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Aggregate Employment, Job Polarization And Inequalities: A Transatlantic Perspective

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Abstract

This paper develops a multi-sectorial search and matching model with endogenous occupational choice in a context of structural change. Our objective is to shed light on the way labor market institutions affect aggregate employment, job polarization and inequalities observed in the US and in European countries. We consider the cases of the US, France and Germany that are representative of alternative institutional settings, having the potential to induce divergent time-paths in the evolution of labor market outcomes during the process of technological transition. In the US and in Germany, we find employment gains from technological change and job polarization, whereas, in France, the technological change reduces aggregate employment in a context of job polarization. In the US, an half of these employment gains are due to the technological change, and the other half to the changes in the LMI, the contribution of the rise in share of skilled worker being negligible. In France, the change in LMI affects new job opportunities in manual jobs: the reallocation of routine workers towards manual jobs is obstructed for want of job creations of manual services. Hence, without technological change, the fall in French employment would have been cut by 70%. The model also predicts that, without the increase in skilled labor supply, the fall in French employment would have doubled. The improvement in educational attainment dampened the unfavorable consequences of technological change. we show that Germany transforms this structural change in employment gains, only after the labor reforms implemented after the middle of the 90s.

Keywords: Search and matching, job polarization, reallocation, labor market institutions.

JEL Classification: E24, J62, J64, O33

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1 Introduction

This paper develops a multi-sectorial search and matching model with endogenous occupational choice to shed light on the way structural changes affect aggregate employment. The originality of our approach is to analyze the dynamic path of the employment reallocations. Indeed, the transformations of the production process have been progressive, driven by an incremental implementation of new technologies. The originality of our approach is to analyze the dynamic path of the employment reallocations. Indeed, the transformations of the production process have been progressive, driven by an incremental implementation of new technologies. During this structural change, some jobs can disappear, some others can appear only during the transitional path, whereas the composition of the employment of the final steady state is only the end of this reallocation process. This reallocation process can be long, because occupational changes result from search and learning activities from new tasks. Hence, we propose an non-stationary model that allows to understand these employment movements during a structural change. Thus, we point that some labor market institutions (hereafter LMI) can block this reallocation process because they do allow the labor market to open some jobs for inexperienced workers on potential new jobs. By identifying the direction of the structural change by new technologies that suppress jobs in the middle of the wage distribution, our model explains also the job polarization and inequalities observed in the US and in European countries.[1]

In our paper, Autor & Dorn (2013) meet Mortensen & Pissarides (1994) (hereafter MP). Our work then bridges the gap between two strands of literature.

The first strand of literature, in the wake of MP seminal work, tries to identify the reasons behind the low employment level in Europe compared to the US (the so-called "European employment problem", Ljungqvist & Sargent (2008), Ljungqvist & Sargent (1998)). Since the empirical works of Blanchard & Wolfers (1999), this literature lays stress on the role of LMI in interaction with aggregate shocks in shaping transatlantic differences in employment rates and on the role of structural reforms in improving European employment levels.

The second strand of literature deals with the employment structure, and the dynamic of wages across skill groups. Over the last 30 years in the US (and the last 20 years in Europe) employment growth has been fast not only in both high-paid (abstract) jobs but also in low-paid (manual) jobs; employment levels significantly fall among middling (routine) jobs, those involving tasks that can be replaced by machines (Autor & Dorn (2013); Goos et al, 2009, 2014). Unlike in the case of the SBTC theory, job polarization implies that, within the group of unskilled workers, there are winners (workers in service jobs,which require non-routine manual task and mainly involve assisting for others -e.g. janitors, cleaners, child care) and losers (middle-skilled, routine workers - e.g. production and craft, operative and assembler, and transportation, construction, mechanical).

The paper aims bridging the gaps between these two strands of literature by studying the strong interaction between the level and the structure of employment (in terms of opportunities for skilled vs. unskilled workers), and by assessing the contribution of technological change, evolution of LMI and changes in supply in skill labor in shaping the employment level and structure in the past decades. It also shows that the empirical literature that puts emphasis on the dynamic of employment shares, misses something by forgetting the employment levels. Indeed, the evolution of employment shares are sufficient to indicate employment reallocations from the declining (routine)

[1] Job polarization relates to the disappearance of middle jobs (requiring a moderate level of skills, such as autoworkers' jobs) relative to those at the bottom, requiring few skills (such as cleaners, sales and elementary occupations for instance), and those at the top (managers, life science and professionals), requiring greater skill levels.

to the expanding (manual) activities only if the aggregate employment increases. But, this is not the case when aggregate employment decreases. More precisely, let us denote $S_i = N_i/N$ the employment share of occupation i, then $\frac{\Delta S_i}{S_i} = \frac{\Delta N_i}{N_i} - \frac{\Delta N}{N}$. If the level of aggregate employment is neglected, ie $\frac{\Delta N}{N} = 0$, then an increase in $\frac{\Delta S_i}{S_i}$ implies an increase in $\frac{\Delta N_i}{N_i}$. If the aggregate employment grows, then the statistics on shares are also sufficient because when the share increases, jobs are created. But, if aggregate employment falls (French case), then $\frac{\Delta S_i}{S_i} > 0$ and $\frac{\Delta N}{N} < 0$ can be compatible with $\frac{\Delta N_i}{N_i} < 0$. For example, with the French data (1980-2000), we have

Levels	*Initial*	*Final*		Shares	*Initial*	*Final*
Manual	37	33	⇒	*Manual*	37%	42%
Routine	63	46		*Routine*	63%	58%
Total	100	79				

While the share of manual jobs increases, manual jobs are also destroyed, and there is no net-reallocation. Hence, employment levels matter, and thus the LMI as well as their shifts during the structural change.

We consider the cases of three large OECD economies representative of alternative institutional settings, having the potential to induce divergent time-paths in the evolution of labor market outcomes during the process of technological transition: *i)* The US, where flexible wages and institutions ease technology-induced job reallocation. *ii)* France, the polar case with a rigid labor market, a minimum wage that increases over time in real terms, and an evolution of LMI that can potentially stall aggregate unemployment and job reallocation. *iii)* Germany, an intermediate case. The German labor market is rather rigid, but does not feature a "national" minimum wage (but with sector-specific wage "norms"). The evolution of LMI first stalled job reallocation, but then reversed in the second period of the technological transition (a outcome of the labor market reforms began in the middle of the 90s). The 3 countries were chosen to illustrate divergent time-path of LMI along the same technological transition. In addition, these countries are all characterized by job polarization but also by contrasting evolutions of the aggregate employment level. This provides the opportunity to illustrate the interaction between the level of employment and its structure across task groups.

Our results are the following.

- After estimating the model, we check the model's ability to match the evolution of aggregate employment and employment shares by task. We document the theoretical interactions between technological change and LMI in a search and matching framework.

- We then look at the model's predictions regarding inequalities. The model captures the evolution of wage and income inequalities across countries and over time. We then lay stress on the difference between inequalities in wage and income versus inequalities in "permanent" income. While the former provides a "static" measure of inequalities, the latter takes into account future employment opportunities across sectors. We push forward the view that this "dynamic" measure should be the appropriate indicator for policy-makers. Using this dynamic measure, the French economy appears as unequal as the US. The US, with a flexible labor market, high labor reallocation towards manual jobs and low unemployment benefits are characterized by high Gini coefficients at the end of the technological transition. French Gini is actually located at the same level. Indeed, in spite of generous unemployment benefit and social programs, France does not provide enough future job opportunities. This outweighs the rising generosity of the minimum wage as well as of the income granted by existing assistance programs and unemployment benefits.

Given this good fit of the model, we use it to understand the evolution of aggregate employment and employment shares observed in the past decades. We compute the counterfactual evolution of aggregate employment without technological change or the rise in the supply of skilled labor, thereby quantifying the contribution of each element in the understanding of the evolution of aggregate employment and employment shares in the past decades. We contrast 2 countries: US and France.

- In the US, we find employment gains from technological changes. The model predicts that, without technological change (without the rise in skilled labor), the rise in US employment would have been cut by half (by 20%).
- In France, we find that technological change reduce employment, and generates job polarization. French aggregate employment would actually been higher in the past without technological changes. The fall in aggregate employment would have been cut by 70% without technological change. This is due to the fact that, because of rigid LMI, especially minimum wage that affect new job opportunities in manual jobs, labor reallocation does not occur. Routine workers lose their jobs, but cannot reallocate towards manual jobs, whose creation is stalled. The share of service in aggregate employment in France only mirrors the fall in aggregate employment. Hence, France, through its LMI, transform new opportunities into losses for its workforce. The model also predicts that, without the increase in skill labor, the fall in employment would have doubled. The improvement in educational attainment dampened the unfavorable consequences of technological change.

Section 2 presents our contribution to the literature. We look at the data in section 3 then present the model in Section 4, the calibration and estimation strategy in section 5. Results on the model fit and predicted inequalities are reported in section 6. We also document the theoretical interactions between technological change and LMI in a search and matching framework. In section 7, we quantify the contribution of technological change, changes in LMI and rise in the supply of skilled labor in the understanding of the evolution of aggregate employment and employment shares in the past decades. We contrast 2 countries: US and France. Section 8 concludes.

2 Contribution to the literature

In our paper, Autor & Dorn (2013) meet Mortensen & Pissarides (1994). What insight can be gained from the interaction between two strands of literature?

2.1 Job polarization with search and matching frictions

Autor & Dorn (2013) propose a model of frictionless labor reallocation across sectors. There is full employment on unskilled and skilled labor market. In addition, the supply of skilled and unskilled labor is constant.

The introduction of search and matching alters the theoretical predictions on the dynamics of polarization. Even in the US, hiring takes times, labor reallocation is then sluggish. In the short and medium run, unemployment dynamics is affected by the search process when unskilled workers switch from one job to the other. With search frictions, even in a flexible labor market such as the US, transitional "technological unemployment" appears because of the fast shutting down of routine labor opportunities, while reallocation to manual jobs takes time. The dynamic process of labor reallocation is also affected by LMI. Our contribution with respect to Autor and Dorn's model lies not only in taking into account search frictions but also in adding an international perspective by looking at different institutional settings. By looking at France and Germany, we will illustrate 2 striking elements. First, polarization (as summarized by changes in employment shares in each task cannot) can be understood only with respect to the evolution of aggregate employment. The French case will be striking. The share of service in total employment in France can actually increase only because of the fall in aggregate employment. Hence, the share of service in total employment *per se* is not relevant to measure the extent of polarization in one country with falling aggregate employment. Secondly, we will show how French LMI can slow down labor reallocation from routine to manual jobs. We will stress the importance of wage-setting rules in the dynamics of job polarization and illustrate our results in 3 countries characterized by very different wage-setting arrangements and evolutions of aggregate employment.

2.2 Search and matching frictions with polarization in a context of technological change

Papers focusing on the European employment problem focus on the level of employment but discard the study of the employment, wage dynamics across skill groups and inequalities. However, the extent employment reallocation is significantly affected by labor market institutions (LMI), with excess rigidities potentially able to prevent firms and workers to seize opportunities created by technological changes. These interactions might be crucial to our understanding of the "European employment problem". The impact of technological changes have been explored in the search and matching literature (Mortensen & Pissarides (1998); Hornstein et al. (2007)). We extent their work by laying stress on transitional dynamics (rather than steady state). In addition, along the transitional path, we document the interaction between technological change, labor market institutions and occupational choice. Occupational choices have also been explored in the search and matching literature (Alvarez & Shimer (2011); Carrillo-Tudela & Visschers (2014)). We extend their work by looking at occupational changes in a context of technological changes, rather than in a business cycle perspective. This significantly alters the theoretical analysis since occupational decisions are made in a non-stationary environment. In particular, in our model, occupational mobility are flows towards the *bottom* of the wage distribution, where employment opportunities are expanding.

Finally, in both strands of literature, the supply of skilled labor is fixed. We will relax this assumption and explore the quantitative implications of rising supply of skilled labor (as observed in the data). We will quantify the contribution of the rise in skilled labor in sustaining the rise in employment along the transitional path.

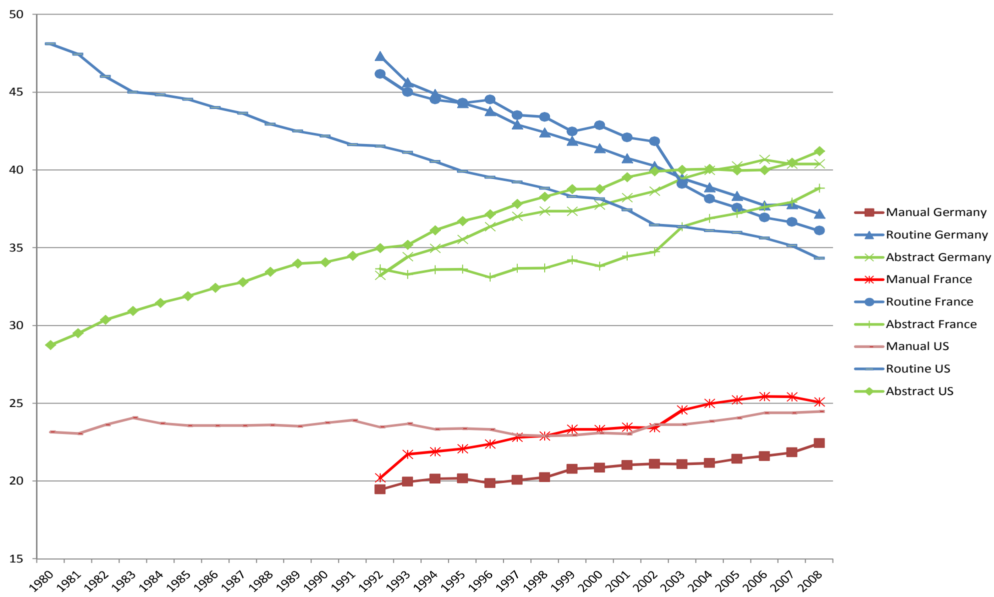
3 Data analysis in the US, France and Germany

A glance at the data suggests that the interaction between the level and the structure of employment can be complex.

3.1 Pervasive job polarization

Let us first have a look at polarization. Figure 1 reports the evolution of share of employment in the US, France and Germany in 3 tasks: abstract (non routine, cognitive tasks requiring creativity, problem-solving), routine (repetitive, specific activities accomplished by following well-defined instructions and procedures) and manual (non routine job requiring human interaction) jobs. The data comes from OECD computations based on CPS US data, French and German labor surveys. Total employment by occupational groups is disaggregated by occupational groups. Occupations are then divided into abstract, routine or manual jobs based on Goos and Manning (2009) classification. The data suggest that job polarization is prevalent in the US, France and Germany, with a rising employment share of service manual jobs and abstract jobs along with a pervasive fall in routine jobs.

Figure 1: Job polarization: Changes in employment share in abstract, routine, and manual tasks



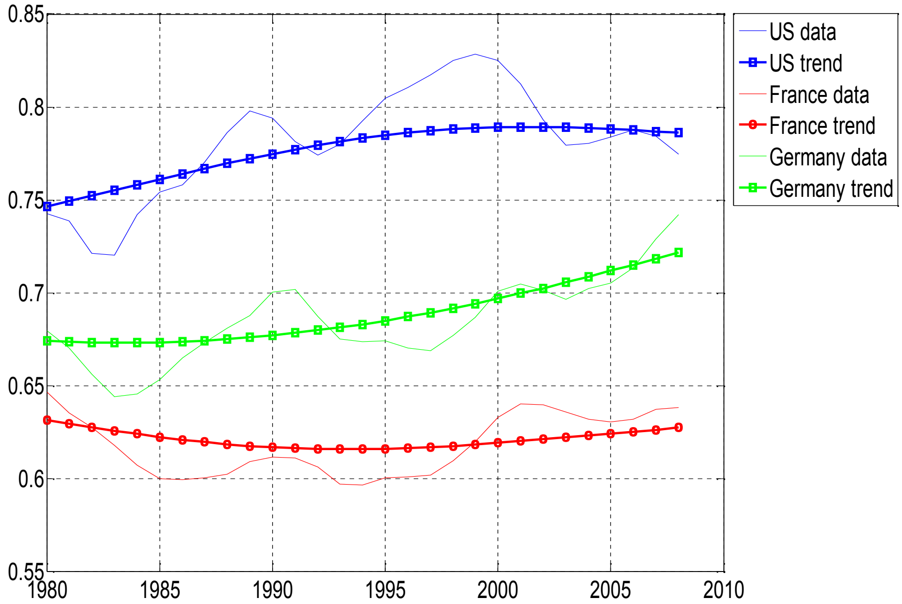
Source: OECD computations based on CPS US data, French and German labor surveys.

