^\alpha + A^G(1+\gamma)\left(l_I^G + l_M^G\right)^\alpha + A^G\left(l_I^G - l_M^G\right)^\alpha \right\} \quad (20)$$

The two first-order conditions yield:

$$MP_I^G \equiv \partial Y_I^G / \partial\left(l_I^G + l_M^G\right) = \partial Y_N^G / \partial l_N^G \equiv MP_N^G \quad (21)$$

$$MP_I^S + MP_N^S \equiv \partial Y_I^S / \partial l_I^S + \partial Y_N^S / \partial l_N^S = \partial Y_I^G / \partial\left(l_I^G + l_M^G\right) + \partial Y_N^G / \partial l_N^G \equiv MP_I^G + MP_N^G \quad (22)$$

Condition (21) refers to what has been defined as *ex post* efficiency. It prescribes that marginal productivity be the same in the two sectors employing general skills. Since non-GP innovations increase total factor productivity in the innovating sector but not in the non-innovating one, optimal allocation of labour requires the shift of some workers towards the latter until marginal productivity is equalised. The term *ex post* emphasises that the achievement of this target requires an adjustment of workers *after* the innovation has occurred.

Condition (22) refers to what has been called *ex ante* efficiency. Given the impossibility for a specific skill worker to move across sectors, a condition analogous to (21) cannot hold in this case. What (22) prescribes instead is that the loss of output from the transfer of a worker from the general skill sector to the specific skill sector should be compensated by an increase in output of the same magnitude in the latter sector. That is, the allocation of workers across the two sectors must be optimal *before* the innovation occurs, so that no reallocation of workers may increase total output.

The solution to the maximisation defines the *first best* solution for this economy. The presence of both labour market rigidity and training costs to acquire specific skills introduce a gap between marginal productivity in those sectors, thus leading to a violation of these conditions. Figure 4 reports the optimal level of output in relation to such costs, and shows how they determine a departure from the *first best*, which is located at the origin of the axes. The terms *ex post* and *ex ante* inefficiencies – or output losses - will be used to denote departures from such first best. It is worth stressing that the transfer costs c_S are taken to be *structural* parameters of the model and thus outside the control of policy-makers, whereas transfer costs c_T are the variable subject of economy policy. Therefore, in most of the remainder of the paper, the notions of efficiency will be treated in relation to a given value of c_S, and it will be analysed how changes in c_T bring about variations in efficiency.

