# Low-Skilled Unemployment, Capital-Skill Complementarity and Embodied Technical Progress

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**Abstract**

We construct an intertemporal general equilibrium model with two types of jobs and two types of workers. We allow for job competition between high- and low-skilled workers on the low-skilled segment of the labour market and for on-the-job search. Matching processes are represented by matching functions *à la* Pissarides. Workers search intensities are endogenous. Biased technological change is introduced via embodied technical progress and a capital-skill complementarity. The model is calibrated and simulated to evaluate the impact of various types of shocks. The model reproduces quite well the unemployment rate changes and the relative wage stability observed over the last two decades. It suggests strong interactions between biased technological change, discouragement effects and job competition.

*Keywords*: skill mismatch, equilibrium unemployment, ladder effect, macro dynamics

*JEL* classification: E24, J21, J23

*The first author acknowledges the financial support of the Fundación Ramón Areces. The second author is also at the Université Catholique de Lille.

# 1 Introduction

The rise in unemployment observed in many European countries over the last decades has been particularly strong among low-skilled workers. One possible interpretation for these uneven changes in unemployment changes is biased technological change. If investment in new technologies raises the relative demand for skilled workers[1], low-skilled unemployment increases unless the variation in relative demands is compensated by a change in relative wages or in relative labor supplies. Biased technological change combined with relative wage rigidities may thus lead to "skill mismatch" and thereby, to higher low-skilled unemployment rates (see table 1). However, more and more attention has recently been paid to an alternative explanation in terms of job competition. If high-skilled workers compete with low-skilled ones for low-skilled jobs, but the opposite is not true, purely aggregate shocks can have strong asymmetric unemployment effects by generating a so-called *ladder effect*. The interest for this alternative view has arisen from the observation that all unemployment rates have increased, while a biased technological change should a priori decrease unemployment of high-skilled workers, at least if wage-wage interactions are not too strong.

In many OECD countries, investment in human capital (education) has significantly increased despite a stable wage premium (see for instance Muysken and ter Weel (1999)). Youngsters invest more in human capital not because the relative wage for high-skilled on complex jobs has increased, but rather because a higher education level increases the number of job opportunities. Recent empirical work suggest that the proportion of "overqualified" workers is far from negligible although hard to evaluate. Hartog (2000) collects empirical results from various studies about the level of job competition ("overeducation") in several EU countries. Depending on the methodology used and the country surveyed, this overeducation is estimated to be between 10% and 30% during the first half of the nineties. Moreover, they also show that overeducation increased over the last decades (except in UK). Forgeot and Gautié (1997) report that, in France, the proportion of overeducated workers has strongly increased between 1986 and 1995, partic-

[1]There is wide evidence suggesting that technological progress may have substantially increased the relative demand for skilled workers (see for instance Autor, Katz, and Krueger (1998), Berman, Bound, and Griliches (1994), or Machin, Ryan, and Van Reenen (1998)).

ularly among women and young workers looking for a first job. Following their study, between 1986 and 1995 the proportion of French workers with an university diploma being overqualified in their job increased from 6.6% to 18.7%. Moreover, in 1995, more than 24% of young women were overqualified.

| | UNEMPLOYMENT RATES | | | RELATIVE WAGES | | | |
|---|---|---|---|---|---|---|---|
| | **1970-1979** | **1980-1989** | **1990-2001** | | **1980-1984** | **1985-1989** | **1990-1995** |
| France | 3.9 | 9.1 | 10.7 | D5/D9 | 51.7 | 50.8 | 50.3 |
| | | | | D1/D5 | 60.6 | 61.5 | 60.9 |
| Germany | 1.4 | 5.2 | 7.3 | D5/D9 | 60.8 | 61.0 | 61.4 |
| | | | | D1/D5 | 60.0 | 64.4 | 67.4 |
| Japan | 1.7 | 2.5 | 3.4 | D5/D9 | 55.9 | 54.4 | 53.9 |
| | | | | D1/D5 | 58.2 | 58.5 | 60.4 |
| United Kingdom | 4.3 | 10.0 | 6.8 | D5/D9 | 58.2 | 55.5 | 53.9 |
| | | | | D1/D5 | 59.0 | 56.8 | 55.9 |
| United States | 6.2 | 7.2 | 5.5 | D5/D9 | .. | .. | 48.4 |
| | | | | D1/D5 | .. | .. | 48.1 |

D5/D9: ratio of the upper earnings limit of the fifth decile of workers to the upper limit of the ninth decile. D1/D5: ratio of the upper earnings limit of the first decile of workers to the upper limit of the fifth decile.
Source concerning unemployment rates: For France, Japan, United Kingdom and United States we use LABORSTA database, from the International Labor Office. The data concerning Germany comes from the OECD Economic Outlook.
Source concerning relative wages: OECD Employment Outlook 1996 chapter 3. For Germany we have information only between 1983-1993. For U.S. data concerns only the 1993-1995 period.

Table 1: Average unemployment rates and relative wages in five OECD countries (in percent).

Several theoretical models have been constructed and calibrated to examine this issue. Gautier (2002) develops a stylized partial equilibrium model with two types of jobs and two types of workers and wage bargaining. He focuses on the stationary state properties of the model and emphasizes the diversity of effects that can be obtained as a result of the externalities introduced via the matching function. Dolado, Felgueroso, and Jimeno (2000) use a similar approach with a simpler albeit more realistic representation of wage determination to provide a quantitative analysis of the Spanish case. They calibrate a stationary equilibrium model to evaluate the job competition effect triggered by the dramatic increase in the proportion of skilled workers that took place in the late eighties. Similar models are also considered in Albrecht and Vroman (2002) and Dolado, Jansen, and Jimeno (2002). Collard, Fonseca, and Muñoz (2002) provide a first attempt to include this type of quantitative analysis in a dynamic general equilibrium setup.

Pierrard and Sneessens (2002) use a similar setup with on-the-job search and endogenous search intensities for high-skilled workers so as to obtain a less mechanical job competition effect. Their model is able to explain a significant part of the unemployment rise observed in Belgium over the last twenty years by simply changing two parameters: the relative productivity of high-skilled workers and the proportion of high-skilled workers in the total labor force. They furthermore examine the interactions between skill mismatch and job competition. Although the proportion of overqualified workers they obtain is relatively low, job competition contributes significantly to the overall increase in low-skilled unemployment.

One of the main difficulties in these models is to account simultaneously for the three main stylized facts observed in many EU countries since the mid-seventies: (i) the increase in the overall unemployment rate; (ii) the difference between high-skilled and low-skilled unemployment; (iii) the stability of relative wages. This paper focuses on these issues. It builds on Pierrard and Sneessens (2002). Compared to their model, our contribution is threefold. Instead of assuming that low-skilled wages are indexed on high-skilled ones, we allow separate wage bargaining for all workers. Second, by endogenizing search intensities of low-skilled workers we are able to capture a kind of discouragement effect understood as a decrease in search intensity rather than as duration concept (there is no duration in our model). Finally, we introduce biased technological change as the result of embodied technical progress (defined as the technological progress only affecting new investment goods) with capital-skill complementarity. Concerning technological progress, authors like Greenwood, Hercowitz, and Krussel (2002) or Mairesse, Cette, and Kocoglu (2000) find that it has become increasingly incorporated in new capital goods, *i.e.* if a firm wants to benefit from a technological improvement embodied in a particular capital good it has no other choice but buying that good. Regarding the capital-skill complementary relationship, many empirical studies (see Berman, Bound, and Griliches (1994), Fitz Roy and Funke (1995), Machin, Ryan, and Van Reenen (1998), Krusell et al. (2000) or Moreno-Galbis (2002)) point to the importance of this relationship. The model presented in this paper reproduces quite well the three stylized facts mentioned above. Furthermore we obtain a significant discouragement effect (decrease in search intensity) for low-skilled workers induced by the lower demand for simple jobs. This reinforces the job competition effect.

The paper is organized as follows. In section 2 we present the model. We describe labor market flows, workers and firms behaviors, and wage bargaining. In section 3 we calibrate the model on Belgian data for 1996. We examine the properties of the model by simulating its responses to various types of shocks. We next set the technological and labor force composition variables to their 1976 values and check the ability of the model to reproduce the stylized facts. Finally we analyze the effects of various policy measures. Section 4 concludes.