3.2 Divergent changes in aggregate employment across countries

Notice also that, although job polarization is at work in the US as well as in 2 core countries of continental Europe, aggregate employment has evolved very differently with a striking rise in aggregate employment in the US between 1980 and 2000, a rise that begin after 1990 in Germany and a downward trend in aggregate employment in France until the end of 90s (Figure 2).

Figures 1 and 2 suggest that job polarization must be understood in relation with the evolution of the level of aggregate employment, and can imply very different amounts of underlying reallocation. Indeed, in Figure 1, the US employment share of service occupation jobs has increased by only 6% over the last 30 years. Given the rapid rise in the US aggregate employment level in the 1980s and 1990s, however, this apparently limited increase actually involves large labor reallocations from routine to manual jobs. The evolution of the labor supply, where the supply of skilled workers increases, makes this increase in the share of manual tasks even more remarkable. In contrast, in a country like France the increasing share of workers in service occupations might just be mirroring

Figure 2: Employment rates



Source: OECD computations based on CPS US data, French and German labor surveys.

a mere mechanical effect of the fall in overall employment: in an extreme case where all new fired workers from the routine sector had become permanently non-employed, constant levels of jobs in abstract and manual tasks would have been enough to lead to a rise in their respective employment shares. This point is missed in the current literature on skilled/unskilled workers. This paper therefore provides a tool for assessing the impact of LMI on the aggregate level of employment as well as wage and employment dynamics across skill groups. We will also be able to contrast short-run and long-term effects by looking at the transition path induced by technological changes.

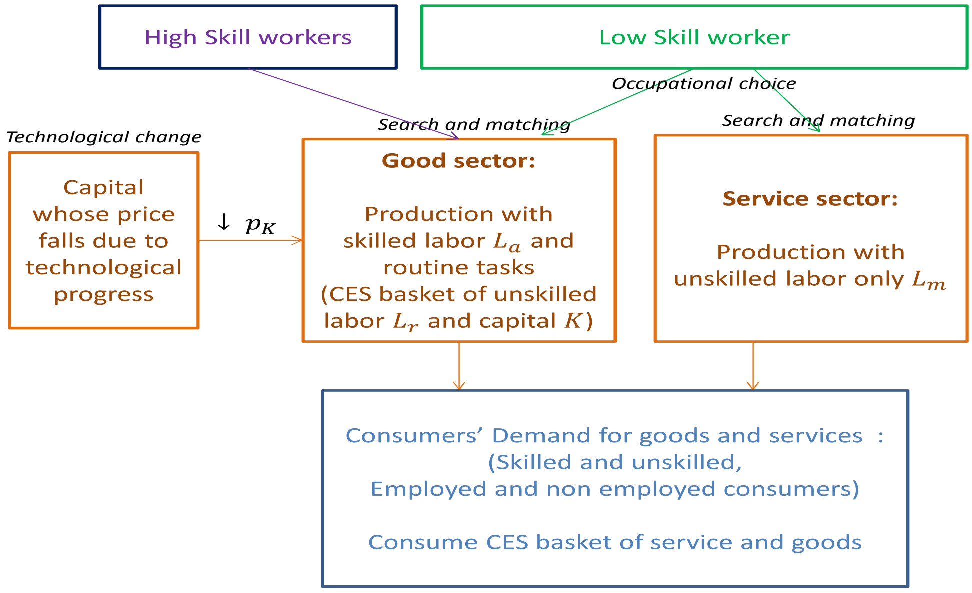
4 A search and matching model with endogenous occupational choice in a context of technological change

The model is a dynamic general equilibrium model with search and matching frictions, featuring workers' endogenous occupational choice and job polarization induced by a deterministic task-biased technological change. In order to make the model tractable, we abstract from financial markets. There are no savings. Figure 3 displays the building blocks of the model.

4.1 Assumptions

The economy consists of 2 sectors: the good-producing sector and manual non-routine services. They are displayed in the middle of Figure 3. The good producing sector uses three inputs: i) high-skilled workers in abstract non-routine cognitive jobs L_a, ii) unskilled workers employed in routine L_r, repetitive tasks and iii) technology K (equipment, computers, machine), a good that can also perform repetitive tasks. Unskilled routine workers can be easily replaced by machines while abstract workers complement repetitive tasks (whether performed by machines or unskilled workers). Technological change is captured by a downward trend in the price of computers p_K, which

Figure 3: Building blocks of the model



creates a strong incentive for good-producing firms to substitute unskilled labor L_r for capital K.

The service sector employs only unskilled labor in non-routine manual tasks L_m (such as janitors, cleaners, etc. occupations involving assisting others).

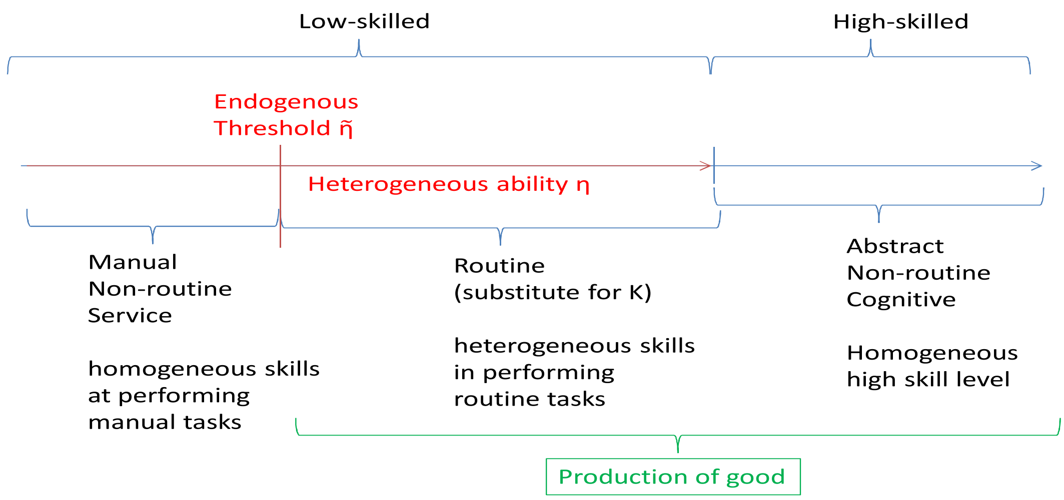
4.2 Labor supply and labor flows

In this section, we have a closer look at the top of Figure 3, with a focus on labor allocation. This part of the model mimics Autor & Dorn (2013)'s model. Labor supply consists of skilled and unskilled workers (Figure 4). Skilled workers are homogeneous and all perform abstract tasks (non-routine, cognitive jobs) in the good-producing firm. There is a continuum of unskilled workers who differ with respect to their abilities η. The model endogenously determines which unskilled workers occupy routine occupations versus service occupations (through the endogenous determination of the $\tilde{\eta}$ below which workers choose to work in manual jobs). Occupational choices, by affecting the number of workers in each unemployment pool, directly alter unemployment rates in each sector of the economy as well as job finding probabilities. Low-skill workers have homogeneous (heterogeneous) skills at performing manual (routine) tasks. This is consistent with the view that blue-collar workers in the factory differ in performing their tasks on the assembly line while jobs such as janitors can hardly differ in terms of productivity in providing non-routine manual services[2]. We depart from Autor & Dorn (2013) by considering the upward trend in educational attainment (as observed in the data), which shifts the relative labor supply of skill labor. In Figure 4, the share of abstract workers expand with time. This element was discarded in the job polarization literature and turn out to play a sizable role in the polarization process.

Labor market flows and occupational choices are summarized in Figure 5. This part of the model departs from Autor & Dorn (2013)'s setting in which labor reallocation is frictionless. Skilled workers

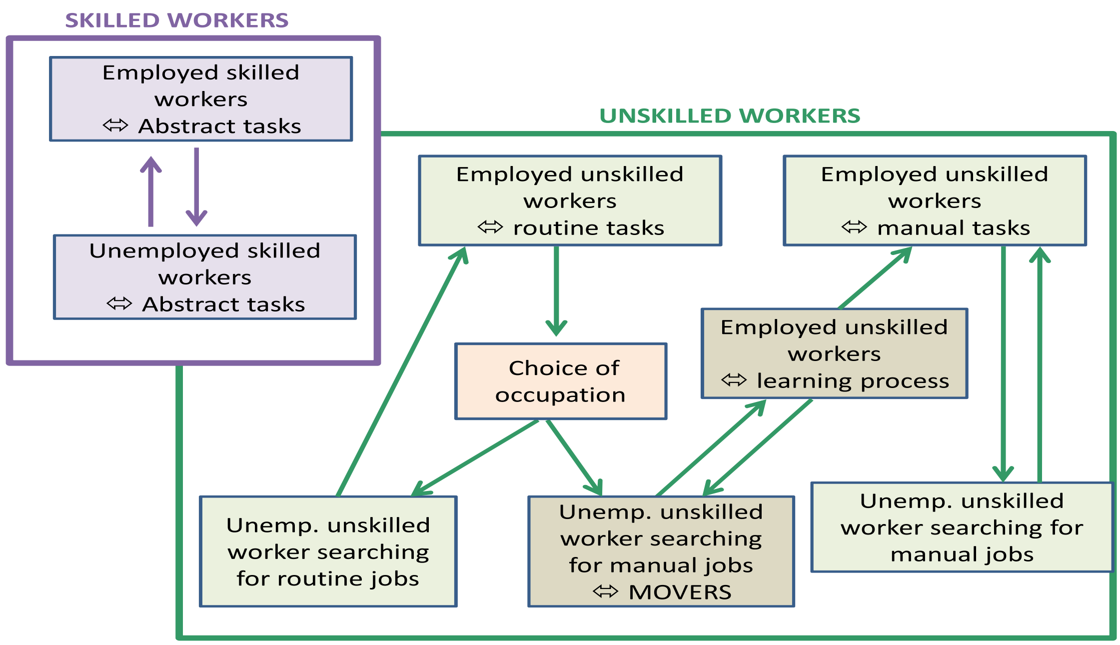
[2]The model proposes a stylized mapping of skilled and jobs. The data might suggest that the real world involves more complex mobility. However, we argue that our stylized model captures the salient mobility involved in job polarization and changes in aggregate employment.

Figure 4: Workers



are employed in abstract tasks. When fired, they join the pool of unemployed skilled workers and look for an abstract job. Unskilled workers can be employed either in routine tasks in the good producing firm or in manual tasks in the service sector. When fired from the good-producing firms, routine unemployed workers can choose to switch occupation (we call them *new movers* L_m^n) and join the pool of unemployed workers looking for manual jobs. New movers differ from other unemployed workers looking for a manual jobs because i) their unemployment benefit depends on their past occupation as routine workers, ii) they just arrived on the market for manual jobs and lack proper information about the tasks and firms on the market. New movers gradually learn about the tasks and the market: their productivity as manual workers is lower than their counterparts.

Figure 5: Labor market flows



Labor markets are characterized by search and matching frictions *à la* Mortensen & Pissarides (1994). Search is directed as there is a labor sub-market for each occupation and for each ability level η in routine jobs. Within each pool, the meeting process between workers and firms is random. There is no one-the-job search. M_t, the number of hiring per period, in each segment of the labor market (abstract, routine for each ability level η and all manual labor), is determined by a constant returns to scale matching function:

$$M_i = \Upsilon V_i^{\psi} U_i^{1-\psi}, \quad 0 < \psi < 1 \tag{1}$$

with $i = a, s, r, m, m^n$. $\Upsilon > 0$ is a scale parameter measuring the efficiency of the matching function, V_t the number of vacancies and U_t the number of non employed workers. ψ is the elasticity of the matching function with respect to vacancies. A vacancy is filled with probability $q_i = M_i/V_i$ and the job finding probability per unit of worker search is $f_i = M_i/U_i$. The labor market tightness is measured by the ratio V_i/U_i.

A job can be destroyed for exogenous reasons at rate s. Endogenous separation occurs in case of real wage rigidity, in which case, a firing cost is incurred. Two remarks must be made at this stage. First, firing costs are not severance payment but rather administrative costs of lay-off procedures. They are pure losses. Secondly, endogenous separations occur in our model because some firms incur negative profits, especially in the routine segment of the labor market. Recall that, in a world of continuous technological change, we can expect routine wages to fall, in which case, the firm would not be likely to incur negative profits, even in a world with falling routine labor productivity. In contrast, it is only when wages are completely rigid that firms can be trapped between production costs and falling labor productivity. This situation leads to negative profits. The firm then closes down, therefore incurs firing costs. In the model, for each ability level in routine jobs, in case of rigid wages only, we can endogenously define a scrapping-time after which the firm shuts down.

4.3 Workers' value functions, occupational choices and demand for goods

The economy includes goods and services. All equations are expressed in real terms in terms of goods. p_s is the relative price of services in terms of goods, and P the consumer price index, which is a function of p_s.

The worker's value functions[3] are

$$\begin{aligned}
W_a &= w_a + \mathcal{T} + \beta[(1-s)W_{a,+1} + sU_{a,+1}] && (2)\\
W_r(\eta) &= w_r(\eta) + \mathcal{T}_t \\
&\quad + \beta[(1-s)W_{r,+1}(\eta) + s\max\{U_{r,+1}(\eta), U^n_{m,+1}(\eta)\}] && (3)\\
W_m &= w_m + \mathcal{T} + \beta[(1-s)W_{m,+1} + sU_{m,+1}] && (4)\\
W^o_m &= w^o_m + \mathcal{T} + \beta\lambda[(1-s)W_{m,+1} + sU_{m,+1}] \\
&\quad + \beta(1-\lambda)[(1-s)W^o_{m,+1} + sU^o_{m,+1}] && (5)\\
W^n_m(\eta) &= w^n_m(\eta) + \mathcal{T} + \beta\lambda[(1-s)W_{m,+1} + sU_{m,+1}] \\
&\quad + \beta(1-\lambda)[(1-s)W^n_{m,+1}(\eta) + sU^o_{m,+1}] && (6)
\end{aligned}$$

where, within manual workers, we distinguish tree type of workers: the experienced manual worker (W_m), the inexperienced manual entitled to an unemployment benefit indexed on wage of a routine job (W^n_m), and the experienced manual entitled to an unemployment benefit indexed on wage of a

[3]For the easiness of the exposure we drop time subscript for present variable. Expected variables are assigned a subscript $+1$.

manual job (W_m^o). $\mathcal{T}$ denotes the transfers perceived by individuals (dividends and surplus of the governments). For unemployed workers,

$$
\begin{aligned}
U_a &= p_s h + z_a + \mathcal{T} + \beta[(1-f_a)U_{a,+1} + f_a \beta W_{a,+1}] && (7)\\
U_m &= p_s h + z_m + \mathcal{T} + \beta[(1-f_m)U_{m,+1} + f_m W_{m,+1}] && (8)\\
U_r(\eta) &= p_s h + z_r(\eta) + \mathcal{T} + \beta[(1-f_r(\eta))\max\{U_{r,+1}(\eta), U_{m,+1}^n(\eta)\} + f_r(\eta)W_{r,+1}(\eta)] && (9)\\
U_m^o &= p_s h + z_m + \mathcal{T} + \beta[(1-f_m^o)U_{m,+1}^o + f_m^o W_{m,+1}^o] && (10)\\
U_m^n(\eta) &= p_s h + z_r(\eta) + \mathcal{T} + \beta[(1-f_m^n(\eta))U_{m,+1}^n(\eta) + f_m^n(\eta)W_{m,+1}^n(\eta)] && (11)
\end{aligned}
$$

Equation (2) refers to the value of employment for an abstract worker with w_a the associated wage and $U_{a,+1}$ the value of unemployment next period. Equation (4) is the equivalent for workers in the manual sector. In the worker's value of employment (Equation (3)), the occupational choice is captured by the term $\max\{U_{r,+1}(\eta), U_{m,+1}^n(\eta)\}$ when unemployed. The exogenous destruction rate s then regulates the pace at which workers face the opportunity of switching occupation. If routine workers switch occupation when unemployed, they join the pool of unemployed workers looking for a manual job. Within this pool, we have to distinguish 3 groups: (1) "Regular" job seekers who got fired from a manual job (Equation (8)) who gets unemployment benefits z_m. (2) New movers who just joined the pool after being fired from a routine job. They then get unemployment benefit based on their past occupation and ability η ($zr(\eta)$ in equation (11)), which then affects their bargained wage when they find a job in the manual sector ($w_m^n(\eta)$ in equation (6)). (3) Old movers are routine workers who switched occupation to manual and had access to one manual job, got fired from this manual job and now get unemployment benefits z_m in equation (10). Their bargained wage w_m^o does not depend on their ability level η. The constant h stands for the leisure and home production.