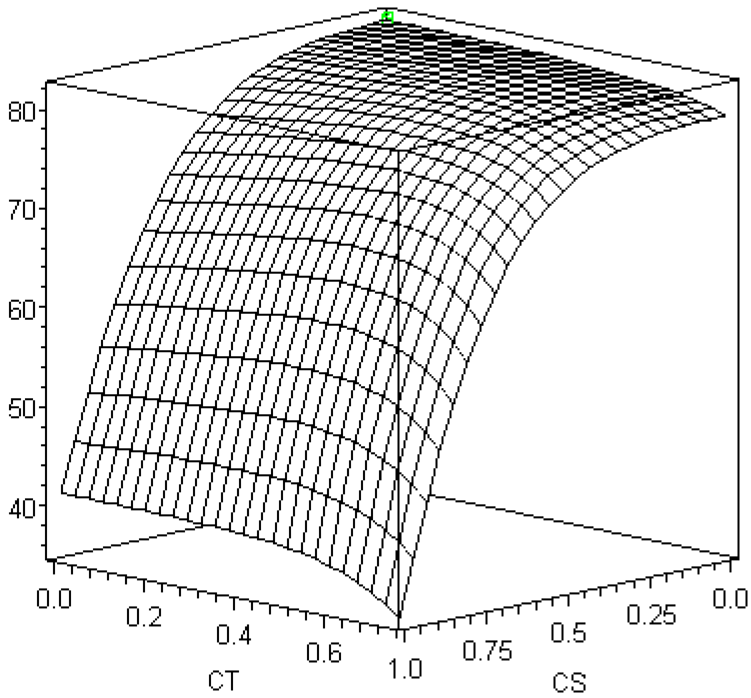

Figure 4: Optimal Output as a Function of Transfer and Training Costs

4 The Impact of an Increase in Labour Market Rigidity

4.1 An Overview

As illustrated in section 3, labour market rigidity is modelled as the transfer costs c_T with which general skill workers are faced when changing their occupations. As will be demonstrated in the next sections, there are two ways in which c_T affects total output, which are associated with the *ex ante* and the *ex post* stages described in section 3.4. As for the former, an increase in c_T will make *more* attractive for workers to acquire specific skills. The reason is that the higher c_T, the lower the expected wage for general skill workers because of their reduced cross-sector transferability. Consequently, more workers will be employed in the specific skill sectors of production in the economy, which will increase total output given the higher average marginal productivity in that sector. Second, an increase in c_T will *ex post* curtail the possibility for general skill workers to move towards the innovating sector. As a result, fewer workers will be able to move to the sector of the economy where the technology is more efficient, thus reducing output. Therefore, an increase in c_T has at the same time a *positive* effect on output in that it makes *ex ante* more convenient for workers to acquire specific skills, but has a negative effect in that it hinders the possibility for general skill workers to migrate to the more efficient sector of the economy *ex post*. The next sections will investigate under which conditions the *ex ante* effect prevails over the *ex post* one. The analytical solution for the steady state and the proofs are reported in the Appendix.

4.2 Effects on General Skill Labour Allocation

The first relevant result concerns the mobility of general skill workers across sectors:

Lemma 1: *As c_T increases, there will be fewer general skill workers able to transfer from the non-innovating to the innovating sector:*

$$\partial l_M^G / \partial c_T < 0 \quad \forall c_T < \bar{c}_T$$

The value of $\bar{c}_T$ is given in (31). It represents the greatest value that transfer costs can assume for an internal solution of the steady state. In fact, as shown in the Appendix, for values of c_T above $\bar{c}_T$, a corner solution obtains where no general skill worker wishes to transfer to the innovating sector. The reason is that transfer costs are then too high in comparison to the productivity premium to make transfer from the non-innovating to the innovating sector profitable. Hence, the study of the model is restricted to values of c_T below $\bar{c}_T$. What Lemma 1 implies is hardly surprising. The higher the transfer costs, the fewer the general skill workers who are able to transfer to the innovating sector.

Lemma 2 concerns general skill workers active in the innovating sector:

Lemma 2: *There exists an internal minimum in the steady state ex ante allocation of general skill labour in the innovating sector with respect to the transfer costs. In particular, l_I^G is increasing (decreasing) in c_T for values greater (smaller) than a threshold $\hat{c}_T$. Such a minimum is unique:*

$$\partial l_I^G / \partial c_T \overset{>}{\underset{<}{-}} 0 \Leftrightarrow l_I^G \overset{>}{\underset{<}{-}} \hat{c}_T, \hat{c}_T < \bar{c}_T$$

The expression for $\hat{c}_T$ is given in (33). The fact that the *ex ante* allocation of general skill worker decreases below the threshold $\hat{c}_T$ is not surprising. In fact, the higher the transfer costs, the lower the expected wage for general skill workers, and thus the fewer the workers who acquire this type of skill *ex ante*. The existence of a threshold beyond which the pattern of labour allocation changes is perhaps more surprising. This is due to the wage dynamics and to the shape of the production function, and will be further commented in section 4.3.

Lemma 3: *As c_T increases, the amount of general skill workers active in the innovating sector will decrease:*

$$\partial\left(l_I^G + l_M^G\right) / \partial c_T < 0 \quad \forall c_T < \bar{c}_T$$

Both l_I^G and l_M^G decrease for $c_T < \hat{c}_T$. For values of c_T above the threshold, instead, the fact that l_I^G starts growing is offset by the decrease in l_M^G. Overall, then, general skill labour in the innovating sector decreases as transfer costs rise. This result leads directly to:

Corollary 1: *As c_T increases, production by general skill workers active in the innovating sector will decrease:*

$$\partial Y_I^G / \partial c_T < 0 \quad \forall c_T < \bar{c}_T$$

This result is now to be contrasted with what occurs in the non-innovating sector for general skill workers:

Lemma 4: *As c_T increases, the amount of general skill workers active in the non-innovating sector will increase:*

$$\partial l_N^G / \partial c_T > 0 \quad \forall c_T < \bar{c}_T$$

The fact that more workers are unable to transfer to the innovating sector as c_T increases causes general skill labour to be rising in c_T. Hence, as far as l_N^G is concerned, this effect must compensate the *ex ante* disincentive to acquire general skills due to increased transfer costs. Consequently:

Corollary 2: *As c_T increases, production by general skill workers active in the non-innovating sector will increase:*

$$\partial Y_N^G / \partial c_T > 0 \quad \forall c_T < \bar{c}_T$$

The impact of c_T on overall production by general skill workers is therefore ambiguous. Lemma 5 states that the impact is in fact negative throughout the relevant interval.