## 2 The model

The structure of the model is based on an earlier work by Pierrard and Sneessens (2002). The economy consists of two broad categories of agents, firms and households. We distinguish two types of households; each type is defined by the skill level (high or low) of its members. All members of a household supply inelastically one unit of labor; they may be employed or unemployed[2].

We distinguish three types of firms: two types of intermediate good firms, producing respectively high- and low-tech intermediate goods with labor as sole input, and one representative final firm, combining capital and the two intermediate goods to produce an homogeneous final good. The final good can be used for consumption or capital accumulation. The production of high-tech intermediate goods involves complex tasks that can only be carried out by high-skilled workers. The production of low-tech intermediate goods consists of simpler tasks that can be carried out by both high- or low-skilled workers. There is thus a double heterogeneity as in Gautier (Gautier 2002): heterogeneity of jobs (complex vs simple) and heterogeneity of workers (high- vs low-skilled).

There are three types of markets: labor, goods and capital. On the labor side, we distinguish between the complex and the simple job markets, where the complex jobs can only be occupied by high-skilled workers and simple jobs by both high- and low-skilled workers. For each type of job, we assume an exogenous job destruction rate and represent the matching process by a standard matching function (Cobb-Douglas). Because they know that their application will always be

[2]The representative household formulation amounts to assuming that workers of a given group are perfectly insured against their own individual unemployment risk. This simplification is common in the literature and is needed to keep the model tractable.

turned down, low-skilled job seekers never apply for complex jobs. High-skilled unemployed workers may look for both types of jobs. Furthermore, the set of parameter values adopted in the model guarantees the absence of corner solutions, *i.e.* there is always a number of high-skilled workers in simple jobs. High-skilled workers hired on a simple job may continue searching for a complex job (on-the-job search). Low-skilled unemployed workers may search more or less intensively for a simple job, depending on its attractiveness compared to home production. All good markets (the two intermediate goods and the final good markets) are assumed to be perfectly competitive. The price of the final good is normalized to one. On the capital market, the supply is determined by the stock of capital previously accumulated by the household (as explained in section 2.5 all capital stock is owned by the high-skilled household). The interest rate adjusts to make the quantity demanded by the representative final firm equal to this predetermined capital stock.

Labor market flows are detailed in the following subsection. Next we successively discuss the behaviors of the intermediate and final firms, the mechanisms of biased technological change and capital accumulation, the behaviors of high- and low-skilled households and, finally, the wage determination processes.

## 2.1 Labor market flows

Let $N_t^c$ and $N_t^s$ represent total employment in complex and simple jobs, respectively. Simple jobs can be occupied by high- ($N_t^{sh}$) or low-skilled ($N_t^{sl}$) workers, so that $N_t^s = N_t^{sh} + N_t^{sl}$. Normalizing the total labor force to one and denoting by $\alpha$ the exogenous[3] proportion of high-skilled workers in the total labor force yields the following accounting identities:

$$N_t^c + N_t^{sh} + U_t^h = \alpha, \qquad \text{and} \qquad N_t^{sl} + U_t^l = 1 - \alpha, \tag{1}$$

where $U_t^h$ and $U_t^l$ denote the number of high- and low-skilled unemployed job-seekers respectively. Let the number of complex and simple job matches be denoted by $M_t^c$ and $M_t^s$ respectively. We assume that the number of such matches is a function of the number of corresponding job vacancies ($V_t^c$ and $V_t^s$) and effective job seekers (the number of job seekers weighted by their

[3]An endogenous $\alpha$ would require the model to consider human capital formation and education issues, which is beyond the scope of the present paper.

search efficiencies), that is, we use the following two matching functions:

$$M_t^c = M^c\left(V_t^c\ ,\ sc_t\, U_t^h + so_t\, N_t^{sh}\right) \qquad \text{and} \qquad M_t^s = M^s\left(V_t^s\ ,\ sh_t\, U_t^h + sl_t\, U_t^l\right)\ , \quad (2)$$

where $sc_t$, $so_t$, $sh_t$ and $sl_t$ stand for the search efficiency of each type of job seeker. Both functions are assumed to be linear homogeneous (Cobb-Douglas). We assume that every period, both the high- and the low-skilled unemployed workers spend a certain amount of time having what we call an *active life*. In other words, every period, a constant fraction of time is spent on searching for a job or doing other productive activities (in our case, domestic production), while the rest of the time is devoted to non-productive activities (such as sleeping, eating, etc.). We assume that the amount of time spent in *active life* is the same for high- and low-skilled workers, and we normalize it to one.

Given the conditions prevailing on the labor market (wages, probabilities to find jobs, ...), a high-skilled unemployed allocates its *active* time between searching for a complex job ($0 \leq eh_t \leq 1$) and searching for a simple job ($0 \leq 1 - eh_t \leq 1$). Since the worker knows that he has a positive probability of being hired in any of the two types of jobs and it is always more profitable to be occupied in a complex or a simple job rather than to stay at home doing domestic activities, the high-skilled worker spends all his *active* time searching in both labor market segments. High-skilled on simple jobs spend a fraction ($0 \leq eo_t \leq 1$) of their leisure time (normalized to 1) searching for a complex job. Besides, a low-skilled unemployed splits his *active* time between searching for a job in the simple segment ($0 \leq el_t \leq 1$) and staying at home doing domestic activities ($0 \leq 1 - el_t \leq 1$). Because they know that their application will always be turned down, low-skilled job seekers never apply for complex jobs, so when they are not looking for a job in the simple segment, they simply stay at home doing domestic activities. We have, therefore, an asymmetry in the behavior of high- and low-skilled workers that results from the asymmetry between complex jobs, which can only be occupied by high-skilled workers, and simple jobs, which can be occupied by both types of workers. Search efficiencies, $so_t$, $sc_t$, $sh_t$ and $sl_t$ are concave and increasing functions of the search efforts, $eo_t$, $eh_t$, $1 - eh_t$ and $el_t$, respectively.

We define labor market tensions as the ratio between the number of vacancies and the number of effective job seekers and denote them by $\vartheta_t^c$ and $\vartheta_t^s$ respectively, where:

$$\vartheta_t^c \equiv \frac{V_t^c}{sc_t\, U_t^h + so_t\, N_t^{sh}} \qquad \text{and} \qquad \vartheta_t^s \equiv \frac{V_t^s}{sh_t\, U_t^h + sl_t\, U_t^l}. \tag{3}$$

With linear homogeneous matching functions, the probabilities $p_t^c$ and $p_t^s$ of finding a complex or a simple job per unit of search intensity can be respectively written as follows:

$$p_t^c = \frac{M_t^c}{sc_t\, U_t^h + so_t\, N_t^{sh}} = p^c\left(\vartheta_t^c\right) \qquad \text{and} \qquad p_t^s = \frac{M_t^s}{sh_t\, U_t^h + sl_t\, U_t^l} = p^s\left(\vartheta_t^s\right). \tag{4}$$

The probabilities $q_t^c$ and $q_t^s$ of filling a complex and a simple job vacancy are similarly given by:

$$q_t^c = \frac{M_t^c}{V_t^c} = q^c\left(\frac{1}{\vartheta_t^c}\right) \qquad \text{and} \qquad q_t^s = \frac{M_t^s}{V_t^s} = q^s\left(\frac{1}{\vartheta_t^s}\right). \tag{5}$$

The probability that a simple job is filled is the sum of the probabilities of hiring a high-skilled worker and a low-skilled worker:

$$q_t^{sh} = \frac{sh_t\, U_t^h}{sh_t\, U_t^h + sl_t\, U_t^l}\, q_t^s \qquad \text{and} \qquad q_t^{sl} = \frac{sl_t\, U_t^l}{sh_t\, U_t^h + sl_t\, U_t^l}\, q_t^s. \tag{6}$$

Finally, we assume two exogenous job destruction rates, $\chi^c$ (for the complex jobs) and $\chi^s$ (for the simple jobs), which implies for each type of job and worker the following employment dynamics (in terms of vacancies and job-seekers' search effort respectively):

$$\begin{aligned} N_{t+1}^c &= (1-\chi^c)\, N_t^c + q_t^c\, V_t^c, & (7)\\ &= (1-\chi^c)\, N_t^c + p_t^c\, \left[sc_t\, U_t^h + so_t\, N_t^{sh}\right]. & (8)\end{aligned}$$

$$\begin{aligned} N_{t+1}^{sh} &= (1-\chi^s - so_t\, p_t^c)\, N_t^{sh} + q_t^{sh}\, V_t^s, & (9)\\ &= (1-\chi^s - so_t\, p_t^c)\, N_t^{sh} + p_t^s\, sh_t U_t^h. & (10)\end{aligned}$$

$$\begin{aligned} N_{t+1}^{sl} &= (1-\chi^s)\, N_t^{sl} + q_t^{sl}\, V_t^s, & (11)\\ &= (1-\chi^s)\, N_t^{sl} + p_t^s\, sl_t U_t^l. & (12)\end{aligned}$$

Figure 1 summarizes these labor market flows and transition probabilities. Armed with these definitions and notations, we can now describe the behaviors of the firms and households.