For tractability reasons, we use directed search such that each type of unemployed worker in the pool (Equations (8), (10) and (11)) has a corresponding job value (Equations (4), (5) and (6)). All movers, whether old or new, can get a regular manual job with probability λ. This regulates the pace of the learning process from routine workers who switched occupation and are not fully informed about the new tasks and vacancies in the manual sector. This is consistent with the view that an important component of human capital is task and occupation-specific (Poletaev & Robinson (2008), Kambourov & Manovskii (2009), Cortes (2015)), which is lost by the worker who switches task.

4.4 Good-producing firm

As in Autor & Dorn (2013), the production function in the good sector uses skilled labor and an aggregate of low-tech input (that includes unskilled labor and capital). Unskilled labor and capital are very substitutable to perform routine repetitive tasks while skilled labor and repetitive tasks are more complements. We assume the same production function as in Autor & Dorn (2013). However, because of wage bargaining for both skilled and unskilled workers, we need to preserve the constant return to scale in the bargaining process. As a result, we present the good-producing firm as using two separate inputs: one is abstract workers L_a, the other is the aggregate of unskilled labor and capital. The good-producing firm's problem is

$$\Pi^g = \max\{Y^g - p_{z1}Z_1 - p_{z2}Z_2\}$$

$$\text{s.t. } Y^g \le A Z_1^{\alpha} Z_2^{1-\alpha}$$

The behavior of the firms producing high-tech intermediate good Z_1 is

$$\Pi^{z1} = \max \left\{ p_{z1} Y^{z1} - w_a L_a - V_a c_a + \beta \Pi^{z1}_{+1} \right\}$$

$$\begin{aligned} \text{s.t. } Y^{z1} &\leq L_a & (12) \\ L_{a,+1} &= (1-s) L_a + q_a V_a & (13) \end{aligned}$$

For high-tech firms, the production Y^{z1} is linear function (Equation (12)), and firms pay search cost to hire new workers: c_a is the cost of posting a vacancy for an abstract job.

The behavior of the firms producing low-tech intermediate goods Z_2 is

$$\Pi^{z2} = \max \left\{ \begin{array}{l} p_{z2} Y^{z2} - p_k K - \sum_\eta w_r(\eta) L_r(\eta) \\ -c \sum_\eta V_r(\eta) - \sum_\eta l(\eta) F + \beta \Pi^{z2}_{+1} \end{array} \right\}$$

$$\begin{aligned} \text{s.t. } Y^{z2} &\leq \left[\left((1-\mu) \sum_{\eta^S}^{\overline{\eta}} \eta L_r(\eta) \right)^\sigma + (\mu K)^\sigma \right]^{\frac{1}{\sigma}} & (14) \\ L_{r,+1}(\eta) &= (1-s) L_r(\eta) + q_r(\eta) V_r(\eta) - l_{+1}(\eta) & (15) \\ l(\eta) &\leq (1-s) L_r(\eta) \qquad (\lambda(\eta)) & (16) \\ V(\eta) &\geq 0 \qquad\qquad\qquad (\mu(\eta)) & (17) \end{aligned}$$

For low-tech firms whose value is Π^{z2}, Y^{z2} denotes the intermediate good production, K the computer stock, p_K its price and c the cost of posting a vacancy. F is the firing costs. It is discussed later. Equation (14) is the production function with σ and $\mu \in (0,1)$. The elasticity of substitution between routine labor and computer capital is $\frac{1}{1-\sigma}$ and, by assumption, is greater than 1. Equations (15) and (13) capture the evolution of labor stock given the probability of filling q a vacancy V. Equation (16) gives the maximum number of η-type workers that can be fired (those who are not exogenously separated). Finally, equation (17) allows to distinguish between two regimes: the first where it is profitable for the firm to replace the exogenous separations ($V_r(\eta) > 0$), and the second, where it is optimal to voluntarily reduce its workforce ($V_r(\eta) = 0$).[4]

4.5 Service-producing firm

The representative firm's problem

$$\Pi^s = \max \left\{ \begin{array}{l} p_s Y^s - \left(w_m L_m + \sum_\eta w^n_m(\eta) L^n_m(\eta) + w^o_m L^o_m \right) \\ -c V_m - c \sum_\eta V^n_m(\eta) - c V^o_m + \beta \Pi^s_{+1} \end{array} \right\}$$

[4]FOCs are reported in Appendix A.1.

$$
\begin{aligned}
\text{s.t. } Y^s &\geq A_s\left(L_s+\delta\sum_\eta L_m^n(\eta)+\delta L_m^o\right) && (18)\\
L_{m,+1} &= (1-s)L_m+q_mV_m+(1-s)\lambda\sum_\eta L_m^n(\eta)+(1-s)\lambda L_m^o && (19)\\
L_{m,+1}^o &= (1-s)(1-\lambda)L_m^o+q_m^oV_m^o && (20)\\
L_{m,+1}^n(\eta) &= (1-s)(1-\lambda)L_m^n(\eta)+q_m^n(\eta)V_m^n(\eta) && (21)
\end{aligned}
$$

with $A_s > 0$ a relative productivity parameter (with respect to good). The service production function (equation (18)) uses all low-skilled workers, including new and old movers: L_m, $L_m^n(\eta)$ and L_m^o. δ captures the lower productivity of workers who switched occupation and are not fully familiar with manual tasks. Notice that p_s is the relative price of services relative to goods. For simplicity, we assume, as it is the case in the scenarii chosen for the simulations, that we have always $V > 0$, which allows us to abstract from the constraints $V \geq 0$ and the existence of firings $l > 0$.[5]

4.6 Job creation conditions and creation costs

We consider that firms are subject to a cost of advertising the vacant job (c_a or c) Job creation conditions are given by

$$
\frac{\widetilde{c}}{\widetilde{q}} = \beta\widetilde{J}_{+1} \qquad (22)
$$

$$
\begin{aligned}
&\widetilde{c}=c_a, c\\
&\widetilde{q}=q_a, q_r(\eta), q_m, q_m^n, q_m^o\\
&\widetilde{J}_{+1}=J_{a,+1}, J_{r,+1}(\eta), J_{m,+1}, J_{m,+1}^n, J_{m,+1}^o
\end{aligned}
$$

Together with the firm present values of a filled job, we obtain the following job creation condition for skilled workers:

$$
\frac{c_a}{q_a} = \beta\left[y_{a,+1}-w_{a,+1}+(1-s_a)\frac{c_a}{q_{a,+1}}\right]
$$

whereas for unskilled workers, the job creation conditions are:

$$
\begin{aligned}
\frac{c}{q_r(\eta)} &= \beta\left[y_{r,+1}(\eta)-w_{r,+1}(\eta)+(1-s)\frac{c}{q_{r,+1}(\eta)}\right]\\
\frac{c}{q_m^n(\eta)} &= \beta\left[p_{s,+1}\delta A_s-w_{m,+1}^n(\eta)+(1-s)\left(\frac{c(1-\lambda)}{q_{m,+1}^n(\eta)}+\frac{c\lambda}{q_{m,+1}}\right)\right]\\
\frac{c}{q_m^o} &= \beta\left[p_{s,+1}\delta A_s-w_{m,+1}^o+(1-s)\left(\frac{c(1-\lambda)}{q_{m,+1}^o}+\frac{c\lambda}{q_{m,+1}}\right)\right]\\
\frac{c}{q_m} &= \beta\left[p_{s,+1}A_s-w_{m,+1}+(1-s_a)\frac{c}{q_{m,+1}}\right]
\end{aligned}
$$

For these unskilled workers, the η-type matters: the endogenous segmentation of the labor market determines the threshold $\widetilde{\eta}$ such that for $\eta < \widetilde{\eta}$ workers are in the market of manual tasks, whereas for $\eta \geq \widetilde{\eta}$ they are in the labor market of the routine tasks.

[5]FOCs are reported in Appendix A.2.

4.7 Wage setting

The 3 countries differ with respect to their wage setting: these differences correspond to specific adjustments to a targeted wage which is the solution of a bargaining process à la Nash. Before going into the institutional specificity in each country, it is thus useful to present the Nash bargaining between individual workers and firms for each type of job (abstract, routine for each η and manual regular, old or new mover). The wage is set so as to maximize the joint surplus from the match

$$w_{Nash} = \text{argmax}\,(J_i - V_i)^{1-\gamma}\,(W_i - U_i)^{\gamma} \quad \text{with} \quad i = a, r, s, m, m^n \tag{23}$$

with $J - V$ the marginal value of a match for a firm and $W - U$ the marginal worker's surplus from the match. γ denotes the worker's share of a job's value, i.e., worker's bargaining power.

- In the DMP model, a Nash bargaining gives the WS (wage setting) curve: the wage is highly flexible and follows both productivity and labor market tightness.
- A first real wage rigidity *à la* Hall (2005): social norms reduce the wage flexibility (Germany).
- A second real rigidity: a "Minimum wage" by tasks that can disconnect wage from the productivity (France).

For all jobs, we have the following WS rule:

$$w \;=\; \max\{mw, w^B\} \quad \text{with} \quad w^B = \omega\overline{w} + (1-\omega)w_{Nash}$$

using all Bellman equations W, U, V and J, and the free entry conditions $V = 0$, the Nash wages are:

Abstract jobs:

$$w_a \;=\; \gamma_a\left(y_a + \frac{\phi_{a,+1}}{\phi_a}c_a\theta_a\right) + \gamma_a(1-s_a)\frac{c_a}{q_a}\left(1 - \frac{\phi_{a,+1}}{\phi_a}\right) + (1-\gamma)(p_s h + z_a)$$

where $\phi_a = \frac{\gamma_a}{1-\gamma_a}$. This equation shows that the bargained surplus captured by employees is the sum of: *(i)* the marginal productivity and *(ii)* the search returns. For the worker, the returns on the search process are equal to the discounted time duration to find a job offer; for the firm, returns are instead equivalent to the discounted time duration to find a worker. These relative time spans cannot be proxied by the ratio of the average duration for these two search processes ($\theta_a = \frac{f_a}{q_a}$), as it would be the case when bargaining powers are constant ($\phi_{a,+1}/\phi_a = 1$ in this case). But, if, for example, the workers expect that tomorrow their bargaining powers are close to zero ($\phi_{t+1} \approx 0$), the evaluation of the current match surplus is only driven by the search costs saved by the firm if the job is not destroyed ($(1-s)\frac{c_a}{q_a}$). At the opposite, when the bargaining power of the worker increases ($\phi_{t+1} > \phi_t$), the match value must be depreciated by the firm (it expects a decrease in its bargaining power), whereas the relative time spans must be over-evaluated by the worker because its bargaining power increases. Thus, the value of the search cost is a function of the bargaining power and taxes which themselves change over time.

Finally, the reservation wage is sum of the home production with the non-employment incomes.

Unskilled workers

For all job occupied by unskilled worker, we have $\phi = \frac{\gamma}{1-\gamma}$ that summarizes the dynamics of the bargaining power.

(i) Routine:

$$\begin{aligned} w^r(\eta) &= \gamma\left(y_r(\eta) + \frac{\phi_{+1}}{\phi}c\theta_r(\eta)\right) + \gamma\frac{c}{q_r(\eta)}(1-s)\left(1-\frac{\phi_{+1}}{\phi}\right) \\ &+(1-\gamma)\left(p_s h + z_r(\eta) + (1-s-f_r)\beta\max\{0, U^n_{m,+1}(\eta) - U_{r,+1}(\eta)\}\right) \end{aligned}$$

With respect to the wages of abstract jobs, the novelty comes from the reservation wage. If they are unemployed, workers know that they can move from routine to manual occupations if these last ones are more profitable: they take into account this new opportunity in their reservation wage. When $U^n_m > U_r(\eta)$, this surplus is obtained only if an unemployed worker does not find a job (with a probability $1-f_r$), net of the chance to obtain it directly after a separation (with probability s). This opportunity to move is offered only to unemployed workers: thus, this increases the reservation wage.

When $U^n_m(\eta) > U_r(\eta)$ and given that $U^n_m(\eta)$ is increasing whereas $U_r(\eta)$ is decreasing, the wage of routine job is

$$\begin{aligned} w^r(\eta) &= \gamma\left(y_r(\eta) + \frac{\phi_{+1}}{\phi}c\theta^n_m(\eta)\right) + \gamma\frac{c}{q_r(\eta)}(1-s)\left(1-\frac{\phi_{+1}}{\phi}\right) \\ &+(1-\gamma)\left(p_s h + z_r(\eta)\right) \end{aligned}$$

This wage is paid to workers on routine jobs, after η-type unemployed workers had moved to the market of manual jobs.

(ii) Manual (incumbent):

$$\begin{aligned} w_m &= \gamma\left[p_s\delta A_s + \frac{\phi_{+1}}{\phi}c\theta_m\right] + \gamma\frac{c}{q_m}(1-s)\left[1-\frac{\phi_{+1}}{\phi}\right] \\ &+(1-\gamma)(p_s h + z_m) \end{aligned}$$

These workers are incumbent: they do not expect any mobility, except the one associated to the unemployment risk. Thus the wage equation is the same as for the "abstract" workers.

(iii) Manual (new movers):

$$\begin{aligned} w^n_m(\eta) &= \gamma\left[p_s\delta A_s + \frac{\phi_{+1}}{\phi}c\theta^n_m(\eta)\right] + \gamma\left(\frac{c(1-\lambda)}{q^n_m(\eta)} + \frac{c\lambda}{q_m}\right)(1-s)\left[1-\frac{\phi_{+1}}{\phi}\right] \\ &+(1-\gamma)\left[p_s h + z_r(\eta) + \beta\Big(\lambda(U^n_{m,+1}(\eta) - U_{m,+1}) + s(1-\lambda)(U^n_{m,+1}(\eta) - U^o_{m,+1})\Big)\right] \end{aligned}$$

The value of the opportunity to become an experimented worker is included in the reservation wage of the new movers: this changes workers' outside option $U^n_{m,+1}(\eta) - U_{m,+1}$ with a probability λ. But workers also know that they can lose the state of "new mover" even if they do not become experimented: they can lose their "new mover" jobs and become "old mover" unemployed workers, implying a change in their outside options $U^n_{m,+1}(\eta) - U^o_{m,+1}$. This event can appear with a probability $s(1-\lambda)$. In the "regular" case, we have $U^n_{m,+1}(\eta) < U_{m,+1}$ and $U^n_{m,+1}(\eta) > U^o_{m,+1}$: the expectation of the promotion leads workers to reduce their reservation wage to increase their opportunities to access this labor market state, whereas the loss of their unemployed benefits indexed to the wage of a routine job is a risk shared with the firm that hires an "new mover".