Lemma 5: *As c_T increases, overall production by general skill workers will decrease:*

$$\partial Y^G / \partial c_T < 0 \quad \forall c_T < \bar{c}_T$$

where:

$$Y^G = Y_I^G + Y_N^G \tag{23}$$

Lemma 5 shows that higher transfer costs hinder general skill workers mobility from the less productive to the more productive sector of the economy. As a result, production from general skill workers decreases. This result reflects *ex post* efficiency (see section 3.4). The increase in transfer costs hampers the possibility of transferring labour inputs of the general type towards the more efficient sector of the economy, so that condition (21) of equality of marginal productivity is violated. In this sense, higher labour market rigidity is detrimental to the economy in that it prevents adjustment to sectors with higher productivity. This idea may be restated more formally in Lemma 6:

Lemma 6: The only ex post efficient allocation of labour inputs is for $c_T=0$. The higher c_T, the more ex post--inefficient the allocation is.

4.3 Effects on Specific Skill Labour Allocation

The implications described in Lemma 5 and 6 above are to be contrasted with the following results for specific skill workers:

Lemma 7: *There exists an internal maximum in the steady state allocation of labour in the specific skill sector with respect to transfer costs. In particular, specific skill labour is increasing (decreasing) in c_T for values smaller (greater) than the same threshold $\hat{c}_T$ as in Lemma 2. Such a maximum is unique. That is,*

$$\partial l_j^S / \partial c_T \underset{<}{\overset{>}{-}} 0 \Leftrightarrow l_j^S \underset{>}{\overset{<}{-}} \hat{c}_T, \hat{c}_T < \bar{c}_T; j = \{I, N\}$$

This result is symmetrical to what found in Lemma 2. As c_T increases, more workers will prefer to choose the specific type of skill, as the expectation of higher mobility costs in the alternative type of skill will hinder mobility and thus decrease the expected wage were they to acquire general skills. However, for values of c_T above the threshold $\hat{c}_T$, this pattern is reversed. The latter result is linked to the wage dynamics for general skill workers. Lemma 1 states that, as c_T rises, fewer workers will be able to move from the non-innovating towards the innovating sector of the economy. This has two opposite effects on wages earned by general skill workers. On the one hand, it will increase the wages of workers active in the innovating sector, because, as Lemma 2 shows, the overall number of workers who are active in that sector will drop. On the other hand, for symmetrical reasons, it will also decrease the wages of workers active in the non-innovating sector. However, these two effects are not equal in size, and expected general skill wages present a U-shaped pattern with respect to c_T. In particular, for values of c_T below (above) $\hat{c}_T$, the latter (former) between these two effects dominates, so that expected wages for general skill workers will decrease (increase). As a result, the number of workers acquiring specific skills will be decreasing (increasing) in the region when c_T exceeds (is below) the threshold $\hat{c}_T$.

Lemma 7 leads to the following

Corollary 3: *There exists an internal maximum in the steady state production from specific skill workers with respect to transfer costs. In particular, production from specific skill labour is increasing (decreasing) in c_T for values smaller (greater) than the threshold $\hat{c}_T$. Moreover, such a maximum is unique. That is,*

$$\partial Y^S / \partial c_T \underset{<}{\overset{>}{-}} 0 \Leftrightarrow c_T \underset{>}{\overset{<}{-}} \hat{c}_T , \hat{c}_T < \bar{c}_T$$

where:

$$Y^S = Y_I^S + Y_N^S \tag{24}$$

Corollary 3 underpins the *ex ante* efficiency argument set out above. It states that higher transfer costs have, for values of c_T below the threshold $\hat{c}_T$, a positive impact on production from specific skill workers. The reason is that higher transfer costs imply a decline in the expected general skill wage, so that more workers will find it optimal to acquire specific skills. Lemma 8 restates this argument in terms of efficiency:

Lemma 8: The only ex ante-efficient allocation of labour inputs is for $c_T = \hat{c}_T$. The closer the economy to this value, the more ex ante--efficient the allocation is.

4.4 Overall Effects

We have seen how *ex ante* efficiency prescribes to allocate more resources to specific skills (Lemma 8), whereas *ex post* efficiency calls for increasing the share of general skill workers (Lemma 6), which makes it possible a better use of technical innovations. Lemma 9 states a general result on these two effects.

Lemma 9: *Suppose c_S is positive. Then, there exists a maximum in the region $(0, \hat{c}_T]$ where total output as a function of c_T is maximised:*

$$\exists\ c_T^* \in (0, \hat{c}_T) \text{ such that } c_T^* = \underset{c_T}{\operatorname{argmax}} \left\{ Y^S(c_T) + Y^G(c_T) \right\}$$

Lemma 9 thus claims that an economic system will maximise its output when labour market rigidity is set at some *positive* levels.