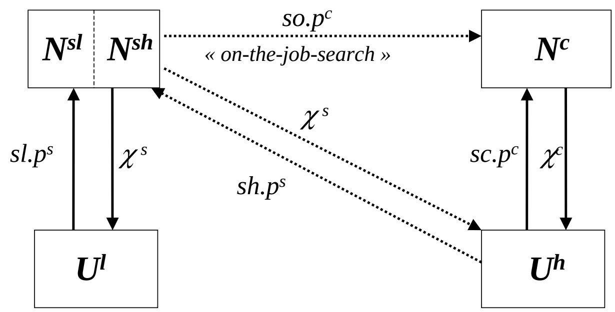


Figure 1: Labor market flows and transition probabilities.

## 2.2 Intermediate firms

We use the standard one-job-one-firm representation. Each intermediate firm can open either a complex or a simple vacancy. Let us denote the asset value[4] of a vacant (resp. filled) complex job by $W^V_{N^c_t}$ (resp. $W^F_{N^c_t}$). The cost of opening a complex vacancy equals $v^c_t$ per period. A filled complex job produces each period one unit of complex intermediate good sold at a price $c^c_t$; the wage paid to the worker is denoted $w^c_t$. The asset values of the vacant and filled complex jobs are then given by:

$$W^V_{N^c_t} = -v^c_t + \mathrm{E}_t\left[\tilde{\beta}_{t+1}\left(q^c_t\, W^F_{N^c_{t+1}} + (1-q^c_t)\, W^V_{N^c_{t+1}}\right)\right], \tag{13}$$

$$W^F_{N^c_t} = c^c_t - w^c_t + \mathrm{E}_t\left[\tilde{\beta}_{t+1}\left((1-\chi^c)\, W^F_{N^c_{t+1}} + \chi^c\, W^V_{N^c_{t+1}}\right)\right], \tag{14}$$

$$\tag{15}$$

where $\tilde{\beta}_{t+1}$ is the firm's discount factor (defined in section 2.5).

Simple job vacancies can be filled with either a high-skilled or a low-skilled worker. The two workers may however have different productivity. Let $W^V_{N^s_t}$ denote the asset value of a vacant simple job. The asset value of a filled simple job will be denoted $W^F_{N^{sh}_t}$ when filled by a high-skilled worker and $W^F_{N^{sl}_t}$ when filled by a low-skilled worker. Let $v^s_t$ denote the vacancy cost per period, $c^s_t$ the selling price, $w^{sh}_t$ and $w^{sl}_t$ the wage paid to the high- and low-skilled worker

[4]The asset value is equal to the discounted value of all expected current and future profits. This value is, of course, different for a firm with a filled or a vacant job.

respectively. Asset values are then given by:

$$W^V_{N^s_t} = -v^s_t + \mathrm{E}_t\left[\tilde{\beta}_{t+1}\left(q^{sh}_t\, W^F_{N^{sh}_{t+1}} + q^{sl}_t\, W^F_{N^{sl}_{t+1}} + (1-q^{sh}_t-q^{sl}_t)\, W^V_{N^s_{t+1}}\right)\right], \tag{16}$$

$$W^F_{N^{sh}_t} = c^s_t - w^{sh}_t + \mathrm{E}_t\left[\tilde{\beta}_{t+1}\left((1-\chi^s-p^c_t\, so_t)\, W^F_{N^{sh}_{t+1}} + (\chi^s+p^c_t\, so_t)\, W^V_{N^s_{t+1}}\right)\right], \tag{17}$$

$$W^F_{N^{sl}_t} = \nu\,.\,c^s_t - w^{sl}_t + \mathrm{E}_t\left[\tilde{\beta}_{t+1}\left((1-\chi^s)\, W^F_{N^{sl}_{t+1}} + \chi^s\, W^V_{N^s_{t+1}}\right)\right], \tag{18}$$

where the parameter $\nu$ allows different productivity levels for high- and low-skilled workers ($\nu$ may *a priori* be larger or smaller than unity). We finally assume the usual free entry conditions (the firms open vacancies until no benefit can be obtained from an additional vacancy):

$$W^V_{N^c_t} = W^V_{N^s_t} = 0. \tag{19}$$

### 2.3 Final firm

The representative final firm uses capital ($K_t$), complex and simple intermediate goods ($Q^c_t$ and $Q^s_t$ respectively) in order to produce a final good *via* a linear homogeneous production function $F\big(K_t, Q^c_t, Q^s_t\big)$. The firm's optimization problem can be represented by:

$$\max_{K_t,\, Q^c_t,\, Q^s_t} F\big(K_t, Q^c_t, Q^s_t\big) - c^K_t\, K_t - c^c_t\, Q^c_t - c^s_t\, Q^s_t\ , \tag{20}$$

where $c^K_t$ is the usage cost of capital, while $c^c_t$ and $c^s_t$ stand, respectively, for the price of complex and simple intermediate goods. The first order optimality conditions are given by the standard marginal productivity conditions:

$$F_{K_t} = c^K_t\ , \qquad F_{Q^c_t} = c^c_t\ , \qquad F_{Q^s_t} = c^s_t\ , \tag{21}$$

where $F_{X_t}$ stands for the first derivative of $F$ with respect to $X_t$. In the rest of the paper, we assume a Cobb-Douglas production function with constant returns to scale:

$$F(K_t, Q^c_t, Q^s_t) = z\left[K_t\right]^{1-\mu}\left[\big(Q^c_t\big)^{\theta^c_t}\big(Q^s_t\big)^{\theta^s_t}\right]^{\mu}, \qquad \theta^c_t + \theta^s_t = 1\ , \tag{22}$$

where $z$ represents total factor productivity and $1-\mu$ is the capital share. As discussed below, we allow the productivity coefficients, $\theta^c_t$ and $\theta^s_t$, of the two intermediate inputs to vary over time. Notice that the equilibrium conditions in the intermediate goods markets imply:

$$Q^c_t = N^c_t \qquad \text{and} \qquad Q^s_t = N^{sh}_t + \nu N^{sl}_t\ , \tag{23}$$

so that changes in the values of $\theta_t^c$ and $\theta_t^s$ induce changes in the marginal productivity (in value added terms) of complex and simple jobs respectively.

### 2.4 Skill-Bias

The empirical evidence reveals that the use of new technologies is associated to an increased relative demand for skilled labor, as a result of either technological requirements (see Berman, Bound, and Griliches (1994) for an example on the U.S. economy and Machin, Ryan, and Van Reenen (1998) for European countries) or induced organizational changes (see for instance Caroli and Van Reenen (2001) and Bresnahan, Brynjolfsson, and Hitt (2002)). This suggests that the change in the demand for skilled labor should best be seen as a result from a combination of embodied technological progress and capital-skill complementarity. The empirical relevance of these two aspects has been emphasized by Greenwood, Hercowitz, and Krussel (2002) or Mairesse, Cette, and Kocoglu (2000) for embodied technological progress and by Berman, Bound, and Griliches (1994), Krusell et al. (2000), Lindquist (2004) or Machin, Ryan, and Van Reenen (1998), among others, for capital-skill complementarity. In line with this empirical literature, we consider that the change in the relative demand for high-skilled workers is associated to embodied technological progress.