(iv) Manual (old movers):

$$w_m^o(\eta) = \gamma\left[p_s\delta A_s + \frac{\phi_{+1}}{\phi}c\theta_m^o\right] + \gamma\left(\frac{c(1-\lambda)}{q_m^o} + \frac{c\lambda}{q_m}\right)(1-s)\left[1 - \frac{\phi_{+1}}{\phi}\right]$$
$$+(1-\gamma)\left(p_s h + z_m + \beta\lambda(U_{m,+1}^o - U_{m,+1})\right)$$

With a probability λ, these workers become experimented manual workers and then access this new labor market: this changes their outside option by a amount of $U_{m,+1}^o - U_{m,+1}$. Notice that, if $U_{m,+1}^o < U_{m,+1}$, this leads them to accept lower wages when they are "old movers".

It should be noted that we did not introduce firing costs in the wage negotiation. The reason is that firings are unilaterally decided by firms when the profit is lower than paying firing costs. This situation only happens when the minimum wage is binding, *i.e.* when the wage negotiation fails to prevent the sharing of the fall in profits. As a consequence, firing costs only matter when the wage reach the statutory level in our model. It follows that $w_t = mw$. One may wonder whether wages higher than the minimum wage could be influenced by the firing costs due to future changes in the policy. Since we are in a perfect foresight world, it seems not credible that employers use firing costs as a threat in bargaining to lower wages in a situation that never give rise to endogenous separation. For this reason, we only assume that firing costs impacts the timing of the dismissal decision.

Given that we introduce real rigidities in the bargaining wage w^B, the equilibrium is defined only if $w_r^H < w^B < w_r^F$, where w_r^H and w_r^F define respectively the reservation wage of the worker and the firm. These reservation wages (or the "bargaining set") are such that $W(w_r^H) - U = 0$ and $J(w_r^F) = 0$. We add these constraints in the numerical algorithm that solve the equilibrium paths of the general equilibrium model.

4.8 General equilibrium

4.8.1 Household preferences and Demands for goods and services

We present here the elements in the bottom part of Figure 3. The demand for good and service stems from the skilled and unskilled households. They consume goods and services. Both are complements. This is a crucial element. The adoption of new technologies by good-producing firms allows them to expand their production. The resulting fall in the price of good increases the demand for goods. As goods and services are complements, the demand for services also expands. The relative price of services goes up, which also drives the increase in real wages in the service sector, thereby inducing workers to switch occupations from routine to service jobs.

We have several households in the model, one for each type of job and unemployment. In order to keep the model tractable, there is no savings. All households share the same preferences. Their consumption basket C include goods C_g and services C_s

$$C = \left[\nu C_g^\rho + (1-\nu)C_s^\rho\right]^{\frac{1}{\rho}} \quad \text{with } \rho \in [0,1]$$

with $\frac{1}{1-\rho}$ the elasticity of substitution between goods and services. For each worker, budget constraint is

$$\begin{aligned} P\,C &= I \\ \text{with } I &\in \{w_a, w_r(\eta), w_m, w_m^o, w_m^n, z_a, z_m, z_r(\eta)\} + \mathcal{T} \end{aligned}$$

The optimal sharing of the consumption basket good C is given by:

$$\begin{aligned} p_s &= \frac{1-\nu}{\nu}\left(\frac{C_g}{C_s}\right)^{1-\rho} \qquad (24) \\ \Rightarrow & \left\{ \begin{aligned} C_g &= \nu^{\frac{1}{1-\rho}}\left(\tfrac{1}{P}\right)^{\frac{1}{\rho-1}}\tfrac{I}{P} \\ C_s &= (1-\nu)^{\frac{1}{1-\rho}}\left(\tfrac{p_s}{P}\right)^{\frac{1}{\rho-1}}\tfrac{I}{P} \end{aligned} \right. \end{aligned}$$

which are the demand functions. The consumer price index is

$$P = \left[\nu^{\frac{1}{1-\rho}} + (1-\nu)^{\frac{1}{1-\rho}}(p_s)^{\frac{\rho}{\rho-1}}\right]^{\frac{\rho-1}{\rho}} \qquad (25)$$

4.8.2 Market clearing conditions

The production of the goods/service equals the demand for final goods/services from households.

$$\begin{aligned} \widetilde{Y}_g &= \sum_k C_g^k \equiv C_g \quad \text{with } k \in \{ae, re(\eta), me, me^o, me^n, au, mu, ru(\eta)\} \\ Y_s &= \sum_k C_s^k \equiv C_s \end{aligned}$$

where $\widetilde{Y}^g$ is the production of the intermediate goods net of hiring and entry costs:

$$\begin{aligned} \widetilde{Y}_g &= Y_g - p_k K - c_a V_a - c\sum_\eta V_r(\eta) \\ &\quad - cV_m - c\sum_\eta V_m^n(\eta) - cV_m^o \\ C_s &= Y^s \end{aligned}$$

4.8.3 Government and transfers

Government expenditures are

$$\Gamma = z_a U_a + \sum_\eta z_r(\eta)U_r(\eta) + z_m(U_m + U_m^o) + \sum_\eta z_m^n(\eta)U_m^n(\eta) + \mathcal{C}^h$$

with the unemployment benefit being a function of the productivity[6].

$$z_i = \rho_i y_i$$

[6]While unemployment benefits are usually proportional to wages, we simplify the definition of z_i for tractable reason. However, it does not matter so much since wage are mainly driven by movements in productivity.

Finally, given that firms generate profits, we can also define total dividends as:

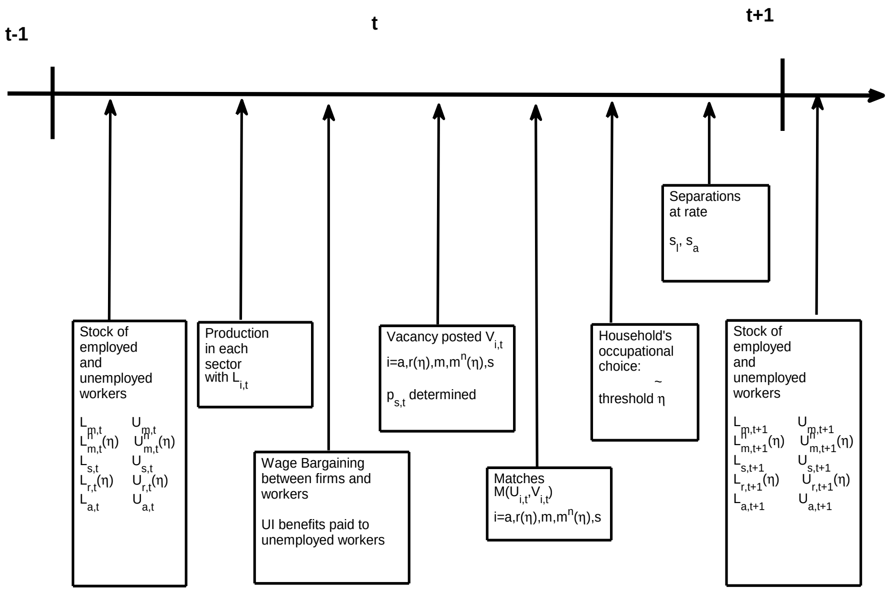
$$\Omega = \Pi^{z1} + \Pi^{z2} + \Pi^{s}$$

This leads to the following definition of total transfers received by each household (the population is normalized to unity)

$$\mathcal{T} = -\Gamma + \Omega$$

Figure 6 summarizes the sequence of events within a period.

Figure 6: Sequence of events within a period



5 Calibration

Regarding the model calibration, some parameter values are set based on existing empirical evidence and others calibrated to match selected moments in the data. Since the paper is focused on trends in employment, the selected moments in the data include employment shares and employment rates at 2 different times: the beginning and the end on the sample. Labor market institutions and wage-setting are country-specific while we consider that consumer preferences, technology and distribution of abilities within unskilled labor are the same cross countries. In addition, given that the model predicts the complete path of employment composition and level following a technological change, we need to set values for the *path* of labor market institutions, technological change and increase in skilled labor.

5.1 Exogenous trends : technology, LMI and supply of skilled labor

We assume that

- Technological change (the fall in the price of computers) starts in 1980 in the US while it starts in 1990 in European countries but, due to a catching-up effect, technological change is twice faster than in the US. (Figure 7, panel (8)).[7]

- We take into account the improvement in the population educational attainment: the share of skilled workers increases at the same pace in all countries, even if the levels in 1980 are not the same (Figure 7, panel (9)).[8]
- The evolution of LMI is country-specific and fits general trends found in LMI data (Figure 7)
  - US : a continuous decline in assistance programs (unconditional income, not linked to labor market activities, available to unskilled workers only), replacement ratios and workers' bargaining power.
  - France: since the mid-1980s, an upward trend in generosity of assistance programs, replacement ratios and minimum wage.
  - Germany: is characterized by 2 sub-periods, with, first, as in France, an upward trend in generosity (until the mid-1990s), then, starting in 1995, a reversal on workers' bargaining power and generosity of assistance programs as well as unemployment replacement ratios.

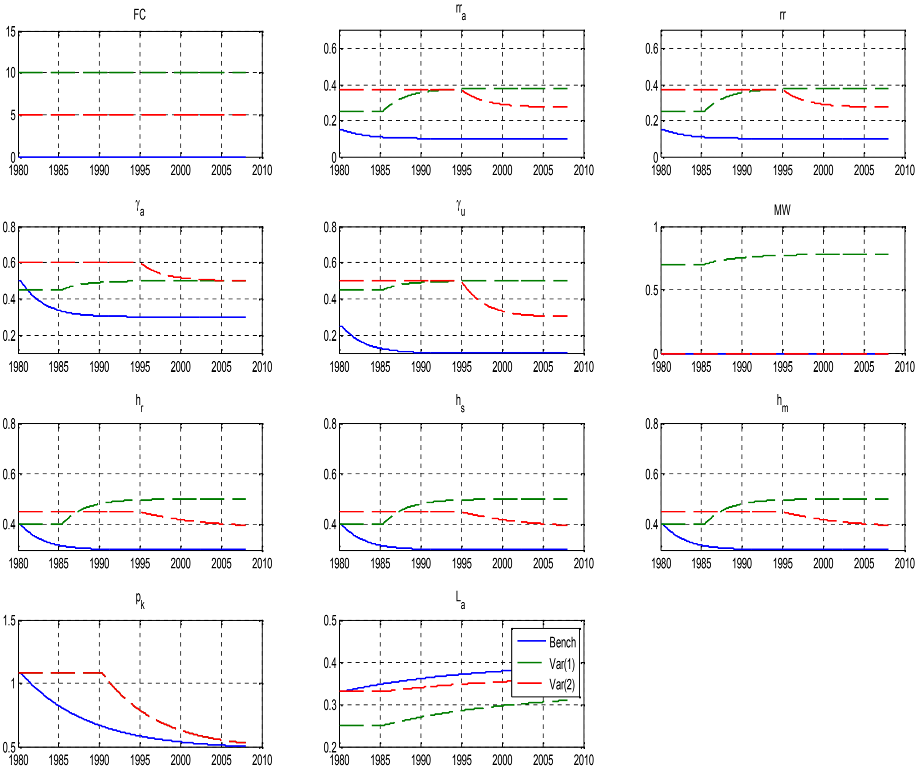
5.2 Calibrated parameters

The calibration is monthly. Some parameters are considered as common to all countries. These parameters include preferences, matching function (panel (a) of Table 1) and speed of learning for movers (panel (b)). The discount factor β is such that the annual real interest rate is 4%. Skilled workers are not eligible to social assistance programs ($h_s = 0$). The exogenous separation rate is set to 1.25% per month. This value is consistent with the French and German destruction rates (Elsby et al. (2008)), which we take as a benchmark. If we had taken a higher destruction rate for the US (around 3.5% per month in Elsby et al. (2008)), our results would have implied even more labor reallocation in the US: indeed, as s regulates the pace at which workers face the occupational choice, with a higher s, reallocation would have been faster in the flexible labor market. The elasticity of the matching function is set to 0.5, which is consistent with the estimates reported in Petrongolo & Pissarides (2001). The calibration of the vacancy posting cost c is close to the results of Barron

[7] The path of technological change across countries is consistent with several empirical evidence. First, the data on the relative price of investment computed by Karabarbounis & Neiman (2014) for the US, France and Germany (Figure 18, in Appendix B) show that the fall in the relative of investment fell in France and Germany especially after the early 1990s while the decline started in the early 1980s in the US. Secondly, Duernecker (2014) reports average ICT investment to GDP ratio for the periods 1980-1990 and 1998-2004 in several OECD countries. This measure is a proxy for technology adoption. In all countries, this ratio has increased over time, which points at faster technological change. Interestingly, the US is characterized by the highest ICT investment to GDP. France and Germany lag behind.

[8] We consider the same speed of growth in L_a in order to make the results comparable across countries. In addition, levels of L_a are consistent with the values reported in Barro & Lee (2013) for the US in 1980. The values for France are also consistent with French Census data on educational attainment (INSEE Census data on educational attainment, Baccalauréat et plus, 21% in 1990 and 29.5% in 1999 of population of 16 years old and more). Finally, OECD data suggests that labor supply of abstract workers in Germany was larger than in France in the early 1990s. This is based on the percentage of population that has attained at least upper secondary education in 2009 on chart A1.2 in 2011 OECD Education at a glance, http://www.oecd.org/education/skills-beyond-school/48631602.pdf. The educational attainment for individuals of 55-64 years old is larger in Germany than in France. These individuals were prime-age workers in the 1990s, at the beginning of our technological transition. In order to make the results transparent and comparable across countries, the pace of growth in labor supply of educated workers increase at the same pace in all countries.

Figure 7: Calibrated evolution of LMI, technological shock, supply of skill labor



US = solid line; Germany = red dashed-line; France = green dashed-line; FC Firing Costs; rr_a replacement ratio for abstract workers; rr replacement ratio of unskilled workers; γ_a abstract workers' bargaining power; γ_u unskilled workers' bargaining power; MW Minimum Wage; h_r, h_s and h_m social assistance programs (for unskilled workers only in routine job h_r and service jobs h_s, new movers h_m); p_K price of computers; L_a labor supply of abstract workers.

et al. (1997) and Barron & Bishop (1985). These authors suggest that an amount to 17 percent of a 40-hour workweek (nine applicants for each vacancy filled, with two hours of work time required to process each application). We also suppose that the work time required to process each application is twice larger to skilled workers. We set $c = .15$ given that average productivity in the routine sector is one. Job creation costs consist of costs for recruitment, screening and training. Acemoglu (2001) argue that job creation costs are likely to be larger for high-wage jobs. We assume that job creation costs for abstract jobs are twice larger than for low-wage jobs: $c_a = 2c$. This value lies within the range found in the literature (Acemoglu (2001) and Krause & Lubik (2006) suggest $\frac{c_a}{c} > 1$, $\frac{c_a}{c} = 1.15$ in Angelopoulos & Malley (2015) and 4 in Krause & Lubik (2006) and Hagedorn et al. (2014)).

Panel (b) of Table 1 summarizes the mobility costs. When a routine worker switches occupation, his productivity in the manual task is $\delta = 90\%$ the ones of a regular manual worker. This is consistent with the view that an important component of human capital is task and occupation-specific (Poletaev & Robinson (2008), Kambourov & Manovskii (2009), Cortes (2015)), which is lost by the worker who switches task. The learning process takes on average 3 years[9] for the routine worker who switch occupation to manual jobs.

