Labor Market Rigidity and Productivity Growth

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Abstract

Empirical studies investigating the relationship between productivity performance and labor market rigidity have generated a negative result. In this paper we try to provide a theoretical explanation for this empirical result. In doing so, we construct a no-shirking model of innovation-based growth and investigate the impact of a set of labor market reforms aimed at reducing labor market rigidities. We focus on the steady-state equilibrium and find that a negative relationship between growth and labor market rigidity exists. The economic explanation of this result is that the presence of moral-hazard in the employer-employee relationship makes the productivity growth of the economy (via its innovation intensity) very sensitive to the level of the efficiency-wage offered by manufacturing.

Keywords: Productivity growth, knowledge mismatch, labor market reforms

JEL-Classification: O33, O34, J6

1 Introduction

Labor market rigidity has always been charged as the major responsible of the unsatisfactory mix of low productivity growth and high equilibrium unemployment of the European Union (EU) economy. The received wisdom is that the European economy is rigid and low-performing, while the US economy is dynamic and high-performing (OECD, 2003). In spite of the common practice of considering the EU a common market, Europe is far from being a unique economy; it is a collection of 25 independent economies, with many of them operating well enough to produce unemployment rates lower than in any of the non-European developed OECD countries including the flexible US. So why is average equilibrium unemployment so high and productivity growth so low in Europe?

In order to answer this question, the empirical literature proposes an array of studies on many particular aspects of labor markets such as firing costs and severance payments

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(Bentolila and Bertola, 1990; Garibaldi and Violante, 2002), the unemployment benefit system (Layard et al., 1991), the loss of human capital during unemployment spells (Ljungqvist and Sargent, 2002), insider-outsiders relations (Blanchard and Summers, 1987), the inability of systems to adjust either to macroeconomic shocks (Blanchard and Wolfers, 2000; Nickell, 2003) or to microeconomic ones (Gottshalk and Moffitt, 1994). The main conclusion of all these studies is that rigid labor markets lead to low productivity performance.

Motivated by the aforementioned empirical evidence, in this paper we aim at providing a possible theoretical explanation of the negative relationship between productivity growth and labor market rigidity. In doing so, we build a dynamic no-shirking model in the spirit of Shapiro and Stiglitz (1984) with endogenous R&D investment and labor market rigidity. Our goals are twofold. On the one hand, we are interested in extending the Mortensen analysis to the case of a Schumpeterian growth model with moral hazard. On the other, we are interested in studying the long-run impact that active labour market policies (ALMPs)[1] have on long-run innovation and economic growth.

In our model efficiency-wages have the usual twofold impact. Firstly, they solve moral hazard or selectivity issues that prevent firms from offering desirable job contracts. Secondly, they generate equilibrium unemployment (misallocation of resources) because they prevent wages from equaling their marginal product in equilibrium. In terms of a growth model though, the main drawback of the original Shapiro and Stiglitz (1984) model is its unrealistic prediction of a fall in the equilibrium unemployment rate in presence of productivity improvements. This result is owed to its characteristic of making the no-shirking condition independent of productivity improvement. To get around this problem, we link the rate of job destruction of the economy to the average innovation rate of the economy, in such a way as to make the equilibrium unemployment rate of the economy dependent on the long-run performance of the aggregate productivity.

To incorporate labor market rigidity into the Schumpeterian growth model, we modify the standard quality ladder model of Grossman and Helpman (1991) by assuming that (*i*) after an innovation is introduced, it generates a knowledge mismatch between new incumbents and workers, and that: (*ii*) the probability that an unemployed worker could find a new job in the next period is not infinite and depends on an endogenous job-finding rate. Each time an innovation occurs, we assume that it generates a mismatch between the knowledge (or human capital) required by the new technology vintage and the level of knowledge embodied by workers that forces a fraction of the workers of the industry to enter unemployment. Once in the unemployment spell, the probability that the worker can get a job depends on both an exogenous term reflecting the condition of the labor market and an endogenous term linked to the innovation intensity of the economy, i.e. on the strength with which innovation can generate employment.

The model is solved for the steady state and exploited to study whether a negative relationship between productivity growth an labor market rigidity exists. In doing so, we restrict attention to studying the steady state effects of two different types of ALMPs.

[1] According to OECD (2004), ALMP refers to that set of labor market measures aiming at facilitating transitions from unemployment to employment in several ways, including: job-placement services, labour market programmes (such as job-search assistance, vocational training for the unemployed), hiring subsidies and job-creation schemes.

Firstly, we focus on the steady state effects of a set of ALMPs geared to reduce the knowledge mismatch generated by innovation. Next, we shift the focus of our analysis on the steady state effects of a set of ALMPs aimed at facilitating transitions from unemployment to employment. We find that the negative relationship between labor market rigidity and productivity growth exists in the case of a no-shirking model. We also find that improving the performance of the labor market through ALMPs increases the steady state rate of innovation of the economy and decreases the equilibrium rate of unemployment. However, the impact on the rate of job turnover, per capita GDP and the equilibrium efficiency-wage is not clear-cut and turns out to depend on the exogenous parameters of the model.