We model the embodiment process by allowing new investment goods to be more productive than older ones, which is simple to formalize and, at the same time, seems quite intuitive. Following Boucekkine, del Rio, and Licandro (2002), we write the law of motion of capital[5] as:

$$K_{t+1} - K_t = e_t \, I_t - \delta \, K_t \, , \qquad 0 < \delta < 1 \, , \tag{24}$$

where $I_t$ denotes investment expenditures and $\delta$ is the exogenous depreciation rate of capital. The variable $e_t$ is an index measuring the marginal contribution of investment expenditures to the aggregate capital stock (it stands for the embodied technological progress). The term $1/e_t$ is interpreted as the relative price of new capital goods. The increase in the decline rate of the relative price of new capital goods over the last 30 years can thus be attributed to an increase in the importance of embodied technological progress, *i.e.* a rise in $e_t$ implies a fall in $1/e_t$.

[5] Boucekkine, del Rio, and Licandro (2002) show that this simple representation can be obtained from an explicit vintage model.

We represent this type of embodied technical progress by a simple *learning-by-doing* (LBD) process (Arrow (1962)), *i.e.* the productivity of the capital goods sector, measured by $e_t$, is a positive function of the size of that sector, measured by $K_t$:

$$e_t = e_0 \, K_t^{\gamma} \; , \qquad \gamma \geq 0 \; , \tag{25}$$

where $e_0$ is the scale parameter and $\gamma$ measures the efficiency of the LBD process. Equations (24) and (25) describe this process: for each unit of final good invested in period $t$, we obtain $e_t > e_{t-1}$ units of capital. These productivity gains generated by the LBD lead to lower capital good prices, which stimulates investment, increases the total capital stock, and (via the learning process described in equation (25)) leads to further productivity gains. This process comes to an end when these productivity gains ($\Delta e_t$) are more than compensated by the decrease in the marginal productivity of capital ($\Delta F_{K_t}$).

The complementarity relationship between capital and skills is introduced by allowing the use of new technologies to change the relative productivity (in value added terms) of skilled labor:

$$\frac{\theta_t^c}{\theta_t^s} = a_0 \, e_t^{a_1} \; , \quad a_1 \geq 0 \; . \tag{26}$$

An upturn in $e_t$ (either coming from an increase in the learning efficiency, $\gamma$, or from a more important capital accumulation) improves the productivity of new investment goods and complex intermediate goods (which stimulates the relative demand for high-skilled labor). This specification endogenizes the observed complementarity between new technologies and skilled labor and keeps the Cobb-Douglas production function framework supported by the aggregate evidence and used in most dynamic macro models[6].

## 2.5 Households

The household decisions bear on consumption and savings and on job search intensities. To avoid untractable *ex post* heterogeneity issues, most general equilibrium models with search assume

[6]Manacorda and Petrongolo (1999) estimate a production function with two types of labor for several OECD countries and conclude that the Cobb-Douglas hypothesis cannot be rejected; biased technical progress takes the form of an exogenous change in the productivity coefficients. The Cobb-Douglas specification is also motivated in the RBC literature by the observation that the capital share remains stable in the long run.

that workers are perfectly insured against individual unemployment risks. Assuming a large representative household is a simple way of introducing such an assumption. For our purpose, it is important though to distinguish at least two types of households, a high- and a low-skilled household. Employment probabilities and expected wage incomes are quite different for high- and low-skilled workers. This will affect their search behaviors, as well as the negotiated wages. To simplify we assume that the whole capital stock is owned by the high-skilled (high-income) household. This amounts to assuming that the low-skilled household consumes its current income in every period.

**The representative high-skilled household**

The members of the high-skilled household can be either unemployed, employed on a complex job getting paid a wage $w_t^c$, or employed on a simple job getting paid a wage $w_t^{sh}$. The decision variables of the household are the consumption level of each of its members and the amount of time devoted to job search for those who are unemployed or employed on a low-paid simple job. We assume that unemployed job seekers devote all their free time (normalized to unity) to search; they choose the fraction of this time, $eh_t$, that will be devoted to the complex market. Similarly, workers on a simple job devote a fraction, $eo_t$, of their leisure time to "on-the-job search". The optimization problem of the representative high-skilled household can be written as the following Bellman equation (see appendix A for a detailed explanation on this type of equations):

$$\mathcal{W}_t^H = \max_{C_t^h,\, eh_t,\, eo_t} \left\{ \alpha\, \mathcal{U}\left(\frac{C_t^h}{\alpha}\right) - N_t^{sh}\, \mathcal{D}\left(eo_t\right) + \beta\, \mathrm{E}_t\Big[\mathcal{W}_{t+1}^H\Big] \right\}, \tag{27}$$

subject to constraints (1), (8), (10) and to the flow budget constraint :

$$w_t^c N_t^c + w_t^{sh} N_t^{sh} + w_t^u U_t^h + c_t^k\, K_t + \Pi_t = \frac{1}{e_t}\, \Big(K_{t+1} - (1-\delta)K_t\Big) + C_t^h + T_t. \tag{28}$$

$\mathcal{W}_t^H$ is a function of the initial values of the three state variables $K_t, N_t^c, N_t^{sh}$; $\mathcal{U}(.)$ is an increasing and concave function of per capita consumption ($C_t^h$ measures thus the total consumption of the high-skilled household); $\mathcal{D}(.)$ is an increasing and convex function of the amount of leisure time devoted to on-the-job search; $\beta$ is a psychological discount factor. The resources of the high-skilled household include wage incomes, an unemployment benefit $w_t^u$, the rents from capital plus the profits $\Pi_t$ redistributed by the intermediate goods firms. Investment expenditures are equal to net capital accumulation times the relative price of new capital goods $1/e_t$ (see (24)). $T_t$ represents a lump-sum tax levied on the high-skilled household to finance government expenditures.

Let us define $r_t$ as the net interest rate measured in units of capital[7]. More precisely:

$$r_t = c_t^k \,.\, e_t - \delta \; . \tag{29}$$

Let us also define the asset values (from the high-skilled household's point of view) of an additional complex or simple job as:

$$W^H_{N^c_t} = \frac{1}{\mathcal{U}_{C^h_t}} \; \frac{\partial \mathcal{W}^H_t}{\partial N^c_t} \qquad \text{and} \qquad W^H_{N^{sh}_t} = \frac{1}{\mathcal{U}_{C^h_t}} \; \frac{\partial \mathcal{W}^H_t}{\partial N^{sh}_t} \; , \tag{30}$$

respectively. The first-order optimality conditions can then be written as follows:

$$\mathcal{U}_{C^h_t} \;=\; \beta \, \mathrm{E}_t \left[ \left(1 + r_{t+1}\right) \frac{e_t}{e_{t+1}} \; \mathcal{U}_{C^h_{t+1}} \right] , \tag{31}$$

$$0 \;=\; \mathrm{E}_t \left[ p^c_t \; sc_{eh_t} \; \tilde{\beta}_{t+1} \; W^H_{N^c_{t+1}} - p^s_t \; sh_{1-eh_t} \; \tilde{\beta}_{t+1} \; W^H_{N^{sh}_{t+1}} \right] , \tag{32}$$

$$\frac{\mathcal{D}_{eo_t}}{\mathcal{U}_{C^h_t}} \;=\; p^c_t \; so_{eo_t} \; \mathrm{E}_t \left[ \tilde{\beta}_{t+1} \left( W^H_{N^c_{t+1}} - W^H_{N^{sh}_{t+1}} \right) \right] \; , \tag{33}$$

where the discount factor $\tilde{\beta}_{t+1}$ is defined by:

$$\tilde{\beta}_{t+1} = \beta \, \frac{\mathcal{U}_{C^h_{t+1}}}{\mathcal{U}_{C^h_t}} \; . \tag{34}$$