[9] $\frac{1}{\lambda}$ months

Table 1: Model parameters values based on external information

		Matching			
$c^\star$	$c_a^\star$	$\psi^\star$	$s^\star = s_a^\star$	$\Upsilon^\star$	
0.15	$2c^\star$	0.5	0.0125	0.025	
	Preferences			Learning	
$\beta^\star$	$h_s^\star$		$\delta^\star$	$\chi^\star$	$\lambda^\star$
4%	0		0.9	1	0.025
		Labor supply composition			
	US		France	Germany	
	$0.33-0.4$		$0.25-0.33$	$0.3-0.37$	
		Labor Market Institutions			
	γ	rr	$sp^\star$	MW	FC
US	$0.3-0.15$	$0.15-0.1$	$0.1-0.0875$	$0-0$	0
Fr	$0.45-0.5$	$0.25-0.38$	$0.1-0.125$	$0.65-0.75$	10
Ger(1)	$0.55-0.55$	$0.275-0.37$	$0.1125-0.1125$	$0-0$	5
Ger(2)	$0.55-0.4$	$0.37-0.275$	$0.1125-0.095$	$0-0$	5

$\star$: the initial levels h_i of social programmes are calibrated
Ger(1): Germany before 1995
Ger(1): Germany after 1995

5.3 Estimation strategy.

The other set of parameters $\Phi = \{\Phi_1, \Phi_{2,US}, \Phi_{2,F}, \Phi_{2,G}, \Phi_3\}$:

$$\begin{aligned}
\Phi_1 &= \left\{ \ \rho, \nu, A, \sigma, \mu, \alpha, A_s, p_k(0), p_k(T), \overline{\eta}, \underline{\eta}, \sigma_\eta \ \right\} \\
\Phi_{2,i} &= \left\{ \ \omega_{a,i}, h_{u,i}(0) \ \right\}_{i=US,F} \\
\Phi_{2,G} &= \left\{ \ \omega_{a,G}, \omega_{r,G}, h_{u,G}(0) \ \right\}
\end{aligned}$$

The dynamics of all the exogenous variables are

$$x(t) = (x(0) - x(T))e^{-g_x t} + x(T) \quad \text{for } t \in [0, T]$$

This adds $\Phi_3 = \{g_{p_k}, g_{L_a}, g_r, g_{h_u}, g_{MW}\}$ parameters, with $dim(\Phi) = 24$.

The empirical targets are:

$$\Psi_T = \left\{ \begin{array}{l} N_{a,i}(0), N_{r,i}(0), N_{m,i}(0), N_{a,i}(T), N_{r,i}(T), N_{m,i}(T), \\ E_i[N_a], E_i[N_r], E_i[N_m] \end{array} \right\}_{i=US,F,G}$$

with $dim(\Psi_T) = 27$. 24 parameter values are then estimated to fit the 27 moments, by solving $\min_\Phi[\Psi(\Phi) - \Psi_T]$. The model is non-stationary and non-linear, which requires an innovative solution method. The algorithm is presented in Appendix C. The solution for Φ is reported in the table 2.

6 Model fit

6.1 Aggregate employment

Figures 8 and 9 summarize the model's predictions regarding aggregate employment levels and employment rates across skill groups. As for employment rates (top panels of Figure 8), the model

Table 2: Calibrated parameters

Preferences	ρ	ν	h_{US}	h_{Fr}	h_{Ger}
	0.825	0.6	0.4	0.4	0.45
Technology (1)	A	A_s	σ	α	μ
	4.5	0.95	0.78	0.6	0.5
Technology (2)	$p_k(0)$	$p_k(T)$	η	η	σ_η
	1.08	0.48	0.8	1.65	0.6
Wage norms	$\omega_{a,US}$	$\omega_{a,Fr}$	$\omega_{a,Ger}$	$\omega_{r,Ger}$	
	0.95	0.1	0.55	0.55	
Adjustments	g_{p_k}	g_{L_a}	g_{rr}	g_{h_u}	g_{MW}
	0.012	0.005	0.03	0.03	0.02

matches the upward trend found in the US until 2000, that is 20 years after the start of the "technological transition"[10]

Figure 8 displays the theoretical and observed employment rates for skilled and unskilled workers. In the model as well as in the data, skilled and unskilled workers benefit from technological change: the balance between falling routine and rising manual is positive, showing the positive effects of reallocation. The model is also able to capture the fall in the French unemployment rate. The rebound in 2000 is missed in the model. In our view, this employment hike is related to the French extensive program of cuts on payroll taxes for low-wage workers starting in 1998. This resulted in an increase in the employment rate of unskilled workers. This policy change is missed in the model.

6.2 Job polarization

6.2.1 Model fit

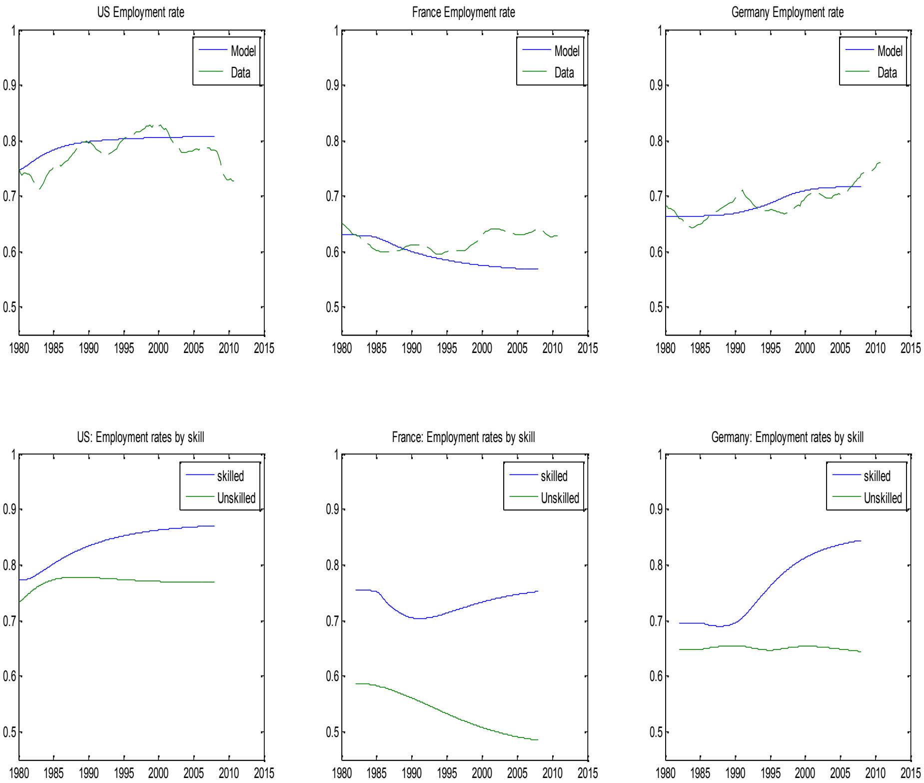
The model captures the job polarization in all countries (Figure 9). The theoretical predictions are consistent with the levels of employment shares as well as their evolution, especially the starting and ending points (with the exception of the French routine and service share at the start of the sample). The model's predictions are slightly different from the data for Germany but the trend is consistent with the data.

6.2.2 Job polarization in a search and matching model : Economic mechanisms at work

Frictional labor market and the long run impact of the Task Biased Technological Change Figure 10 illustrates the mechanisms at work in the model, in countries without minimum wage (US and Germany). In each labor market (routine, manual and abstract tasks, Figure 10, panels (1)-(3)), the equilibrium is determined as the intersection of the job creation condition (JC) and the wage curve (WC). JC is a decreasing relation between the ratio "vacancies over unemployment", tightness (θ), and wage (w): it indicates that hiring intensity declines with the labor cost. WC is an increasing relationship between θ and w, showing that workers ask for a higher wage when their relative scarcity is large. The general equilibrium effects are captured by the usual AD/AS model, in each market, goods and services (Figure 10, panels (4)-(6)). Finally, the last

[10]The model misses the fall in the employment rate since 2000. However, this contraction is essentially explained by the reduction in labor force participation of youth (staying longer in education) and the increase in disability rates among adults (see e.g. OECD, 2014): OECD Employment Outlook 2014, Box 1.1 and Annex Table B. Neither factor is modeled in the analysis, though.

Figure 8: Model vs Data - aggregate employment. Model's prediction on aggregate employment in the US, France and Germany.

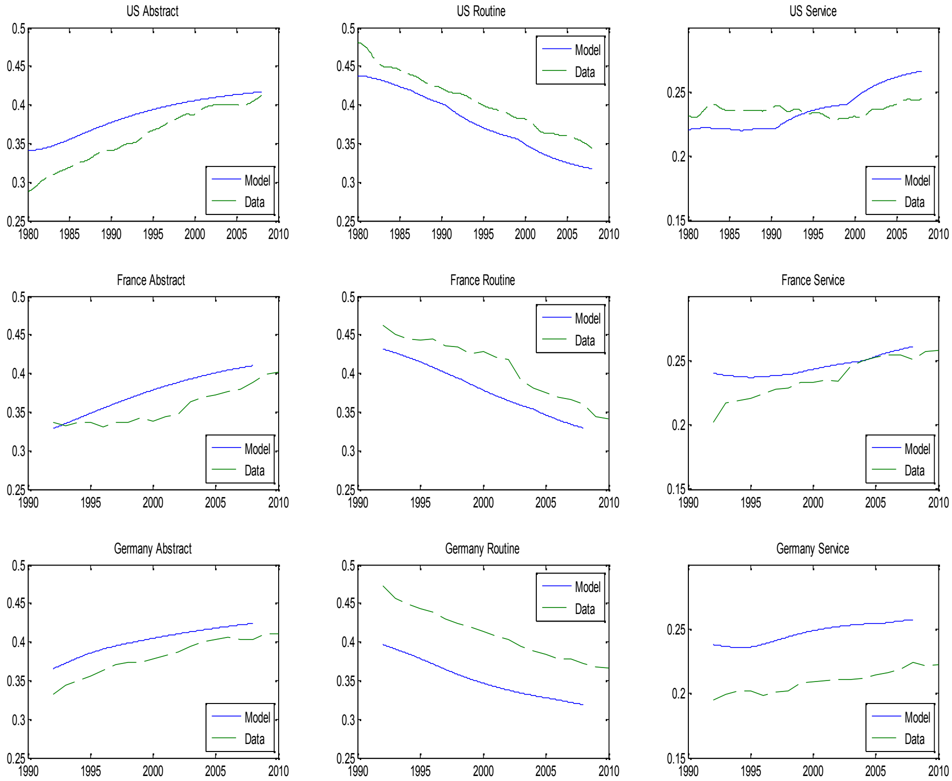


relationship summarizes occupational choices with the threshold $\tilde{\eta}$ under which it is optimal for routine workers of ability η to switch from routine to manual tasks (Figure 10, panel(5)): given that the ability increases the productivity for the routine tasks whereas it does not affect it on manual tasks, the incentive to hire, and thus the tightness, raises with η, whereas for the tightness for the manual tasks is independent from η.

The impact of the Task Bias Technological Change (TBTC) can be decomposed as follows:

- The direct impact of technological change (From E_0 to E_1 in Figure 10)
  - The decline in the computer price reduce the marginal productivity of the routine task (they are replaced by computers). This shifts down the JC curve in panel (1) of Figure 10. Part of this lost competitiveness is absorbed by a wage reduction (the WC curve shifts up as wage are partly indexed on productivity change). The total effect is a decline in both tightness and wages for these workers.
  - At the opposite, TBTC increases the productivity of abstract tasks (JC shifts up in panel 3). Despite a crowding effect induced by wage bargaining (WC curve shifts down), the total effect is an increase in both tightness and wages for these workers.
  - This supply shock shifts down the AS in the good market (the AS curve shifts down in the panel 4), and for a given level of η, the profitability of routine task declines, leading the curve $\theta_r(\eta)$ to rotate to the right (panel 5).
- General equilibrium effect : Taking into account the expansion in demand and the rise in the relative price of service (E_2 in Figure 10).

Figure 9: Model vs Data - Employment share. Model's prediction on employment shares by task in the US,France and Germany.



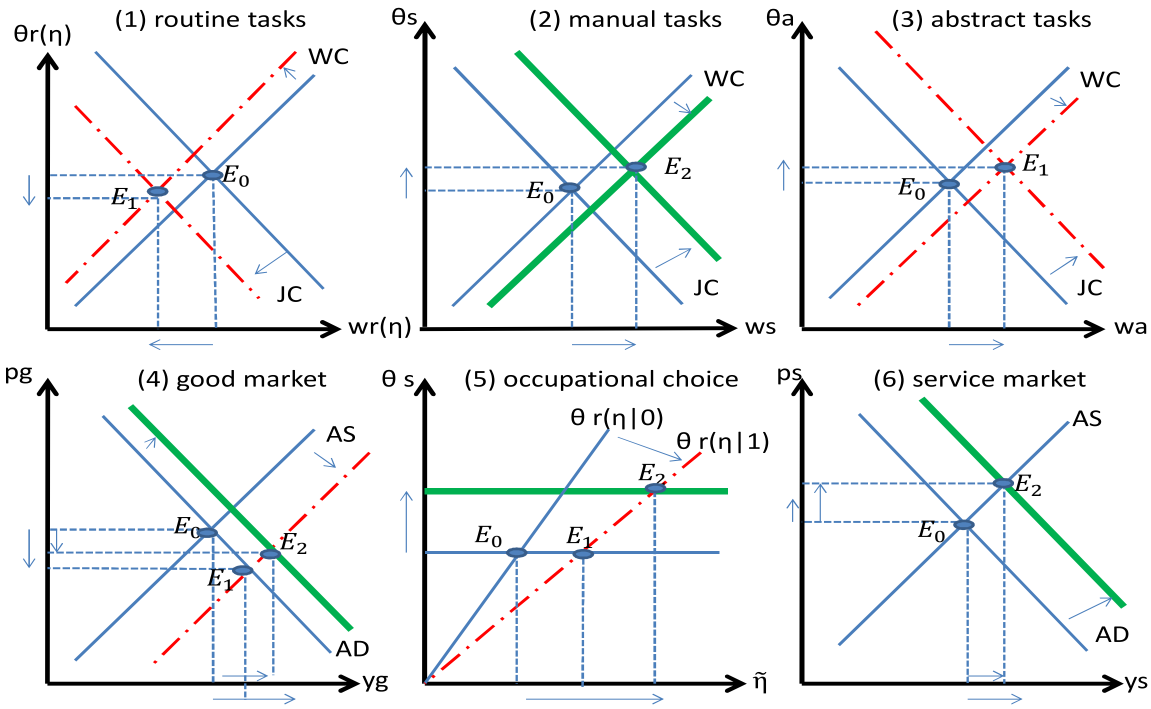
- This supply shock also generates additional incomes. Demand for goods and services increase. In panels (4) and (6) of Figure 10, demand AD shifts to the right. Given that the goods market is also affect by the positive supply shock, the increase in the price of the services is necessarily larger than the one observed in the goods market. Hence, the relative price of the services p_s increases, hence the marginal gains of each produced services.
- The feedback effect on the labor market magnifies the initial impact of the supply shock. Indeed, the marginal return of services goes up: this leads to a shift up (down) of the JC (WC) curve in the labor market of the manual tasks (panel (3) of Figure 10). This higher returns of service entices more worker to move towards service jobs (the horizontal line representing the value of θ_s shifts up in the panel (5) of Figure 10).

These adjustments show that job polarization can also be described by a matching model. The value added of a matching model comes from its ability to account for persistence in the adjustment dynamics, and to its flexibility to introduce labor market institutions.

Why does time for reallocation matter? Given that the employment state is always preferred to unemployment, occupational choices, ie. the decision to search for a "routine" or a "manual" job, are governed by unemployment values.[11] These unemployment values depend on two main components: the expected gains (wages and benefits) and the time duration of an unemployment

[11] Only situations where the employment value is larger than the unemployment value in "routine" or "manual" labor markets for a η-type worker. Employed workers always prefer their "insider" positions.

Figure 10: The TBTC in a model with labor market frictions



Legend: E_0 (solid lines) = before the technological change; From E_0 to E_1 (dash-dot lines) = after the technological change without General Equilibrium feedback (no increase in p_s); E_2 (bold lines) = after the technological change with General Equilibrium feedback (after increase in p_s).

episode.