4.5 Discussion

The underlying reason for the result in Lemma 9 lies in the distortions brought about by the training costs c_S. This represents an entry cost in the labour market for specific skill workers, which is compensated by a rent in terms of higher average wages after their entry. Only under the expectation of a higher average wage would workers take up specific-skills in the first place. Another way to look at this aspect of the model, is to consider higher average specific-skill wages as the cost that firms are available to pay to their specific skill workers in exchange of their higher productivity.

The presence of a rent inevitably brings about some form of inefficiency in the economy. In the present model, this is given by the reduction in the number of specific skill workers with respect to the *first best* (see section 3.4). This is necessary in order for their average wage to rise above the *first best* level, but causes average marginal productivity of specific skill workers to be higher than that of generic skill workers. This entails an output loss with respect to the *first best*, which every increase in the number of specific skill workers helps to alleviate. In other words, the more specific skill workers, the lower their wage and thus their rent, thus reducing the inefficiency in the economy. An increase in c_T is thereby efficiency-enhancing because it rises the incentives for workers to invest in specific skills, thus reducing their rent. This is nothing but a restatement of the *ex ante* efficiency argument (see section 3.4).

Nonetheless, in the present model an increase in c_T also curbs the possibility of general skill workers to transfer to the innovating sector of the economy. This represents the *ex post* form of inefficiency. Lemma 9 determines the value of c_T that trades off optimally *ex ante* against *ex post* efficiency, and it ensures that such a value lies in the interior of the feasible range for c_T. For every value of the transfer costs, a further rise in c_T brings about both an output *loss* due to the lower mobility of general skill workers after the innovation, and an output *gain* associated with more workers learning specific skills and thus reducing the rent prior to the innovation. Lemma 9 states that at c_T^* these two costs are exactly equal to each other, and thus it represents the optimal solution for the economy given c_S. Therefore, some positive levels of labour market rigidity lead to higher efficiency in the economy.

The reason why *ex ante* efficiency prevails over *ex post* efficiency at relatively low values of c_T depends on the nature of the distortions associated the two forms of efficiency. By definition, the output losses associated with *ex post* inefficiency equal zero when c_T is equal to zero, and then monotonically increase with c_T. Conversely, the output losses brought about by *ex ante* inefficiency are strictly positive when c_T is equal to zero, the reason being that this form of inefficiency is originated by the training costs c_S. So, provided that training costs are positive, *ex ante* inefficiency will be positive even when

c_T is equal to zero, and then progressively diminishes as c_T increases. Figure 5 plots a typical pattern of the output losses associated with *ex ante* and *ex post* inefficiency.

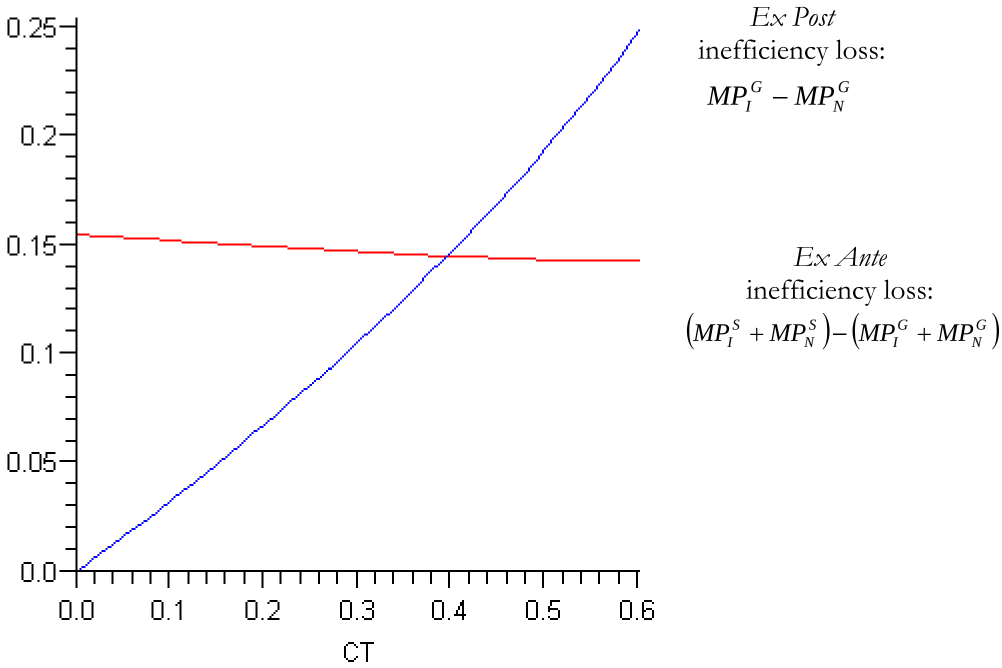

Figure 5: Ex Post and Ex Ante Inefficiency Losses
Notes: The diagram has been obtained for the following set of parameters: $\{\alpha = 0.5; A_S = 3; A_G = 1; \gamma = 3; c_S = 0.2; L = 100\}$