[7] The optimal capital stock is defined by the usual optimality condition:

$$F_{K_t} = c^K_t$$

where $F_{K_t}$ stands for the marginal productivity of capital and $c^K_t$ for the capital usage cost. We should keep in mind, however, that the marginal productivity of capital, $F_{K_t}$, is defined in terms of final goods, while the rate of return to investors is defined in terms of capital goods. The relative price of the latter is $1/e_t$. Hence, the marginal cost of capital, $c^K_t$, is related to the rate of return by:

$$c^K_t = \frac{1}{e_t}(r_t + \delta) \; .$$

From the envelope theorem, we can obtain the following additional dynamic relationships:

$$\begin{aligned} W^H_{N^c_t} &= \left(w^c_t - w^u_t\right) + \left(1 - \chi^c - p^c_t\, sc_t\right) \mathrm{E}_t\left[\tilde{\beta}_{t+1}\, W^H_{N^c_{t+1}}\right] \\ &\quad - p^s_t\, sh_t\, \mathrm{E}_t\left[\tilde{\beta}_{t+1}\, W^H_{N^{sh}_{t+1}}\right], \qquad (35) \\ W^H_{N^{sh}_t} &= \left(w^{sh}_t - w^u_t\right) - \mathcal{D}\left(eo_t\right)/\mathcal{U}_{C^h_t} + p^c_t\left(so_t - sc_t\right) \mathrm{E}_t\left[\tilde{\beta}_{t+1}\, W^H_{N^c_{t+1}}\right] \\ &\quad + \left(1 - \chi^s - so_t\, p^c_t - p^s_t\, sh_t\right) \mathrm{E}_t\left[\tilde{\beta}_{t+1}\, W^H_{N^{sh}_{t+1}}\right]. \qquad (36) \end{aligned}$$

**The representative low-skilled household**

While high-skilled unemployed workers can search for a job on both the complex and the simple job markets, low-skilled unemployed workers have only the choice between searching for a simple job or doing some "domestic production". By assumption, the low-skilled household accumulates no capital. Its sole decision variable is the fraction of time $el_t$ that the unemployed worker devotes to job search rather than to domestic activities. Its optimization problem can thus be written as the following Bellman equation:

$$\mathcal{W}^L_t = \max_{el_t} \left\{ (1-\alpha)\, \mathcal{U}\left(\frac{C^l_t}{1-\alpha}\right) + \beta\, \mathrm{E}_t\left[\mathcal{W}^L_{t+1}\right] \right\}, \qquad (37)$$

subject to (12) and the flow budget constraint:

$$C^l_t = w^{sl}_t N^{sl}_t + U^l_t \left[ w^u_t + (1-el_t)\, y^d_t \right]. \qquad (38)$$

$\mathcal{W}^L_t$ is a function of the initial value of the state variable $N^{sl}_t$, $C^l_t$ is the total amount consumed by the low-skilled household and $y^d_t$ is the productivity of unemployed workers on domestic activities.

The first order optimality condition can be written as follows:

$$y^d_t = p^s_t\, sl_{el_t}\, \mathrm{E}_t\left[\hat{\beta}_{t+1}\, W^L_{N^{sl}_{t+1}}\right], \qquad (39)$$

where $\hat{\beta}_{t+1} = \beta\, \mathcal{U}_{C^l_{t+1}}/\mathcal{U}_{C^l_t}$ is the discount factor of the low-skilled household and $W^L_{N^{sl}_t} = \frac{1}{\mathcal{U}_{C^l_t}}\, \frac{\partial \mathcal{W}^L_t}{\partial N^{sl}_t}$ the asset value of an additional simple job at time $t$. From the envelope theorem we obtain:

$$W^L_{N^{sl}_t} = \left( w^{sl}_t - w^u_t - (1-el_t)\, y^d_t \right) + \left(1 - \chi^s - p^s_t\, sl_t\right) \mathrm{E}_t\left[\hat{\beta}_{t+1}\, W^L_{N^{sl}_{t+1}}\right]. \qquad (40)$$

### 2.6 Wage determination

There are three types of matches (high-skilled worker on a complex or a simple job; low-skilled worker on a simple job). We assume that the wage rate is in each case determined at the beginning of every period by a Nash bargaining between the intermediate good firm and its worker, which yields the following sharing rules:

$$W^H_{N^c_t} = \eta^c \left( W^H_{N^c_t} + W^F_{N^c_t} \right) , \tag{41}$$

$$W^H_{N^{sh}_t} = \eta^{sh} \left( W^H_{N^{sh}_t} + W^F_{N^{sh}_t} \right) , \tag{42}$$

$$W^L_{N^{sl}_t} = \eta^{sl} \left( W^L_{N^{sl}_t} + W^F_{N^{sl}_t} \right) . \tag{43}$$

where $\eta^i$ for $i = c$, $sh$, $sl$, represent the workers' bargaining power.

## 3 Model calibration and simulations

In this section we calibrate the model and use deterministic simulation exercises to illustrate the properties of the model and gain insights on the effects of various types of shocks. The emphasis will be on the effects of labor force composition and biased technological changes and their interactions with "institutional" settings over the period 1976-1996.

### 3.1 Specification and calibration

The matching function on each job market is represented by the usual Cobb-Douglas specification with constant returns to scale:

$$M^c_t = m^c \left( V^c_t \right)^{1-\lambda^c} \left( sc_t \, U^h_t + so_t \, N^{sh}_t \right)^{\lambda^c} , \tag{44}$$

$$M^s_t = m^s \left( V^s_t \right)^{1-\lambda^s} \left( sh_t \, U^h_t + sl_t \, U^l_t \right)^{\lambda^s} , \tag{45}$$

for complex and simple jobs respectively. The Cobb-Douglas specification for the matching process is quite standard in the literature since it is mathematically simply to deal with and it seems to provide a good approximation of the real matching process (see Petrongolo and Pissarides (2001)). We follow Manacorda and Petrongolo (1999) and use also a constant returns to scale Cobb-Douglas function with three inputs to represent the technological constraint faced by the representative final firm (see equations (22) and (23)). The skill-biased change is seen as the consequence of embodied technological progress and capital-skill complementarity (see equations (25) and (26)). As in many RBC models, we represent the instantaneous utility of consumption by the logarithm of consumption expenditures. The leisure cost of on-the-job search is proportional to the amount of time spent and home productivity is assumed to be equal to a fraction $\psi$ of aggregate productivity. More formally:

$$\mathcal{U}_t = \ln c_t \,, \qquad \mathcal{D}_t = \tau \; eo_t \qquad \text{and} \qquad y_t^d = \psi \, \frac{y_t}{N_t} \,. \tag{46}$$

Search efficiencies are represented by linear functions of the square root of the time devoted to search:

$$so_t = \phi_0^o + \phi_1^o \sqrt{eo_t} \qquad \text{On-the-job search efficiency} \tag{47}$$

$$sc_t = \phi_0^c + \phi_1^c \sqrt{eh_t} \qquad \text{and} \qquad sh_t = \phi_0^h + \phi_1^h \sqrt{1 - eh_t} \tag{48}$$

High-skilled unemployed search efficiencies

$$sl_t = \phi_0^l + \phi_1^l \sqrt{el_t} \qquad \text{Low-skilled unemployed search efficiency} \tag{49}$$

We follow Pissarides (2000) and assume that recruiting costs are proportional to aggregate productivity:

$$v_t^c = v_0^c \, \frac{y_t}{N_t} \qquad \text{and} \qquad v_t^s = v_0^s \, \frac{y_t}{N_t} \,. \tag{50}$$

The parameters of the model are whenever possible set to values compatible with the available empirical evidence. The parameters for which no empirical estimates are available are chosen so as to reproduce the situation observed in Belgium[8] in the mid nineties (1996). As most EU countries, the Belgian economy was then neither in a recession nor in a boom. In terms of employment performance, the Belgian economy is in the EU average and quite representative of a typical "European" economy.