At the time of the technological change, workers, employed and unemployed, learn that their contemporaneous and future labor incomes will be modified. For some unemployed workers searching for a "routine" task, the unemployment duration can become infinite (firms stop opening vacancies on η-type labor market segment). Workers then decide to start searching a manual job. But, at this time, the intensity of the "computerization" of the production process is at its beginning. Thus, the increase in the demand, and thus in the relative price of the service is moderate. This implies that the creation of new jobs in the services is also moderate: a labor market with "reasonable" unemployment duration disappears, and workers move to a labor market where this unemployment duration is higher, but with the perspective of a decline. Hence, search frictions allow to account for transitional "technological unemployment", which is an unemployment "excess" generated by the instantaneous closure of opportunities in the labor market of routine jobs, replaced by lower opportunities than the ones before the shock. Moreover, when η-type unemployed workers decide to move towards labor market of services, the stock of unemployment worker is transitionally beyond its long-run value. Hence, non-employment is larger than its "natural" rate even if workers have instantaneously a higher probability to be hired than in their previous unemployment spells. This last point underlines the importance to develop a dynamic model to account for a reallocation process.

Given that the computerization process takes time, and that the re-organization of production extends this transition, one can observe a decline in the employment rates of the unskilled workers, despite their occupational choices leading them to search on service markets where opportunities are better and are improving.

Notice that these opportunities are "better" because previous jobs disappears (the opportunities attached to the labor market of the routine tasks). Hence, this additional "technological unemployment" can be resorbed only after a meeting, and this search process can take time.

These adjustment processes can be quantitatively large because non-employment adjusts to its long-run level with some persistence. The service labor market slowly absorbs the new arrivals from the labor market of the routine jobs. This search process is not the same across countries. In a flexible labor market, when η-type workers have no opportunities in the routine labor market, they move towards the service labor market: instantaneously, non-employment in the service labor market jumps, but the high job finding rate allows worker to rapidly find a job. In contrast, in a rigid labor market, after the same type of reallocation, given the low job finding rate, persistence of the non-employment is large.

Why do labor market institutions matter? The labor market institutions can modify the allocation and its dynamic through the wage setting rules: the bargaining process can be country-specific, workers'outside options are also country-specific and finally, a minimum wage (MW) can be a substitute for this bargained wage for low-paid workers.

The basic effect of the heterogeneity in LMI among countries is the gap between US and European employment rate. In order to enlighten the differences between countries, we present in Figure 11 the same set of graphs as Figure 10, except that the minimum wage is now binding in the service sector. These pictures shows that the presence of MW changes the elasticity of labor market adjustments to TBTC. More importantly, the rise in MW during the TBTC can cancel the positive effects of these new opportunities on labor demand in services, leading the fired workers from routine jobs without any new opportunity.

Analytical analysis The impact of TBTC in Autor & Dorn (2013)'s model can be summarized as

$$\text{Mobility: } \widehat{\eta} F_R' = A_M p_s \qquad \text{Demand: } p_s = MRS(C_g, C_s)$$

Elasticities of substitutions of $F(\cdot)$ and $C(\cdot)$ depend on $\{\sigma, \alpha\}$ and ρ respectively. This implies that the impact of BTC depends only on these 3 parameters. There is no labor supply elasticity because the supply of skilled labor is fixed in all markets. In our model, we keep the same equation for the demand for good and service ($p_s = MRS(C_g, C_s)$), whereas on the labor market, we have

$$\text{Mobility:} \quad U(\theta_R(\widehat{\eta}), LMI) = U(\theta_M, LMI)$$

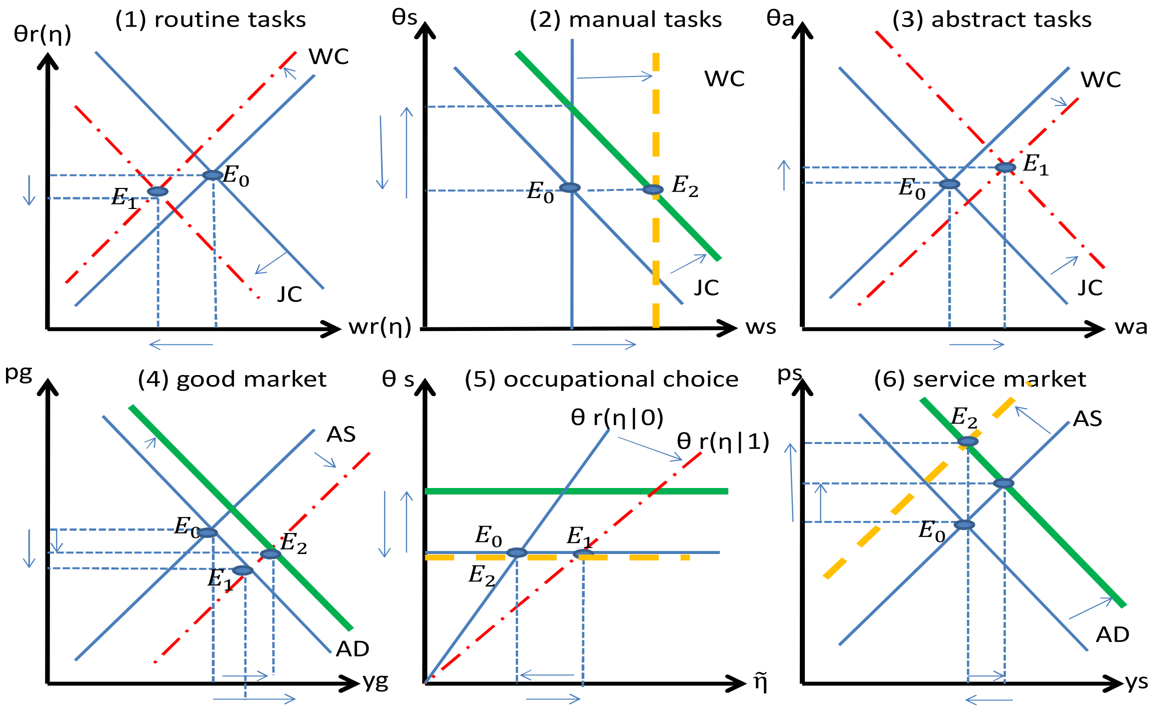
showing that occupational choices are based on worker's evaluation of search returns in each market. Tightness θ are deduced from firms free entry condition: they post vacancies until their expected returns are equal to their costs. This leads to

$$\text{where Hirings:} \quad \left\{ \begin{array}{lcl} \theta_R(\eta) & = & \varphi_R(\eta F_R', LMI) \\ \theta_R(\eta) & = & \varphi_M(A_M p_s, LMI) \end{array} \right.$$

In a simplified model where the functions $U(\cdot)$ do not depend on labor market occupation, we then deduce from the "Mobility" and the "Hiring" conditions that the threshold $\widehat{\eta}$ is such that:

$$\varphi_R(\widehat{\eta} F_R', LMI) = \varphi_M(A_M p_s, LMI)$$

Figure 11: TBTC in a model with labor market frictions and minimum wage



Legend: E_0 (solid lines) = before the technological change; From E_0 to E_1 (dash-dot lines) = after the technological change without General Equilibrium feedback (no increase in p_s); E_2 (bold lines) = after the technological change with General Equilibrium feedback (after increase in p_s); bold-dashed lines = rise in minimum wage

As in Autor & Dorn (2013), the impact of TBTC depends on $\{\sigma, \alpha\}$ and ρ, which determines the dynamics of $\{\widehat{\eta}, F_R', p_s\}$. In a model with labor market frictions, the impact of the TBTC also depends on

$$LMI = \{\underbrace{r, h}_{w^r}, \underbrace{\gamma, sc}_{w_{Nash}}, \underbrace{MW, \omega, \overline{w}}_{wage\ rigidity}\}$$

and thus on the market-specific elasticities $\varphi_i(\cdot)$, $i = R, M$, through the wage setting rules and the dynamics of each sector.[12] Hence, asymmetries between labor market, in addition to productivity, are necessary to find a value for η that differs from the ones proposed by Autor & Dorn (2013). To illustrate an alternative solution, assume for simplicity that wages are $w_r(\eta) = (\gamma + (1-\gamma)r)\eta y_r$ and $w_m = (\gamma + (1-\gamma)r)p_s A_s$ (wage bargaining à la Hall & Milgrom (2008) with an unemployment benefit proportional to productivity). Second, assume that p_s is constant but y_r decreases at rate g (ie. $y_r(t+1) = (1-g)y_r(t)$). We deduce that the occupational choice ("Mobility" condition) is given by:

$$\eta y_r \left[r + \frac{\beta f_r(\eta)\gamma(1-r)}{1-\beta(1-g)(1-s-f_r(\eta))} \right] = pA_m \left[r + \frac{\beta f_m \gamma(1-r)}{1-\beta(1-s-f_m)} \right]$$

The "capitalization effect" in the LHS, and absent in the RHS, implies that $\widehat{\eta} y_r = A_m p_s$ is not the equation that determines the threshold of ability, because $\varphi_M(\cdot) \neq \varphi_R(\cdot)$. A simple way to interpret

[12]If the behaviors and the history of each market were the same, then $\varphi_M(\cdot) = \varphi_R(\cdot)$. In this case, the solution for $\widehat{\eta}$ would be $\widehat{\eta} F_R' = A_M p_s$, simply because the only source of heterogeneity lies in productivity.

the previous equation is to notice that it defines $\widehat{\eta}$ as follows:

$$\Gamma(\widehat{\eta}, g) = \Upsilon \quad \text{with } \Gamma_1'(\eta, g) > 0 \text{ and } \Gamma_2'(\eta, g) < 0$$

When $g = 0$, the solution is, as in Autor & Dorn (2013) (AD) model, $\widehat{\eta}_{AD} y_r = p_s A_m$, whereas when $g > 0$, we necessary have $\widehat{\eta} > \widehat{\eta}_{AD}$. The search and matching framework transforms employment into an investment decision: time matters, and thus the capitalization of future profit flows. If profit flows are decreasing with time, the firm's incentive to open vacancies is reduced. This leads workers to quit earlier the routine labor market than in a frictionless market. This results appears even if wage is flexible (Nash bargaining rule) and even if there are no revenues non-indexed on wages, like social programs. The gap between $\widehat{\eta}$ and $\widehat{\eta}_{AD}$ depends on the LMI, ie. in this example on $\{r, \gamma, c\}$.

The wage setting rule is also a crucial element of labor market adjustments (the shape of WC in Figures 10 and 11). It allows to share the labor market adjustments between wage and employment, as a labor supply curve. The elasticity of WC locus is thus central in the quantitative analysis. The steeper this curve, the larger the adjustments though quantities. If quantities react rapidly, then unemployment duration is also highly elastic and the more persistent the dynamic adjustments.

- **Routine jobs.** The sluggishness of real wages (the weight of the "social" norms) imply that the quantities must largely decline in the market of the routine jobs in response to these relative loss of competitiveness. This is not the case when bargaining does not include "social" norm, all the regulation being at the charge of the State via a minimum wage. In this last case, the employment decline in routine tasks is less important, a large part of the adjustment being absorbed by the wage. Routine jobs are maintained longer and their wages converge to the minimum wage: this generates a concentration of low-paid worker at the minimum wage level.
- **Manual jobs.** In the service sector, the absence of a MW allows labor market to start with a higher employment rate for the manual tasks, but a wage moderation (the "social" norms) allows them to generate a higher employment growth in the service sector. With a Minimum wage, the growth of the service sector is ensured by the rise in the service price with a constant unit cost, the minimum wage. Even if a minimum wage is more rigid than a wage that accounts for "social norms", the employment growth is slower because the number of vacancies is smaller (level effect of the MW) and also because the number of worker that choose to move is smaller than in US or in Germany (lower finding rates).

6.3 Model predictions on inequalities

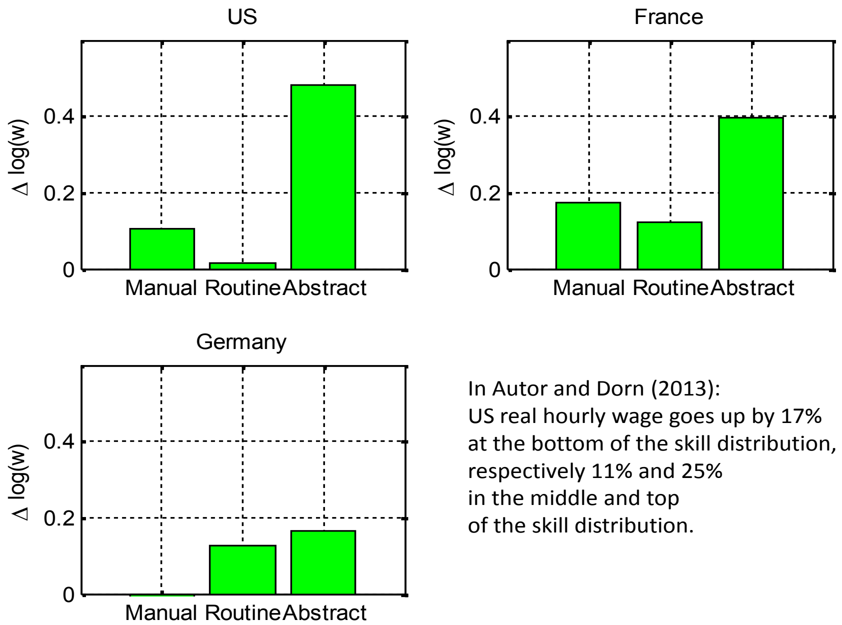
6.3.1 Static perspective : wage and income polarization

Job polarization induces shifts in labor demand and supply across tasks, which generates divergent wage dynamics in the pool of employed workers; wage and income inequalities are further affected by the prevailing labor market institutions. In the model, the patterns of inequality can be captured in two complementary ways. First, by simply looking at the relative growth of wages paid for different groups (tasks); second, exploiting the simple heterogeneous agent structure of the model to look at changes in earnings or income inequality through more standard indicators as the Gini index.

Figure 12 reports the impact of job polarization on wage dynamics across tasks. We compute the predicted increase in wage for each task group between the beginning and the end of the technological transition[13]. Our model is able to capture the polarization of US wages found in Autor and Dorn (2013): wage growth is largest at the top and bottom of the wage than in the middle[14].

The cases of France and Germany illustrate the impact of wage-setting rules on wage polarization, which suggests that wage polarization has no the same characterization in all countries. In Germany, the wage is set with respect to a sector-specific reference wage whose value is based on past wages (the "social norm"). For abstract workers whose labor demand is rising, the reference wage tends to dampen the rise in the wage as shown in Figure 12. In contrast, for routine workers whose labor demand is falling, the reference wage contributes to containing downward pressures on the wage: the wage declines for these occupations are lower than in the US. In France, by contrast, the growth of abstract workers' wages captures changes in labor demand (abstract workers benefit from rise in productivity), while those of routine and manual workers stem from the increases in the real minimum wage. Figure 12 reports growth rates across task groups. In order to fully grasp the evolution of inequalities, one must take into account the evolution of the number of workers in each group. Next section fills this gap.