Figure 6 plots the economy's overall output against c_T for various levels of c_S. It shows that the maximum is located in the origin when c_S equals zero, and that this shifts rightwards as c_S increases. Moreover, the absolute level of the maximum decreases as c_S increases, because the distortion in *ex ante* efficiency increases. Table 2 reports the numerical values for the maximum and maximand of total output for different values of c_S.

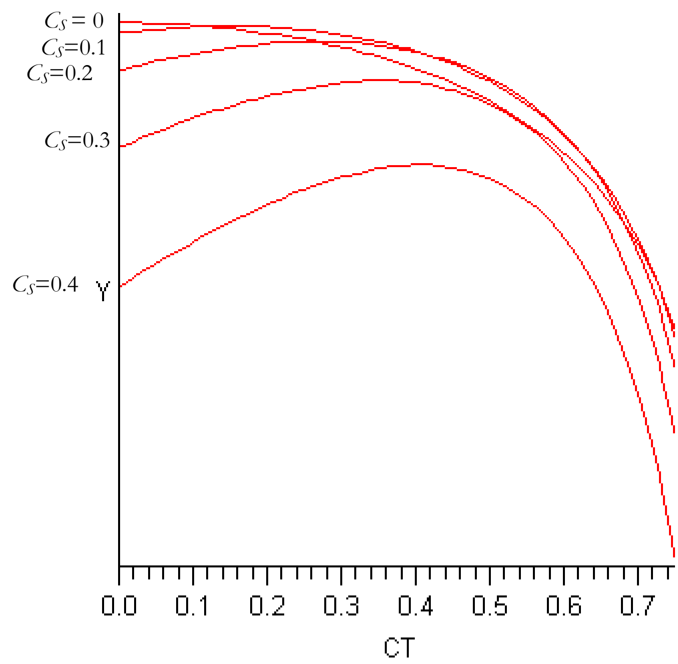

Figure 6: Optimal Output as a Function of Labour Market Rigidity
Notes: See note to Figure 5

Values for c_S	Optimal value of c_T	Optimal Value of Output
0	0	81.85
0.05	0.08	81.85
0.1	0.15	81.82
0.15	0.21	81.77
0.2	0.27	81.67
0.25	0.31	81.54
0.3	0.35	81.32
0.35	0.38	81.01
0.40	0.41	80.55

Table 2: Optimal Output and Optimal Value of Labour Market Rigidity as a Function of Training Costs
Notes: See note to Figure 5

Figure 7 shows that not only have positive levels of transfer costs an output-enhancing effect, but the same may be true for the training costs. An interior solution for c_S in the problem of output maximisation *given a certain value of* c_T, is the case for values of c_T in the region above 0.3. In this region *ex ante* efficiency losses are at its lowest (see Figure 5), so an increase in c_S increases the number of general skill workers and reduces *ex post* efficiency losses. Therefore, even in this case augmenting costs may be beneficial for an economy.