The numerical values of the parameters are reported in table 2. The reference period is the quarter. The elasticity of output with respect to capital coincides with the capital share in total

[8] All through the paper we assume a closed economy, while Belgium is an open economy. The assumption can thus be thought as being restrictive. However, extending the model to an open economy would not improve its explicative power on unemployment issues and would complicate the analysis, especially because the interest rate would be externally fixed.

| | Symbol | Value | Symbol | Value |
|---|---|---|---|---|
| Production | $z$ | 1 | $\mu$ | 0.66 |
| | $\nu$ | 1.00 | $\delta$ | 0.025 |
| | $e_0$ | 1.00 | $\gamma$ | 0.071 |
| | $a_0$ | 0.42 | $a_1$ | 10.2 |
| Labor force composition | $\alpha$ | 0.67 | | |
| Preferences | $\beta$ | 0.99 | $\tau$ | 0.30 |
| Domestic productivity | $\psi$ | 0.17 | | |
| Search efficiencies | $\phi_0^l$ | 0.25 | $\phi_1^l$ | 1.00 |
| | $\phi_0^h$ | 0.25 | $\phi_1^h$ | 1.00 |
| | $\phi_0^c$ | 0.25 | $\phi_1^c$ | 0.50 |
| | $\phi_0^o$ | 0.25 | $\phi_1^o$ | 0.50 |
| Matching efficiencies | $m^c$ | 0.38 | $\lambda^c$ | 0.50 |
| | $m^s$ | 0.38 | $\lambda^s$ | 0.50 |
| Bargaining power | $\eta^c$ | 0.50 | | |
| | $\eta^{sh}$ | 0.50 | $\eta^{sl}$ | 0.50 |
| Vacancy costs | $v_0^c$ | 0.55 | $v_0^s$ | 0.10 |
| Job destruction rates | $\chi^c$ | 0.03 | $\chi^s$ | 0.05 |
| Average replacement ratio | $bu$ | 0.34 | | |

Table 2: Numerical parameter values (year of reference: 1996).

income; it is set to the standard value $1-\mu = 0.33$ used in the RBC literature. The depreciation rate $\delta$ is set to 2.5%. We assume that high- and low-skilled workers are equally productive on simple jobs ($\nu = 1$). This particular choice has little impact on the predictions of the model. We fix the parameters describing the embodied technical progress so as to reproduce the change in the relative price of investment goods observed in Belgium during the period 1976-1996. We normalize the relative price to unity in 1976 (that is, $e_0$=1 and $\gamma = 0$ in 1976) and set the 1996 value of $\gamma$ to 0.0705 (implying $e_t = 1.23$ in 1996). The effects of embodied technical progress on the relative demand for high- and low-skilled workers are determined by the values of the parameters $a_0$ and $a_1$. These values are chosen so as to reproduce the 1976 and 1996 values of the Cobb-Douglas coefficients $\mu\theta^c$ and $\mu\theta^s$ reported in Sneessens and Shadman (2000).

We define the high-skilled group by an educational attainment level at least equal to a upper-secondary degree and set $\alpha = 0.67$, the 1996 value reported by Sneessens and Shadman (2000) for Belgium. As in most RBC models, consumers's psychological discount factor $\beta$ is set to 0.99, implying a steady state real interest rate of 0.01 (real interest rate of 4% per annum). The domestic productivity parameter $\psi$ is fixed at 0.17 (*i.e.* the domestic productivity of a low-skilled worker is equal to 17% of the average aggregate productivity), a value which seems reasonable and gives a realistic relative wage ($w^{sl}/w^{c} = 62\%$, a value close to the relative mean gross wage of the 33% lowest-paid full-time workers (see OECD (1996)).

Our representation of the wage determination process remains of course simplified compared to the complexity of the Belgian system. In Belgium, there are three levels of wage negotiation: the intra-sectoral (national) level, the sectoral level and the individual level. Every two years, negotiations at the intra-sectoral level determine the legal minimum wage, as well as the "wage norm". More regularly, wage negotiations are also held within the different economic sectors where the legal minimum wage and the wage norm are taken respectively as the lower and upper bounds. Eventually, wages may, at each period, be (re)negotiated at the individual level. As a consequence, in 1995, only 2% of Belgian workers were paid at the legal minimum wage. This small percentage remains coherent with the quantitative results presented in this paper. More precisely, following Joseph, Pierrard, and Sneessens (2004) we fix the net Katz index (defined as the ratio of the minimum wage to the average wage) to 0.58, so that we obtain for 1996 a minimum wage of 0.7. This value is bigger than the value associated to domestic activities, meaning that it is always in the interest of a low-skilled worker to accept a job paid at the legal minimum wage rather than staying at home. On the other side, we realize that the wage earned in simple jobs equals 0.8, and whatever the shocks we introduce, it never falls below the minimum wage (probably due to the rigidity introduced by the presence of an indexed domestic productivity).

We have four search intensity equations, two for each segment of the labor market. We impose identical parameter values for a given segment, which leaves four values to fix. The simple job market search intensity coefficients have been chosen so as to normalize low-skilled workers' search intensity to unity in 1976 and have a sensitivity to labor market tightness in the order of magnitude estimated by Patacchini and Zenou (2003) (around 0.3). The complex market search intensity coefficients, the disutility parameter $\tau$, the two matching efficiency parameters and the vacancy cost parameters ($v_0^c$ and $v_0^s$) are given values to reproduce the 1996 values of the high- and low-skilled unemployment rates (6.8% and 20.1%, respectively), the probabilities of filling a vacant complex or simple job ($q_t^c$ and $q_t^s$, around 0.4; see Delmotte, Hootegem, and Dejonckheere (2001)) and the probabilities of finding a complex or a simple job (values $p_t^s$ and $p_t^c$ such that the probability to find a job is around 20% for a low-skilled worker and 40% for a high-skilled-worker; see Cockx and Dejemeppe (2004)). Our calibration of $v_0^c$ and $v_0^s$ implies that total vacancy costs represent 3.5% of output in the reference simulation.

We follow most authors and set the parameter determining the worker's share in a match surplus equal to the coefficient of unemployment in the matching function (see for instance Merz (1995) and Andolfatto (1996))[9]. The latter is set at 0.5, a value obtained in many empirical estimates of the Cobb-Douglas matching function (see Petrongolo and Pissarides (2001)) and that provides reasonable results in our simulations. Calibrations for the average replacement ratio[10] ($bu =$ 34%) and the two job destructions rates ($\chi^c = 3\%$ and $\chi^s = 5\%$) are based on estimations by Van der Linden and Dor (2001) for the Belgian economy. A result of this calibration exercise is that the proportion of high-skilled workers in simple jobs equals 7.3%. Even if this result contrasts with the 24% job competition effect found in Denolf, Denys, and Simoens (2001) for the Belgian economy, we must not forget that our theoretical setup considers job competition only between two groups of workers: high- and low-skilled. However, as pointed by Cockx and Dejemeppe (2004), the competition is probably more intense inside groups. Our ladder effect under-estimates thus the true job competition effect.

### 3.2 Technological shocks, labor force composition and unemployment

We examine the steady state effects of three different types of shocks in order to test the properties of the model[11]. First, we consider a change in labor force composition (an increase

[9] This choice is typically motivated by the so-called Hosios-Pissarides efficiency condition. It is worth noting that in our setup with job competition this condition may not be sufficient to ensure efficiency.

[10] The replacement ratio is defined as the relationship between the unemployment benefits and the average labor income.

[11] To test the robustness of the results, we verify that the variation of every endogenous variable keeps the same sign whatever the size of the shock introduced on the particular exogenous variable. The final size of each shock is chosen in order to be as reasonable as possible with what seems realistic.

in the proportion of high-skilled in the total labor force, $\alpha$). Next we look at two different types of productivity shock (aggregate technological shock, $z$, and embodied technical shock, $\gamma$). Moreover we implement a historical comparison simulation about Belgian unemployment rates and relative wages. The results[12] for the long-run effects are summarized in tables 3 to 6. We briefly comment each exercise.

### Labor force composition

A rise in the proportion of high-skilled workers in the total labor force ($\alpha$) increases the probability to fill a complex job, and thus stimulates the opening of complex vacancies. The higher number of complex jobs improves the marginal productivity of simple jobs, increasing simple wages and stimulating search effort of low-skilled workers ($el_t$).

| | Low-skilled search efficiency | High-skilled unemployment rate | Low-skilled unemployment rate | Aggregate unemployment rate | Relative wage | Ladder effect |
|---|---|---|---|---|---|---|
| Benchmark simulation corresponding to the year 1996 | 55.7% | 7.0% | 21.0% | 11.7% | 62.1% | 7.2% |
| Proportion of high-skilled workers: $\alpha = 0.67 \rightarrow \alpha = 0.70$ | +12.8 | -0.4 | -3.2 | -1.6 | +2.7 | +2.4 |

Table 3: Steady state effects (deviations from the benchmark) of an increase in the proportion of high-skilled workers.

On the other side, the higher demand for simple jobs raises the probability of hiring high-skilled workers on this type of jobs. Their search effort on the simple segment is then stimulated and the ladder effect increases. All in all, the low-skilled unemployment rate decreases and so does the high-skilled unemployment rate (see table 3).