Figure 12: Wage polarization. Change in real wage by task in the US, France and Germany



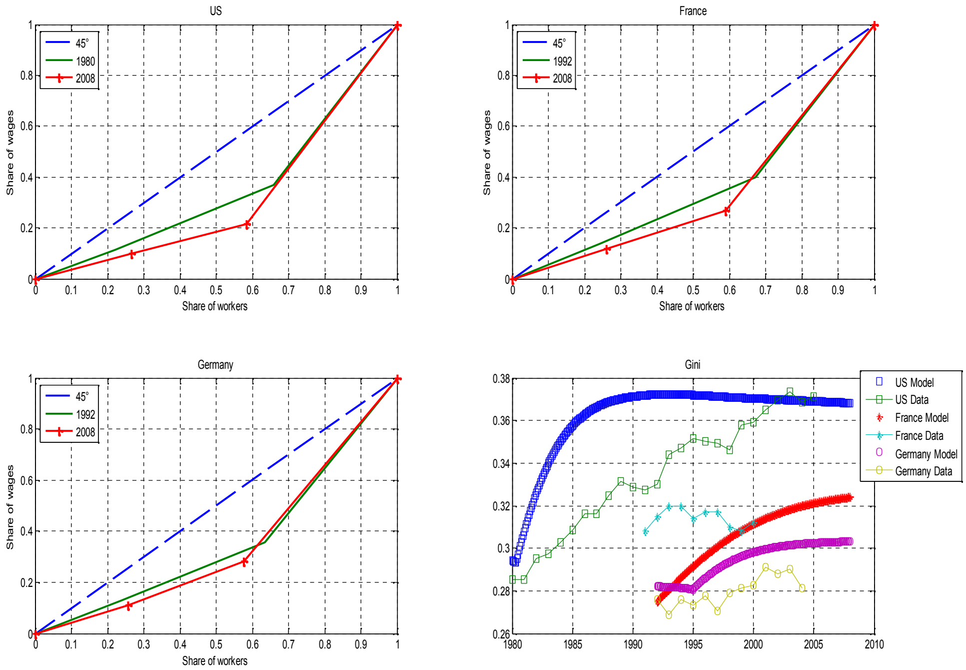
The model features a simple heterogeneous agent framework, including abstract workers, a continuum of routine workers and manual workers. In this section, we assess to which extent job polarization can capture changes in earnings inequality (as summarized by the Gini indicator) in this context. With shifts in labor demand and occupational choices, the mass of workers in each employment pool evolves over time. The Gini coefficient then reflects both the changing shares of workers in each group as well as the wage growth differentials reported in Figure 12. Figure 13 displays Lorenz curves for each country at the beginning and the end of the technological transi-

[13]In order to make the graph comparable to Autor and Dorn (2013), we take into account the general increase in total factor productivity that is common to all wages. This increase is computed on country-specific TFP using GDP, labor and capital data.

[14]In Autor and Dorn (2013) paper, US real hourly wage goes up by 17% at the bottom of the skill distribution (respectively 11% and 25% in the middle and top of the skill distribution. Source : US Census data, 1980-2005)The model over-estimates the wage gain for abstract workers as their wage in the model responds to the rise in labor demand

tion[15]. At both points in time, we can compute a Gini coefficient on wages and compare the model's predictions to the data.

Figure 13: Wage inequalities



Wage inequality along the transition path. Lorenz curves at the beginning and the end of the technological transition for each country. Evolution of Gini coefficients. Source: Gini coefficients (US: Heathcote, Perri, Violante, 2010; Germany: Fuchs-Schündeln, Krueger and Sommer, 2010; France : Atkinson, Glaude, Olier and Piketty, 1997)

The model is consistent with the increase in wage inequality found in US data until the early 1990s (see fourth panel). After the early 1990s, wage inequality continues to rise in the US data, an upward trend which could be matched in the model considering another wave of technological change. The model also predicts a stable Gini along the transition in Germany, which matches the findings on German wages. The data suggest a rebound in wage inequality in 2003, which could be related to "mini-jobs", which we do not have in the model. Finally, the model slightly under-predicts the level of the French Gini coefficient. France is characterized in the model by an increase in Gini along the transition path, which echoes the hump-shape found in the French data in the early 1990s.

Differences in the existing wage-setting mechanisms account for the divergent evolutions of inequalities in France and Germany. In Germany, as shown in Figure 12, the reference wage limits the increase in abstract wages and the fall in routine wages, which tends to narrow the range of wages in the economy. In France, even if the increasing real minimum wage dampens the inequalities with respect to the middle of the distribution, the larger wage inequalities than in Germany come from the larger increase of the high wages.

6.3.2 Dynamic perspective: taking into account future job opportunities

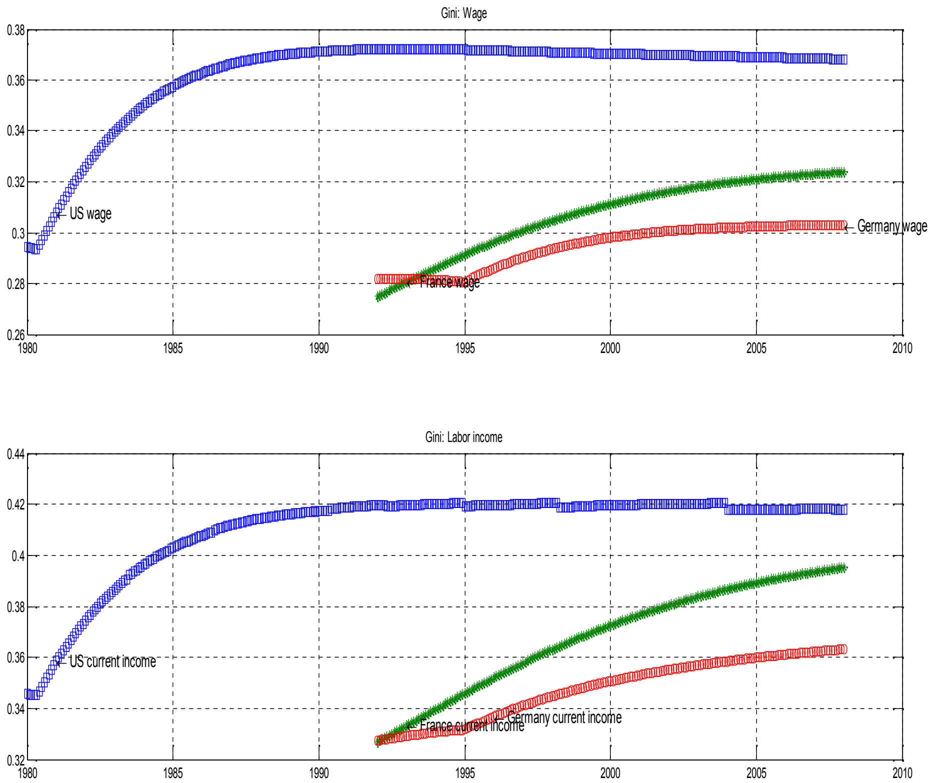
Looking at the evolution of inequality over time, in the US, it reflects the decline in the generosity of income support when non-employed. This is also the case in Germany (after 1995) which now displays a steady rise in current income inequalities. In France, on the other hand, the shape of

[15] Curves are actually piece-wise linear because of the limited heterogeneity in the model.

the Gini evolution remains the same. As can be seen from the shifts of the Lorenz curves, workers in middling positions tend to lose during the transition process: they leave routine jobs, their wage increase less than in other segments of the labor market (Figure 6) while abstract workers keep gaining from the technological change. This change in employment opportunities dominates the rising generosity of the minimum wage as well as income when non-employed through assistance programs and rising unemployment benefits. In a nutshell, in France, the generous assistance programs and unemployment benefits do not succeed in dampening the rise in inequalities driven by the wage growth at the top of the skill distribution (as shown in Figure 6). Nevertheless, France is the country where the poorest worker is less poor than in another country: this could be a foundation of this income distribution. Its cost is that the number of non-employed workers is larger than in the other countries.

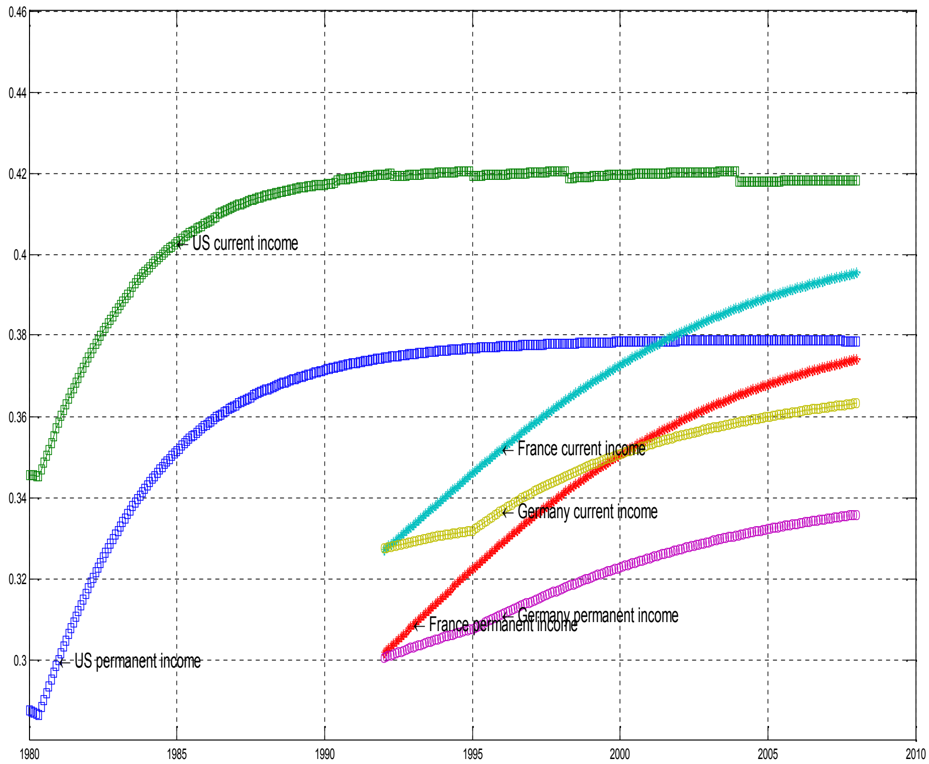
The previous Gini captures inequalities in current income (static perspective). As such, it provides a picture of dispersion of instantaneous income. However, we argue that inequalities in future employment opportunities shall also be taken into account when assessing the impact of technological changes on inequalities (a dynamic perspective). In order to do so, we compute a measure of inequalities based on "permanent income", which accounts for future employment opportunities for each group of workers[16]. So, if there is no mobility from employment to employment (or to an occupation to another) in the economy, this measure is the same as the inequality on current incomes, whereas if mobility is large, the current state does not provide any information about the income status tomorrow and thus all workers can incorporate in his current income the actualized value of these future incomes (a gain if the worker is at the bottom of the distribution, a loss if he is at the top). The results are reported in Figure 14 and 15.

Figure 14: Labor income inequality. Employed and non employed, static measure.



[16]We rely on value functions as they capture the discounted value of income given future employment opportunities for each agent in the economy. We compute the monetary income flow that is equivalent to value functions.

Figure 15: Permanent income inequality.



Dynamic measure based on value functions. This then includes future job opportunities.

Since the aggregate employment rate increases in the US and in Germany after 1995, the chances to become employed rise. Then, the Gini curves on permanent income shifts downward with respect to its counterparts on current income. In France, labor mobility exists, leading the Gini curve on permanent incomes to shift downward with respect to its counterpart on current incomes. However, at the beginning of the technological transition, this shift is small (a gap of 0.01 between the Gini curves on permanent and current income) relative to what can be seen in the US and Germany (Gini gap of 0.02). This slight difference in the French case suggests that France does not perform as well as Germany and the US in terms of improvement in employment opportunities. Interestingly, when considering permanent income France appears more unequal than the US. This is because the relatively weaker contribution of future employment opportunities outweighs the rising generosity of the minimum wage as well as of the income granted by existing assistance programs and unemployment benefits[17].

7 Is Technological Change an opportunity or a risk? Counterfactual experiments in the US and in France

What would have been the employment growth without technological changes, or without the increase in labor supply of skilled workers ? Due to the complexity of the model and the general equilibrium effects it is hard to disentangle the respective role of TBTC, labor supply and LMI shifts. In order to understand the driving force behind movement in aggregate employment we perform a counterfactual analysis. We investigate two alternative scenarios. We wonder what the

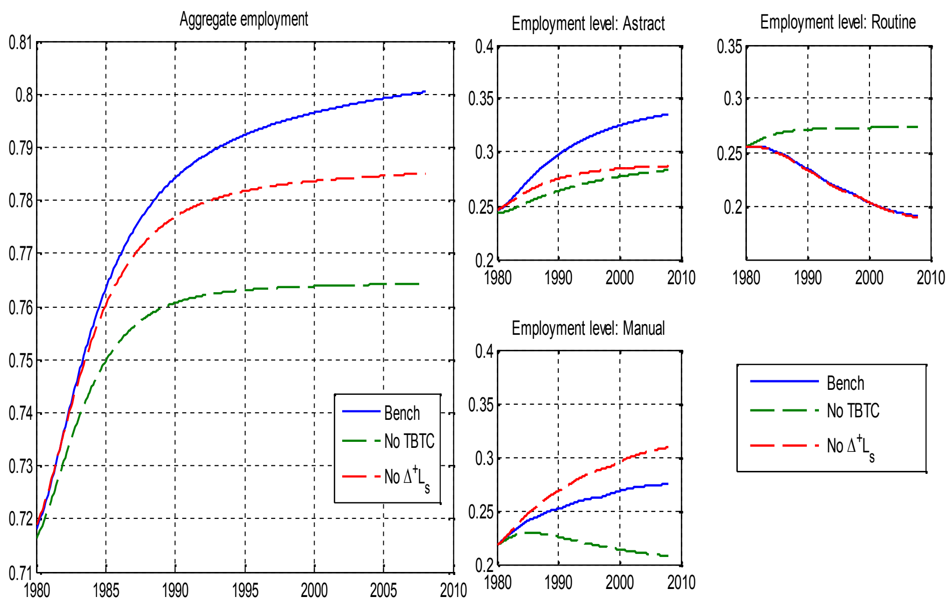
[17]This result echoes findings by Flinn (2002).

path of the economy would have been in absence of 1) the TBTC, 2) increase in labor supply of skilled workers.

7.1 US: Gains from polarization

In the US economy, on Figure 16, the benchmark case depicts job polarization: Routine employment falls while manual and abstract employment both increase. Our results are consistent with Autor & Dorn (2013)'s stress on TBTC as the leading force behind changes in employment shares across tasks. It results in a strong rise in aggregate employment rate of about 8 percentage points (from the beginning to the end of the transition, employment rate goes up from 0.72 to 0.80).

Figure 16: United states. Counterfactuals without TBTC or rise in labor supply of abstract workers.



"Bench" (solid line) = benchmark. "No TBTC" = counterfactual without TBTC. L_a rise and LMI change. "No $\Delta^+ L_s$" = counterfactual without rise in L_a bu TBTC and LMI change.

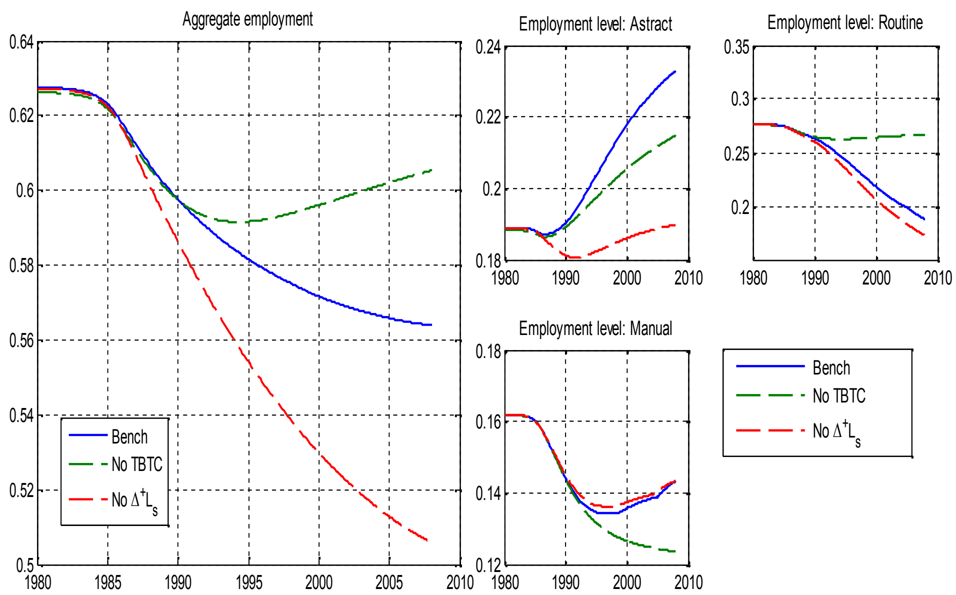
What would have happened in the absence of technological change? The employment level in the routine sector would have increased on impact due to the small decline in workers bargaining power which lowers negotiated wages and prompt employers to post more vacancies. But there is no reallocations. Employment in services declines slightly, meaning that the rise in aggregate employment is almost entirely governed by the labor supply shock of abstract job. It should be noted that TBTC amplifies the rise in abstract jobs by raising the level of capital and therefore their productivity. Absent TBTC, employment growth would have been of 4 percentage points (from 0.72 to approximately 0.76) rather than the 8 percentage points in the benchmark economy. Without technological change, the rise in US employment would have been cut by half.