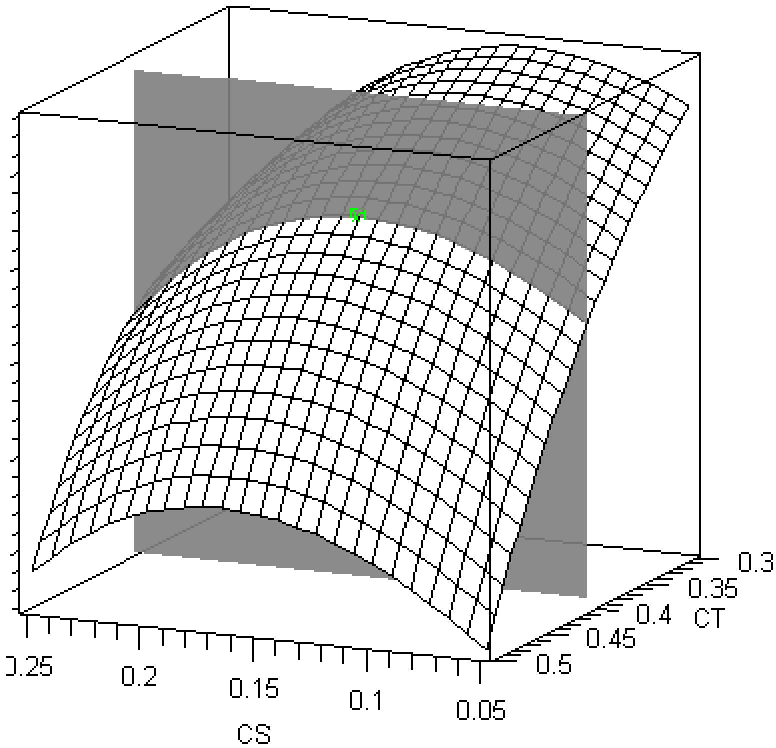

Figure 7: Optimal Value of Output as a Function of Training Costs
Notes: See note to Figure 5

5 Conclusions

The paper has developed a simple model where two contrasting effects of rigidity in the labour market may be analysed. *Ex post* efficiency calls for low market rigidity, as this permits workers having acquired general skills to transfer to the innovating sector of the economy. *Ex ante* efficiency requires high labour market rigidity, as this encourages workers to acquire specific skills, which increases output in equilibrium. This is crucially due to the presence of a rent accruing to specific skill workers for the cost they have to sustain for their skill acquisition. The interaction between these two effects leads to an inverse-U relation between labour market rigidity and output, which implies that some degrees of labour market rigidity are indeed beneficial for the economy.

The model contradicts the argument that removing market rigidities will necessarily increase output by boosting productivity. When technical change is non-GP and factors of production are scarce – so that in particular the production function has decreasing returns to scale in labour -, removing market rigidity will lower the incentives for workers to acquire specific productivity-enhancing skills. The loss in output associated with this effect cannot be compensated by the fact that with less rigidity workers may shift towards the innovating sector of the economy. This argument may be at the basis of the observed non-linear relationship between labour productivity growth rates and degrees of employment protection highlighted in Section 2.

The model lends itself to several generalisations. Firstly, the introduction of a dynamic perspective, that is, the replication of production over an arbitrarily long horizon, would permit the analysis of the 'turbulence' of the economic environment. This would permit us to take into account the role of skills as an insurance against variability in the environment. Since it is generally thought that general skills are better protected against fast technical change than specific skills, then the trade off between *ex ante* and *ex post* efficiency may result in a different outcome than what obtained in the present model. Moreover, the results presented in this paper have been derived for a Cobb-Douglas production function. Their robustness to changes in the shape of the production function would then need to be verified.

In spite of these remarks, the present model seems to offer a suitable framework to investigate the trade-offs between different mechanisms affecting the labour market in a context of non-general purpose technical change and multiplicity of skills.

6 Appendix

The solution of the system of equations leads to the following steady state expressions for labour allocations across sectors and skills:

$$l_I^S = l_N^S = \frac{D_2}{2(1+D_1+D_2)}L \tag{25}$$

$$l_I^G = \frac{1+D_1}{2(1+D_1+D_2)}L \tag{26}$$

$$l_M^G = \frac{D_1}{2(1+D_1+D_2)}L \tag{27}$$

$$l_N^G = \frac{1}{2(1+D_1+D_2)}L \tag{28}$$

where:

$$D_1 = \left\{[(1+\gamma)(1-c_T)]^{\frac{1}{1-\alpha}} - 1\right\} \Big/ 2 \tag{29}$$

$$D_2 = \left[\frac{A^S(1-c_T)(1-c_S)(2+\gamma)}{A^G(2-c_T)}\right]^{\frac{1}{1-\alpha}} \tag{30}$$

D_1 depends positively on the incentives to migrate towards the innovating sector for general skill workers in the *ex post* stage. D_2, instead, weighs the incentives to acquire specific skills *vis-à-vis* general ones in the *ex ante* phase. As a result, a higher value of D_1 relative to D_2 favours allocation of labour to the general skills. A condition must be imposed on D_1 to ensure that l_M^G does not enter the negative region. That is, D_1 has to be non-negative, which leads to:

$$c_T \le \bar{c}_T \equiv \gamma/1+\gamma \tag{31}$$

We assume that such a condition is always satisfied, so that the system is studied over the range $c_T \in [0, \bar{c}_T]$. The above condition requires the productivity gain in the innovating sector be sufficiently high in comparison to the transfer costs.
D_2 is non-negative across the relevant range of parameters. I also define

$$D_3 = \left[(1+\gamma)(1-c_T)\right]^{\frac{1}{1-\alpha}} \qquad (32)$$

so that $D_1 = \frac{1}{2}\{D_3 - 1\}$. As a result of the above restriction, the parameters have to satisfy the following inequalities for $c_T \in [0, \bar{c}_T]$:

$$D_1 \geq 0$$
$$D_2 \geq 0$$
$$D_3 \geq 1$$
$$c_T = \bar{c}_T \Rightarrow D_1 = 0 \wedge D_3 = 1$$