### Aggregate technological shock

A positive disembodied technological shock (table 4 summarizes the effects of a 5% increase in $z$) raises marginal productivity of all factors. As capital cumulates, marginal productivity of

[12] For the variables expressed in percentage, deviations from the benchmark are absolute deviations; for the variables expressed in level, deviations from the benchmark are relative deviations.

complex jobs is even more stimulated *via* the capital-skill complementarity relationship. In spite of the higher negotiated wages, demand for both types of jobs increases (due to the improved productivity). All search efforts ($eh_t$, $eo_t$, $el_t$) are thus stimulated and unemployment rates decrease.

| | Low-skilled search efficiency | High-skilled unemployment rate | Low-skilled unemployment rate | Aggregate unemployment rate | Relative wage | Ladder effect |
|---|---|---|---|---|---|---|
| Benchmark simulation corresponding to the year 1996 | 55.7% | 7.0% | 21.0% | 11.7% | 62.1% | 7.2% |
| Total factor productivity: $z = 1.00 \rightarrow z = 1.05$ | +8.2 | -0.3 | -2.2 | -0.9 | -4.8 | -1.5 |

Table 4: Steady state effects (deviations from the benchmark) of an increase in total factor productivity.

### Biased technological shock

Table 5 considers the effects of an embodied technological shock. The increase in $\gamma$ improves the learning efficiency of the embodied technical progress production process (from each unit of investment the economy is able to obtain more capital than before). Capital accumulation is then accelerated, which *via* capital-skill complementarity stimulates the demand for complex jobs. This, together with the rise in complex wages, results in an increased search effort of high-skilled unemployed ($eh_t$) and employed ($eo_t$) on the complex segment of the labor market.

| | Low-skilled search efficiency | High-skilled unemployment rate | Low-skilled unemployment rate | Aggregate unemployment rate | Relative wage | Ladder effect |
|---|---|---|---|---|---|---|
| Benchmark simulation corresponding to the year 1996 | 55.7% | 7.0% | 21.0% | 11.7% | 62.1% | 7.2% |
| Efficiency of the embodied technical progress learning process: $\gamma = 0.71 \rightarrow \gamma = 0.74$ | -8.3 | +0.2 | +2.9 | +1.1 | -3.3 | -1.3 |

Table 5: Steady state effects (deviations from the benchmark) of a biased technological progress.

The larger share of complex jobs in the production function implies a reduction in the share of simple jobs, leading to a fall in the demand of this type of jobs as well as in their productivity. Wages decrease and so does the search effort of low-skilled unemployed ($el_t$). Because both categories of workers benefit from simple jobs, a downturn in their demand affects both types of unemployment rates. This explains the rise in high-skilled unemployment in spite of the higher demand for complex jobs.

### 3.2.1 Historical comparison

The first row of table 6 reproduces the 1996 values of the proportion of high-skilled workers in the labor force ($\alpha$), the share of complex jobs in the production function ($\mu\theta^c$), the net skill-bias[13], the high- and low-skilled unemployment rates, the relative wage ($w^{sl}/w^c$) and the ladder effect. On the second row we display the change observed for these variables over the period 1976-1996.

The last two rows of table 6 contain the values predicted by the model for 1996 (benchmark simulation) as well as the predicted variation between 1976 and 1996 when we introduce the observed increase in the proportion of high-skilled workers and the observed rise in the decline rate of the relative prices of new investment goods (we combine a variation in $\alpha$ (table 3) with a variation in $\gamma$ (table 5)). The model performs well not only in reproducing the increase in unemployment rates, but also in maintaining relative wage rigidity.

Within the theoretical framework developed in this paper the previous results are interpreted as follows. The post-1975 period in Belgium was characterized by an increase in the proportion of high-skilled workers in the labor force (from 21.5% to 67%), and by the rise in the decline rate of the investment good prices with respect to consumption prices (it attained values around -20% during the considered period). When introducing in our model both phenomena, we observe that the acceleration of embodied technological progress (which is at the origin of the higher decline rate in the relative prices of investment good, $1/e_t$) over the last decades has stimulated complex jobs creation and simple jobs destruction, *via* the capital-skill complementary relationship. The

[13] It is defined as the ratio of the relative productivity coefficient $\mu\ \theta_t^c/(\mu\ \theta_t^s)$ and the relative labor force $\alpha/(1-\alpha)$.

| | Prop. of high-skilled in the labor force | Share complex jobs in the production function | Net Skill Bias | High-skilled unemployment rate | Low-skilled unemployment rate | Relative wage | Ladder effect |
|---|---|---|---|---|---|---|---|
| **Actual data** | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.59 | 6.8% | 20.1% | 66% | n.a. |
| 1976-96 absolute deviations | +0.45 | +0.33 | +0.20 | +2.1 | +13.3 | -0.0 | n.a. |
| **Model's simulation** | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 |

Table 6: Skill-bias, unemployment rates, relative wages and ladder effect in Belgium: comparing actual and simulated data.

increased demand for high-skilled workers in complex jobs has been more than satisfied by the large upturn in their supply. In contrast, the fall in the importance of the low-skilled labor force has not been enough to compensate the massive destruction of simple jobs and the increased job competition. Low-skilled unemployment raises by 13.3 percentage points.

### 3.3 Policy scenarios

In the previous section we tested the ability of the model to reproduce the observed variations in Belgian unemployment rates and relative wages between 1976 and 1996. This section presents alternative historic scenarios that would have arisen if different welfare policies had been implemented in 1996. Results are summarized in tables 7-11. We use the utility level of high-skilled workers $\mathcal{U}^h = ln(C_t^h/\alpha) - N_t^{sh}\ \mathcal{D}\left(eo_t\right)/\alpha$ as an indicator of the high-skilled welfare level. In the same way, the utility level of low-skilled, $\mathcal{U}^l = ln(C_t^l/(1-\alpha))$, proxies the welfare level of this type of workers. Because the utility functions are assumed to be welfare indicators, the attention must be focused on the variation of the value function (rather than on the specific value of the utility function). We will compare the final welfare attained by each type of worker under each policy context with respect to the welfare he obtained in the benchmark simulation corresponding to 1996.

Tables 7-11 consider five different policy scenarios and compare them to the benchmark simulation implemented in section 3.2.1. Comparisons are implemented in a static framework, that is, we compare the final steady states associated to each situation without considering the transitional dynamics.

- We start analyzing a policy measure giving to firms a proportional subsidy of 20% of low-skilled wages in 1996 (table 7), this measure being financed through a tax on high-skilled wages. This target policy turns out to be beneficial for both, high and low-skilled workers, in terms of unemployment reductions (this is consistent with the findings of Pierrard (2004) for the Belgian economy). Indeed, the subsidy increases the marginal value the firm obtains from low-skilled workers, which stimulates the opening of simple vacancies and, thus, search efforts in the simple segment. High-skilled unemployment rates slightly fall whereas low-skilled unemployment decreases considerably. In welfare terms, the comparison with respect to the reference simulation, reveals that this measure mainly favors low-skilled workers, whose welfare level clearly raises.

| | Prop. of high-skilled in the labor force | Share of complex jobs in production function | Net Skill Bias | High-sk. unempl. rate | Low-sk. unempl. rate | Relative wage | Ladder effect | High-sk. welfare indicator | Low-sk. welfare indicator |
|---|---|---|---|---|---|---|---|---|---|
| **Reference Simulation** | | | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% | 0.34 | -0.20 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 | -0.25 | -0.08 |
| **Proportional subsidy to low wages of 20% in 1996** | | | | | | | | | |
| 1996 | 0.67 | 0.52 | 1.80 | 6.8% | 13.0% | 71.8% | 7.2% | 0.33 | -0.09 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.29 | +2.0 | +5.2 | +6.3 | +5.7 | -0.25 | +0.02 |

Table 7: Comparing the reference simulation with a scenario characterized by the presence, in 1996, of a proportional subsidy to low-skilled wages of 20%.