Thus far, the most fundamental papers on growth and unemployment have been mainly based on Pissarides'(1990) standard search models. Mortensen (1994), Pissarides (1996), Millard and Mortensen (1996), Coe and Snower (1996) use search equilibrium models to study the effects of payroll and employment taxes and the provision of unemployment benefit on employment and economic performance. Ljungqvist and Sargent (1996) adopt the same framework to analyze the macroeconomic effects of the reallocation shocks in presence of income support policy. Millard (1995) studies the effects of employment protection legislation on the main macroeconomic variables, whereas Mortensen and Pissarides (1997) study the interaction effects of skill biased technological shocks and unemployment compensation and employment protection. Finally, Mortensen (2005) builds a simple model of Schumpeterian growth with search in which the possible effects of labor market and social welfare policies on both unemployment and growth are isolated.

With respect to the current literature, our model is new in at least two respects. First, it is the first to analyze the effects of ALMPs on productivity growth and unemployment. Second, it proposes an alternative theoretical framework where equilibrium unemployment is due to the presence of efficiency-wages schemes rather than search and recruitment frictions. It is organized in the following way. Section 2 sets up the model by describing the case of a Schumpeterian growth model with rigid labor market. Section 3 describes the steady state equilibrium of the model. Section 3 studies the impact of a labor market policy aimed at reducing market rigidities. Finally, Section 4 concludes.

2 The model

The model is set in continuous time. The production side of the economy consists of three vertically integrated sectors: a final-good sector, an intermediate-goods sector, and a research sector.

The final-good sector produces a single homogeneous output (henceforth GDP) that is used only for consumption. The intermediate sector consists of a continuum of industries, indexed by $i \in [0,1]$, each one producing an intermediate component. In each industry i firms are distinguished by the vintage of technology they use to produce the ith intermediate. Technological progress entails improvement in labor productivity, which in turn raises the average productivity of the final output sector.

We denote the vintage of technology used by the ith industry at time t by $j(i,t)$, with higher values of the index j denoting more efficient production technology. To learn how to introduce the $j(i,t)+1$ vintage, firms participate in sequential and stochastic R&D races. As in Grossman and Helpman (1991) and Aghion and Howitt (1992), we assume free entry into R&D races and a common constant returns to scale technology at the disposal of racers. The discoverer of the $j(i,t)+1$ vintage gets an everlasting patent protection that makes him to be the unique allowed to freely use it.

Labor is the only factor used in all production activities as well as in research. In contrast to the standard Schumpeterian literature, we introduce two main modifications. First, we assume that the technology monitoring workers' and researchers' effort is not perfect. Second, we assume the presence of some impediments that make the labor market inflexible at both industry and aggregate level. At the aggregate level, labour market rigidity refers to the difficulty with which workers and employers can negotiate mutually advantageous labour contracts; at the industry level, labor market rigidity refers to the difficulty with which workers move from an industry to another once a new technology is introduced.

Over time, GDP improves as innovations push upwardly the technology frontier. We focus on the steady state equilibrium where the GDP is the numeraire of the model.

2.1 Consumers/Workers

At each instant of time, the economy is populated by a continuum $N(t)$ of identical, infinitely-lived consumers/workers who dislike putting effort. Population grows over time at an exogenous rate n, so that at each point in time t, the size of total population is $N(t) = N(0)e^{nt}$. Consumers are either employed or unemployed. When employed, individuals decide to either exert effort or not depending on the level of the current wage offered by firms. We assume that firms cannot perfectly monitoring workers' effort and that the monitoring technology is such that there exists an exogenous probability $q \in [0,1]$ that a worker engaged in shirking is caught and fired. To avoid firing, workers must exert effort but they also derive some disutility. We model effort ε as a binary variable depending of whether workers decide to exert effort ($\varepsilon = 1$) or not ($\varepsilon = 0$).

Individuals are allowed to save or borrow in the financial market. To simplify the model, we assume that individuals are risk neutral with instantaneous utility function linear in consumption c and effort $\varepsilon\chi$, where $\chi > 0$ is a measure of the individual's disutility in terms of final-output units. Denoting expectation at time 0 by E_0, the representative consumer/worker intertemporal utility function reads:

$$U(c,\varepsilon) \equiv E_0 \int_0^{\infty} e^{-\rho t}\left[c(t) - \varepsilon\chi\right] dt \tag{1}$$

where $\rho > n$ denotes the subjective discount rate.

The intertemporal maximization problem consists of maximizing [1] subject to intertemporal budget constraint:

$$A(t) + Z(t) = \int_t^{\infty} c(\tau)\, e^{-[R(\tau)-R(t)]} d\tau, \tag{2}$$

where $A(t) \equiv \int_t^{\infty} a(\tau)\, e^{-[R(\tau)-R(t)]} d\tau$ is the present value of the representative consumer/worker's financial assets at time t and $Z(t) \equiv \int_t^{\infty} z(\tau)\, e^{-[R(\tau)-R(t)]} d\tau$ is the present value of labor income at time t (with a and z denoting the consumer/worker's financial assets and labor income respectively), and $R(\tau) \equiv \int_0^\tau r(s)\, ds$ is the cumulative interest rate up to time τ (with $\dot{R}(\tau) = r(\tau)$).