When we remove the increase in educational attainment, the transitional dynamic exhibits a weak increase in abstract employment. In turn, aggregate employment declines with respect to the benchmark scenario. The gap between the benchmark and the counterfactual amounts to 1.5 percentage point, which suggests that, absent the rise in the supply of skilled labor, the US employment growth would have been 20% (1.5pp divided by 8pp) lower.

7.2 France: Pains from polarization

In France, the benchmark economy experiences a decline in employment by around 7 pp: on Figure 17, aggregate employment rate goes down from approximately 0.63 to 0.56. Despite the increase in employment in abstract jobs, the fall in low-skill employment (routine and service) explains the downward trend in aggregate employment. While the routine sector declines the service sector does not depict any clear increase. In other words, there is no reallocation from routine to service, workers remain unemployed. This is consistent with our analysis in section 6.2.2.

Figure 17: France. Counterfactuals without TBTC or rise in labor supply of abstract workers.



"Bench" (solid line)= benchmark. "No TBTC" = counterfactual without TBTC. L_a rise and LMI change. "No $\Delta^+ L_s$" = counterfactual without rise in L_a bu TBTC and LMI change.

Since TBTC generates employment fall, the counterfactual French economy without TBTC is better off than the benchmark scenario. Due to the increasing generosity of French LMI, aggregate employment rate still falls in the long run (by 2 pp, from 0.63 in the initial steady state to 0.61 approximately in the final steady state). However, this falls is lower than the one observed in the benchmark scenario (7pp). We then conclude that, without technological change, the fall in French employment would have been cut by 70% (1-(2/7)).

The counterfactual economy without the rise in educational attainment displays a larger fall in aggregate employment (from 0.63 to 0.51) than the benchmark scenario (from 0.63 to 0.56). The model also predicts that, without the increase in skill labor, the fall in employment would have doubled. The improvement in educational attainment dampened the unfavorable consequences of technological change.

8 Conclusion

This paper develops a multi-sectorial search and matching model with endogenous occupational choice in a context of biased technological change. Our objective is to shed light on the way labor market institutions affect aggregate employment, job polarization and inequalities observed in the US and in European countries. We consider the cases of the US, France and Germany that are representative of alternative institutional settings, having the potential to induce divergent time-paths in the evolution of labor market outcomes during the process of technological transition. In the US, we find employment gains from technological change and job polarization, whereas, in France, the technological change reduces aggregate employment in a context of job polarization. With counterfactuals experiments, we quantify the hypothetical change in aggregate employment without technological change or rise in the supply of skilled labor. In the US, without technological change (without the rise in skilled labor), employment growth would have been cut by half (by 20%). In France, the change in LMI, especially the rise in the minimum wage, affects new job opportunities in manual jobs: the reallocation of routine workers towards manual jobs is obstructed for want of job creations of manual services. Job polarization in France only mirrors the fall in aggregate employment. Hence, without technological change, the fall in French employment would have been cut by 70%. The model also predicts that, without the increase in skilled labor supply, the fall in French employment would have doubled. The improvement in educational attainment dampened the unfavorable consequences of technological change.

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A Model

A.1 Good-producing firms

First, remark that this firm program can be solved in two steps, given the homogeneity of degree one of the production function and the exogenous process of the capital price. This property of the firm program allow us to show that if the firm choose to fire, it is optimal to fire all of the η-type workers simultaneously. Indeed, we have:

$$\begin{aligned} p_{z2}\frac{\partial Y^{z2}}{\partial K} &= p_k && (26)\\ Y^{z2} &= \frac{\partial Y^{z2}}{\partial K}K + \sum_{\eta}\frac{\partial Y^{z2}}{\partial L_r(\eta)}L_r(\eta) && (27)\\ \Rightarrow p_{z2}Y^{z2} - p_k K &= p_{z2}\sum_{\eta}\frac{\partial Y^{z2}}{\partial L_r(\eta)}L_r(\eta) && (28) \end{aligned}$$

Given the production function (14), the equation (26) can be rewritten as follow:

$$p_k = p_{z2}\mu k^{\sigma-1}\left(1-\mu+\mu k^{\sigma}\right)^{\frac{1}{\sigma}-1} = p_{z2}\mu k^{\sigma-1}g(k)$$

where $k \equiv \frac{K}{\sum_{\eta}\eta_r(\eta)}$ is determined by this equation at each period time, given $\{p_k, p_{z2}\}$. The production function leads also to

$$\frac{\partial Y^{z2}}{\partial L_r(\eta)} = \eta(1-\mu)g(k)$$

Thus, we deduce that the equation (28) becomes

$$p_{z2}Y^{z2} - p_k K = p_{z2}(1-\mu)g(k)\sum_{\eta}\eta L_r(\eta)$$

showing that the marginal productivity of one η-type job does not change with the level of $L_r(\eta)$. Thus if at one period of the time, it is optimal to fire one η-type worker, it is optimal to fire all of them.

The FOC of this problem are w.r.t. $\{V_r(\eta), l_{+1}(\eta), L_r(\eta)\}$ are

$$\begin{aligned} 0 &= -c + \mu(\eta) + \beta\Pi_{+1}^{'z2}q_r(\eta)\\ 0 &= -\beta\Pi_{+1}^{'z2} - \beta F - \lambda_{+1}(\eta)\\ 0 &= p_{z2}\frac{\partial Y^{z2}}{\partial L_r(\eta)} - w_r(\eta) + \beta\Pi_{+1}^{'z2}(1-s) + \lambda_{+1}(\eta)(1-s) - \Pi^{'z2} \end{aligned}$$

For the declining firms, we have $\mu(\eta) \geq 0$, with $V_r(\eta) = 0$. In this regime with "no-hiring", there are two cases: the firm hoards its workforce, or the firm will fire the workforce that correspond to the type η. In this case, we have $l(\eta) < (1-s)L_r(\eta)$ implying $\lambda(\eta) = 0$ and $l_{+1}(\eta) = (1-s)L_{r,+1}(\eta)$ and thus $\lambda(\eta) \geq 0$. Using $\beta\Pi'^{z2}_{+1} + \lambda_{+1}(\eta) = -\beta F$, we obtain

$$\Pi'^{z2} = p_{z2}\frac{\partial Y^{z2}}{\partial L_r(\eta)} - w_r(\eta) - \beta(1-s)F$$

and, given that $\lambda(\eta) = 0$, leading to $\beta\Pi'^{z2} = -\beta F$, we deduce

$$0 = p_{z2}\frac{\partial Y^{z2}}{\partial L_r(\eta)} - w_r(\eta) + F - \beta(1-s)F$$

When this condition holds, this determines the period at which the firm fires the η-type workers. If we denote $J_a = p_{z1}\frac{\partial Y^{z1}}{\partial L_a}$ and $J_r(\eta) = p_{z2}\frac{\partial Y^{z2}}{\partial L_r(\eta)}$, the associated Bellman equations of a filled job writes, when $V_a > 0$ and $V_r(\eta) > 0$:

$$\begin{aligned} J_a &= y_a - w_a + (1-s_a)\beta J_{a,+1} && (29) \\ J_r(\eta) &= y_r(\eta) - w_r(\eta) + (1-s)\beta J_{r,+1}(\eta) && (30) \end{aligned}$$

where $y_a = p_{z1}$ and $y_r(\eta) = p_{z2}\eta(1-\mu)g(k)$. The FOC equations for vacant jobs write:

$$\begin{aligned} 0 &= -c_a + \beta q_a J_{a,+1} \\ 0 &= -c + \beta q_r(\eta) J_{r,+1}(\eta) \end{aligned}$$

A.2 Service-producing firms

The associated Bellman equations of a filled job writes:

$$\begin{aligned} J^n_m(\eta) &= p_s\delta A_s - w^n_m(\eta) + (1-s)\beta\left((1-\lambda)J^n_{m,+1}(\eta) + \lambda J_{m,+1}\right) && (31) \\ J^o_m &= p_s\delta A_s - w^o_m + (1-s)\beta\left((1-\lambda)J^o_{m,+1} + \lambda J_{m,+1}\right) && (32) \\ J_m &= p_s A_s - w_m + (1-s)\beta J_{m,+1} && (33) \end{aligned}$$

The FOC for a vacant job write:

$$\begin{aligned} 0 &= -c + \beta q^n_m(\eta) J^n_{m+1}(\eta) \\ 0 &= -c + \beta q^o_m J^o_{m,+1} \\ 0 &= -c + \beta q_m J_{m,+1} \end{aligned}$$

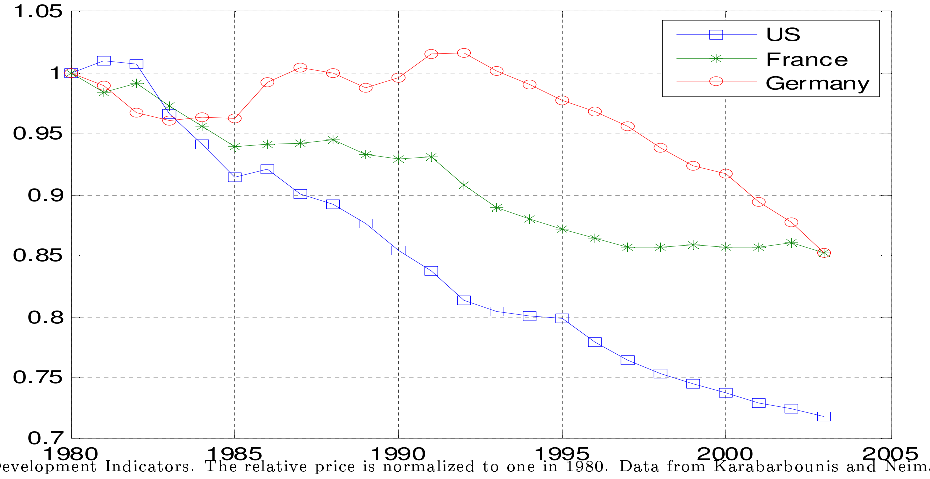
B Model calibration

Figures 18 and 19 provide empirical supports for our calibration of p_K and LMI (replacement ratios and workers' bargaining power), respectively.

C Numerical method used to solve the model

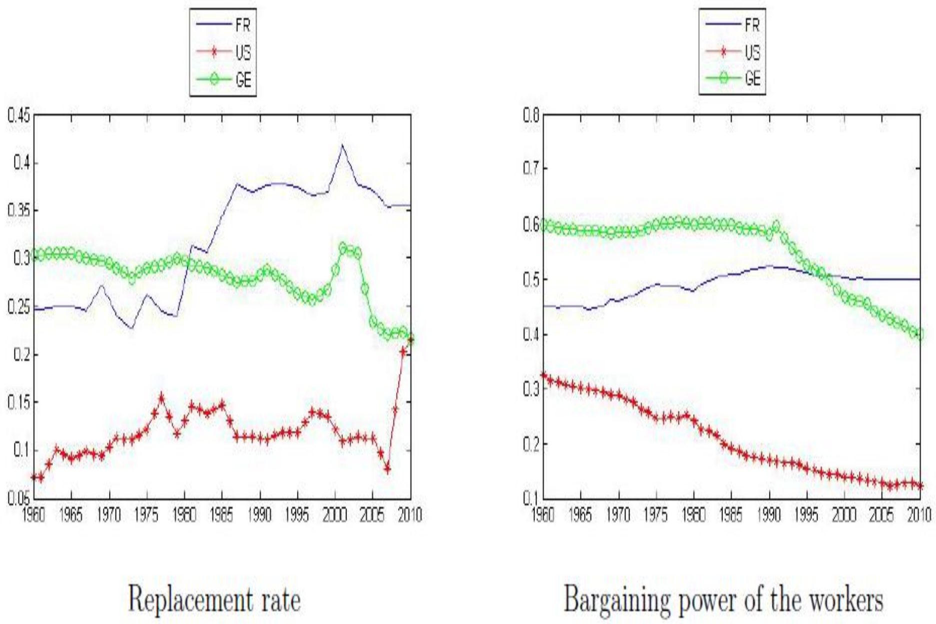
Several elements account for the difficulties we face is solving the model

Figure 18: Investment Price (relative to consumption price)



Source: World Development Indicators. The relative price is normalized to one in 1980. Data from Karabarbounis and Neiman (QJE 2014).

Figure 19: Replacement rate and bargaining power in the data.



OECD data on UB replacement rate. The bargaining power is the average the union density and the union coverage from the Database on Institutional Characteristics of Trade Unions, Wage Settings, State Intervention and Social Pact (ICTWSS).

- The solving of the model involves dealing with a non-stationary environment in order to capture structural changes in the economy. As a result, standard solution methods involving approximation of the dynamics around a unique steady state are not implementable.
- We have heterogeneous agents at the bottom of the wage distribution. The problem is currently solved with 27 ability levels $\eta \sim \mathcal{U}(\underline{\eta}, \overline{\eta})$, which makes the computation burdensome.
- In addition, along the transition path, we face a highly non-linear environment. The reasons behind the non-linearity is 2-fold : *i)* the minimum wage can bind or not in some segments of the labor market. This introduces several regimes in the economy depending on whether the minimum wage binds or not. *ii)* Occupational choices involves also discontinuities as workers of different abilities leave the routine labor market. We then have to deal with occasionally binding constraints. The exact time of occupation switching for each ability level η along the transition path and the exact jobs and periods with binding minimum wage are endogenously determined.
- Finally, this is a general equilibrium problem: the relative price of service is such that good and service markets clear. This relative price also affects relative productivity levels across sectors, which feeds back on occupational choices, therefore employment levels in each sector and relative supply in the good and service markets, hence the relative price of service. This adds a search for a fixed point at the general equilibrium, for each period along the transition path.

Standard procedures can no longer be used here because of the huge number of discontinuities. This leads us to propose an original algorithm for the numerical solution of the model. The algorithm must find a "fixed point" for a trajectory between an initial steady state and a new steady state, given that, during this adjustment process, exogenous variables, such as the policy tools, can change. The numerical method is presented in the case of perfect forecast for the policy instruments $\{x_t\}_{t=0}^{T}$.

We use the block-recursive aspect of the Diamond-Mortensen-Pissarides model. With a block-recursive system, it is possible to solve the paths of forward variables independently from the block that governs the dynamics of backward variables. Let us denote θ the vector of labor market tightness and N the vector of employment stocks, the whole system can be written in a block-recursive way:

$$\theta_t = F_\theta(\theta_{t+1}, p^s_{t+1}, x_{t+1}) \tag{34}$$

$$N_{t+1} = F_N(N_t, \theta_t) \tag{35}$$

Using the block-recursive system, one can solve this problem as follows:

1. conditional on a guess on the equilibrium price $\{p^s_t(0)\}_{t=1}^{T}$ and a sequence of exogenous variables $\{x_t\}_{t=1}^{T}$.
2. For a terminal condition θ_T, and vectors $\{p^s_t, x_t\}_{t=0}^{T}$, we obtain by backward iterations the values for θ_{T-1},θ_{T-2},...,θ_0 using equation (34).
3. With this vector $\{\theta_t\}_{t=0}^{T}$, we deduce, using F_N in equation (35), the vector $\{N_t\}_{t=0}^{T}$, given an initial condition N_0.
4. We then use the general equilibrium condition on good and service markets (see section 4.8.1). This determines a new relative price of service $p^s_t(1) = G(N_t(0), \theta_t(0))$, $\forall t$, we deduce a new sequence for $\{p^s_t(1)\}_{t=1}^{T}$.

5. We repeat steps 1-4 with an updated guess $\{p_t^s(1)\}_{t=1}^T$, until convergence from one iteration z to the next $z+1$: $\{p_t^s(z)\}_{t=1}^T \approx \{p_t^s(z+1)\}_{t=1}^T$.

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