<u>Proof of Lemma 1</u>

Differentiating l_M^G with respect to c_T leads to:

$$\frac{\partial l_M^G}{\partial c_T} = \frac{L}{4(1+D_1+D_2)^2}\left\{\frac{-D_3(2-c_T) - D_2[1+D_3(1-c_T)]}{(1-c_T)(2-c_T)(1-\alpha)}\right\}$$

Given the above restrictions on the parameters, this expression is always negative over the interval $[0, \bar{c}_T]$. QED

<u>Proof of Lemma 2</u>

Differentiating l_I^G with respect to c_T leads to:

$$\frac{\partial l_I^G}{\partial c_T} = -\frac{L}{4(1+D_1+D_2)^2}\left\{\frac{D_2[D_3(1-c_T)-1]}{(1-c_T)(2-c_T)(1-\alpha)}\right\}$$

Given the restrictions imposed on the parameters, it is immediate to verify that this expression is negative for $c_T = 0$ and positive for $c_T = \bar{c}_T$. Moreover, there exists only a value in which the differential is equal to 0, that is:

$$\hat{c}_T = 1 - \left[1/(1+\gamma)\right]^{\frac{1}{2-\alpha}} \qquad (33)$$

Such a value lies in the interior of the interval $[0, \bar{c}_T]$.

<u>Proof of Lemma 3</u>

Differentiating $l_I^G + l_M^G$ with respect to c_T leads to:

$$\frac{\partial\left(l_I^G + l_M^G\right)}{\partial c_T} = \frac{L}{4(1+D_1+D_2)^2}\left\{\frac{-D_3[(1+D_2)(1-c_T)+1]}{(1-c_T)(2-c_T)(1-\alpha)}\right\}$$

Given the above restrictions on the parameters, this expression is always negative over the interval $[0,\bar{c}_T]$. QED

Proof of Lemma 4

Differentiating l_N^G with respect to c_T leads to:

$$\frac{\partial l_N^G}{\partial c_T} = \frac{L}{4(1+D_1+D_2)^2}\left\{\frac{D_3(2-c_T)+2D_2}{(1-c_T)(2-c_T)(1-\alpha)}\right\}$$

Given the above restrictions on the parameters, this expression is always positive over the interval $[0,\bar{c}_T]$. QED

Proof of Lemma 5

By applying the chain rule, one obtains:

$$\frac{\partial Y_I^G}{\partial c_T} = \frac{\partial Y_I^G}{\partial (l_I^G + l_M^G)} \times \frac{\partial (l_I^G + l_M^G)}{\partial c_T}$$

After recalling the expressions for production, steady state labour allocation and the results from Lemma 3, and after simplifying, one obtains:

$$\frac{\partial Y_I^G}{\partial c_T} = \frac{\alpha A^G (1+\gamma) L^\alpha}{[2(1+D_1+D_2)]^{1+\alpha}}\left(\frac{1}{(1-c_T)(2-c_T)(1-\alpha)}\right)\left\{-(D_3)^\alpha[(2-c_T)+2D_2(1-c_T)]\right\}$$

This expression is negative over the interval $[0,\bar{c}_T]$.
Similarly, one has:

$$\frac{\partial Y_N^G}{\partial c_T} = \frac{\partial Y_N^G}{\partial l_N^G} \times \frac{\partial l_N^G}{\partial c_T}$$

After substituting the relevant expressions from Lemma 4, and after some simplifications, the following expression obtains:

$$\frac{\partial Y_N^G}{\partial c_T} = \frac{\alpha A^G L^\alpha}{[2(1+D_1+D_2)]^{1+\alpha}}\left(\frac{1}{(1-c_T)(2-c_T)(1-\alpha)}\right)\left\{D_3(2-c_T)+2D_2\right\}$$

This is a positive expression over the relevant interval.
After summing up the two derivatives, we obtain:

$$\operatorname{sgn}\left\{\frac{\partial Y_I^G}{\partial c_T} + \frac{\partial Y_N^G}{\partial c_T}\right\} = \operatorname{sgn}\left\{D_3(2-c_T)+2D_2-(D_3)^\alpha(1+\gamma)[(2-c_T)+2D_2(1-c_T)]\right\}$$