- In table 8 we assume a situation where the replacement ratio is set to 17% (the half of its actual value) in 1976 and 1996. This measure mainly affects low-skilled workers, whose consumption is constrained by their revenue. Reducing the replacement ratio implies a reduction in the reservation wage. This stimulates employment since firms can now offer

| | Prop. of high-skilled in the labor force | Share of complex jobs in production function | Net Skill Bias | High-sk. unempl. rate | Low-sk. unempl. rate | Relative wage | Ladder effect | High-sk. welfare indicator | Low-sk. welfare indicator |
|---|---|---|---|---|---|---|---|---|---|
| **Reference Simulation** | | | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% | 0.34 | -0.20 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 | -0.25 | -0.08 |
| **Replacement ratio of 17% in 1976 and in 1996** | | | | | | | | | |
| 1996 | 0.67 | 0.52 | 1.82 | 5.7% | 12.1% | 54.3% | 7.0% | 0.43 | -0.33 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.31 | +1.7 | +6.6 | -9.7 | +5.4 | -0.25 | -0.19 |

Table 8: Comparing the reference simulation with a scenario characterized by a replacement ratio of 17% in 1976 and 1996.

lower wages. Both unemployment rates fall, however, only high-skilled welfare is improved, since low-skilled workers suffer from an important loss in their revenue that results in a downturn of their consumption level.

- Table 9 combines the two previous policy measures. This policy mix leads to a Pareto improving situation where unemployment levels of both types of households are lower and their welfare is improved with respect to the reference simulation. The reduced replacement ratio stimulates employment, leading to a decrease in unemployment rates. At the same time, the subsidy to low-skilled wages avoids the loss in the welfare suffered by unskilled workers due to the downturn in their revenue.

- Table 10 combines a reduction in the replacement ratio to 17% during 1976-1996 and a proportional subsidy of 4% in 1996 to low-skilled consumption financed by a tax on high-skilled household consumption. This policy mix is also Pareto improving with respect to the reference simulation. Unemployment rates are lower and welfare levels higher. When comparing tables 9 and 10, we realize that subsidizing low-skilled household's consumption permits to increase their welfare by more than subsidizing their wages. However, in this last case, unskilled unemployment rates are lower. The policy maker faces then two possibilities:

| | Prop. of high-skilled in the labor force | Share of complex jobs in production function | Net Skill Bias | High-sk. unempl. rate | Low-sk. unempl. rate | Relative wage | Ladder effect | High-sk. welfare indicator | Low-sk. welfare indicator |
|---|---|---|---|---|---|---|---|---|---|
| **Reference Simulation** | | | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% | 0.34 | -0.20 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 | -0.25 | -0.08 |
| **Replacement ratio of 17% in 1976 and in 1996 and a subsidy to low-skilled wages of 20% in 1996** | | | | | | | | | |
| 1996 | 0.67 | 0.52 | 1.83 | 5.5% | 8.6% | 66.6% | 7.8% | 0.40 | -0.17 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.32 | +1.4 | +3.1 | +1.3 | +6.2 | -0.28 | -0.03 |

Table 9: Comparing the reference simulation with a scenario characterized by a replacement ratio of 17% in 1976 and 1996 and a proportional subsidy to low-skilled wages of 20% in 1996.

1. Having most low-skilled workers employed but benefitting from a low welfare level (subsidy to wages),
2. or having higher low-skilled unemployment rates but subsidize their consumption so that they can benefit from a higher welfare level.

| | Prop. of high-skilled in the labor force | Share of complex jobs in production function | Net Skill Bias | High-sk. unempl. rate | Low-sk. unempl. rate | Relative wage | Ladder effect | High-sk. welfare indicator | Low-sk. welfare indicator |
|---|---|---|---|---|---|---|---|---|---|
| **Reference Simulation** | | | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% | 0.34 | -0.20 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 | -0.25 | -0.08 |
| **Replacement ratio of 17% in 1976 and in 1996 and a subsidy to low-skilled consumption of 4% in 1996** | | | | | | | | | |
| 1996 | 0.67 | 0.52 | 1.83 | 5.7% | 12.1% | 54.3% | 7.0% | 0.41 | -0.09 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.31 | +1.7 | +6.6 | -9.7 | +5.4 | -0.27 | +0.05 |

Table 10: Comparing the reference simulation with a scenario characterized by a replacement ratio of 17% in 1976 and 1996 and a subsidy to low-skilled consumption of 4% in 1996.

- In table 11 we mix a reduction in the replacement ratio to 17% during 1976-1996 with a subsidy of 4% to low-skilled consumption and of 20% to low-skilled wages in 1996. Putting together the three policy measures allows to improve low-skilled workers' situation not only with respect to the benchmark simulation, but also with respect to the scenarios developed in tables 9 and 10. Regarding high-skilled workers, even if they benefit from lower unemployment rates, their welfare is reduced with respect to tables 9 and 10, since now they must finance two policy measures (their wages and their consumption are taxed).

| | Prop. of high-skilled in the labor force | Share of complex jobs in production function | Net Skill Bias | High-sk. unempl. rate | Low-sk. unempl. rate | Relative wage | Ladder effect | High-sk. welfare indicator | Low-sk. welfare indicator |
|---|---|---|---|---|---|---|---|---|---|
| **Reference Simulation** | | | | | | | | | |
| 1996 | 0.67 | 0.51 | 1.77 | 7.0% | 21.0% | 62.1% | 7.2% | 0.34 | -0.20 |
| 1976-96 absolute deviations | +0.45 | +0.32 | +0.25 | +2.1 | +13.3 | -3.4 | +5.8 | -0.25 | -0.08 |
| **Replacement ratio of 17% in 1976 and in 1996 and a subsidy to low-skilled consumption of 4% and to wages of 20% in 1996** | | | | | | | | | |
| 1996 | 0.67 | 0.52 | 1.83 | 5.3% | 8.6% | 66.6% | 7.8% | 0.37 | 0.04 |
| 1976-96 deviations | +0.45 | +0.32 | +0.32 | +1.4 | +3.1 | +2.7 | +6.3 | -0.31 | +0.18 |

Table 11: Comparing the reference simulation with a scenario characterized by a replacement ratio of 17% in 1976 and 1996, a subsidy to low-skilled consumption of 4% and to low-skilled wages of 20% in 1996.

Of course, policies based on subsidies to low-skilled wages are, at best, effective in the short and medium term (see Pierrard (2004)). However, in the long-run, an increase in the proportion of skilled in the total labor force seems more appropriate. More precisely, as suggested in various studies (see for example Cockx and Dejemeppe (2004)) a human capital investment policy would mitigate skill mismatch and job competition (according to CESRW (2001) only 3.7% of Belgian unemployed workers had participated in a training programme in 2000) and it would stimulate the appearance of technological sites that develop productive activities.

## 4 Conclusions

Over the last 30 years, European average unemployment rates and, especially, low-skilled unemployment rates have followed an increasing trend. Two reasons are traditionally put forward to explain this rise: (*i*) the adoption of new technologies being more demanding in skilled labor, combined with a rigidity in relative wages over the time, has resulted in the appearance of skill mismatch effects; (*ii*) aggregate technological shocks that implied a decrease in the total labor demand have crowded out lower educated workers by higher educated ones (job competition).

Models built up to now were unable to capture simultaneously the stylized facts observed in most European economies: the raise in the overall unemployment rate, the more important increase in low-skilled unemployment rates and the stability in relative wages. Our paper focuses on these issues. We build an intertemporal general equilibrium model based on Pierrard and Sneessens (2002) but incorporating separate wage bargaining for all workers, endogenous search intensities and endogenous skill-biased technological progress. We calibrate it on the basis of Belgian data. The model is then simulated to test its ability to reproduce both the situation in Belgium in 1996 and the observed variation in unemployment rates and relative wages between 1976 and 1996. Our theoretical setup performs well in both cases. Furthermore, the model is able to reproduce the rise in unemployment rates and the relative wage rigidity through the simple introduction of the observed change in the proportion of high-skilled workers in the labor force and the observed decline in the relative price of investment goods. The effects of various policy measures are also analyzed.

Our model constitutes a successful attempt to take simultaneously into account the stylized facts characterizing most European countries over the last decades. Two possible extensions of the model seem quite natural. An immediate one concerns the introduction of endogenous growth. A second extension, would consist in endogeneizing the evolution of the proportion of high-skilled workers ($\alpha$), so that the increase in low-skilled unemployment rates over the last 30 years could be explained by the introduction of skill-biased technological progress alone.

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