After some tedious algebra, the expression in brackets can be simplified so as to yield:

$$\operatorname{sgn}\left\{\frac{\partial Y_I^G}{\partial c_T}+\frac{\partial Y_N^G}{\partial c_T}\right\}=\operatorname{sgn}\left\{-D_3\frac{c_T(2-c_T)}{1-c_T}-2D_2(D_3-1)\right\}<0 \text{ QED.}$$

Proof of Lemma 6

From the wage-setting rules (6), (7), (12), and from the equilibrium condition (16), one can derive the following inequality:

$$MP_I^G - MP_N^G = w_I^G c_T > 0 \tag{34}$$

where MP_I^G and MP_N^G are defined in (20).

Since *ex post* efficiency is associated with marginal productivity being equal in the innovating and non-innovating general skill production, it is apparent from (34) that the only allocation where this occurs is for $c_T = 0$.

Proof of Lemma 7

Differentiating l_I^S with respect to c_T leads to:

$$\frac{\partial l_I^S}{\partial c_T}=\frac{L}{4(1+D_1+D_2)^2}\left\{\frac{D_2[D_3(1-c_T)-1]}{(1-c_T)(2-c_T)(1-\alpha)}\right\}=-\frac{\partial l_I^G}{\partial c_T} \text{ QED.}$$

Proof of Lemma 8:

From the equilibrium condition (19), and considering the wage-setting rules (5), (6), (7), (11), (12), one derives the following inequality:

$$MP^S - MP^G = c_S\left(w_I^S + w_N^S\right) > 0 \tag{35}$$

where

$$MP^S = \partial Y^S / \partial l^S \tag{36}$$

$$MP^G = \partial Y^G / \partial l^G \tag{37}$$

$$l^S = l_I^S + l_N^S \tag{38}$$

$$l^G = l_I^G + l_M^G + l_N^G \tag{39}$$

Given the negative relation between wages and labour, the right-hand side of (34) is minimized when l^S reaches its maximum, that is, according to Lemma 7, when $c_T = \hat{c}_T$. Hence, ex ante efficiency is maximised for $c_T = \hat{c}_T$, and efficiency gains may be obtained by moving closer to this value.

Proof of Lemma 9

Suppose c_S is strictly positive. By applying the chain rule, we have:

$$\frac{\partial Y^S}{\partial c_T} = \frac{\alpha A^S(2+\tau\gamma)L^\alpha}{\left[2(1+D_1+D_2)\right]^{1+\alpha}}\left(\frac{1}{(1-c_T)(2-c_T)(1-\alpha)}\right)(D_2)^\alpha\{D_3(1-c_T)-1\}$$

where $Y^S = Y_I^S + Y_N^S$. Hence, one has to compare the size of this derivative with that determined above for Y^G. After some algebra, this expression reads as follows:

$$\operatorname{sgn}\left\{\frac{\partial Y^S}{\partial c_T}+\frac{\partial Y^G}{\partial c_T}\right\} = \operatorname{sgn}\left\{A^S(2+\tau\gamma)(D_2)^\alpha[D_3(1-c_T)-1] - A^G\left[D_3\frac{c_T(2-c_T)}{1-c_T} - 2D_2(D_3-1)\right]\right\}$$

After some simplifications, we conclude that the expression in brackets is positive for $c_T = 0$:

$$\operatorname{sgn}\left\{\frac{\partial Y^S}{\partial c_T}+\frac{\partial Y^G}{\partial c_T}\right\}\Bigg|_{c_T=0} = \operatorname{sgn}\left\{\left[(1+\gamma)^{\frac{1}{1-\alpha}}-1\right]\left[\frac{A^S(2+\tau\gamma)(1-c_S)^\alpha}{(2A^G)^\alpha}\right]^{\frac{1}{1-\alpha}}c_S\right\} > 0$$

Moreover, on the grounds of Lemma 5 and Corollary 3, we may observe that derivatives are negative for values of c_T above $\hat{c}_T$:

$$\operatorname{sgn}\left\{\partial Y^S/\partial c_T + \partial Y^G/\partial c_T\right\}\Big|_{c_T \geq \hat{c}_T} < 0$$

Hence, given the continuity of Y^S for $c_T \in [0, \bar{c}_T]$, we can conclude that there exists a value of c_T internal to the interval $[0, \bar{c}_T]$ where the derivative of Y with respect to c_T equals 0. QED

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