Labor income z depends on worker's status. It might include either the current wage rate w when employed or the unemployment benefits b when unemployed, i.e., $z = \{w, b\}$.[2] Let now assume that z evolves over time according to two independent Poisson processes, q_w and q_b, governing, respectively, the process of job destruction and that of job finding. Following Wälde (1999) and Sennewald and Wälde (2006), the evolution of labor income z can be represented by the following stochastic differential equation:[3]

$$dz = -(w-b)\, dq_w + (w-b)\, dq_b, \tag{3}$$

where $(w-b)$ represent the finite jump-term of each Poisson process.

Poisson process, q_w, measures how often an individual leaves the status of employed owed to job destruction. It takes place at an exogenous rate $\delta + (1-\varepsilon)\, q$, where δ denotes the rate of job destruction and $(1-\varepsilon)\, q$ is that related to the firms' monitoring technology. Similarly, Poisson process, q_b, measures how often a consumer/worker leaves the status of unemployed owed to job creation. It takes place at a rate $\eta > 0$ reflecting all the institutional characteristics of the labor market - such as, for instance, the employment protection legislation, labor/product market regulations or local rigidities -, as well as the growth perspective of the economy. As usual, η can also be interpreted as the probability of finding a job at each instant of time and $1/\eta$ as the expected duration of the unemployment status.

To solve the problem we resort to the stochastic dynamic programming.[4] As we are interested in the steady state properties of the model, we assume the existence of a long-run equilibrium where a finite consumption implies $r(t) = \rho$. Moreover, the presence of moral hazard in the employer-employee relationship is such that workers will choose to exert effort if and only if the following holds:

$$w \geq \hat{w} \equiv b + \left(1 + \frac{\rho}{q}\right)\chi + (\eta + \delta)\frac{\chi}{q}. \tag{4}$$

Eq. [4] is the aggregate no-shirking condition (NSC) after Shapiro and Stiglitz (1984), which says that the worker will choose to exert effort if and only if the wage rate is higher than threshold $\hat{w}$. As usual for no-shirking models, [4] can be taken as a measure of the labor supply. Observe that the effort-enhancing wage rate, $\hat{w}$, is higher: (*i*) the higher the unemployment benefit, b, (*ii*) the higher the disutility of effort in terms of consumption, χ, (*iii*) the higher the rate of time preference ρ, (*iv*) the less efficient the monitoring technology, q, and (*v*) the higher the rate of job turnover of the economy (the sum of job finding η and job destruction δ).

[2] Throughout the analysis we exclude tax distortion by assuming lump-sum taxation to finance unemployment benefit. Moreover, in order to index the unemployment benefit, we also assume that in the steady-state it increases at the same rate as productivity.

[3] For a more general study with non-linear preferences and consumption smoothing see also Sennewald (2007).

[4] For the sake of presentation, we hereby summarize the main result of the consumer analysis and direct the interested reads to Appendix A for the analytical details of the dynamic optimization as well as the derivation of the aggregate no-shirking condition.

2.2 Manufacturing

The final output sector is composed of a continuum of identical, perfectly competitive producers, whose total is normalized to unity. There is one final good (GDP) produced by a continuum of intermediate products, according to the CRS production function:

$$Y(t) \equiv \exp\left\{\int_0^1 \ln\left[x(i,t)\right] di\right\}, \tag{5}$$

where $Y(t)$ denotes the final output (or GDP) and $x(i,t)$ is the quantity of the ith intermediate used to produce the final output.

Each final output producer will choose $x(i,t)$ to minimize costs. The solution of this minimization problem leads to demand function:

$$p(i,t) = \frac{Y(t)\,P(t)}{x(i,t)}, \tag{6}$$

where $P(t) \equiv \exp\left\{\int_0^1 \ln\left[p(i,t)\right] di\right\}$ is the aggregate price index and $p(i,t)$ is the price of the ith intermediate at time t. Since we let the final-output to be the numeraire, in the remainder of the paper $P(t) = 1$ (i.e., $\int_0^1 \ln\left[p(i,t)\right] di = 0$) always holds.

The intermediate sector consists of a continuum of price-setting oligopolists, each one producing according to the production function:

$$x(i,t) = \lambda^{j(i,t)} L_x(i,t), \tag{7}$$

where $\lambda > 1$ is the innovation-jump separating two consecutive technology vintages, and $L_x(i,t)$ is the amount of workers hired by the ith industry at time t.

According to [7], technological progress entails improvement in labor input through a raise in $\lambda^{j(i,t)}$, which in turn rises total factor productivity in final outputs sector. As in the Shapiro and Stiglitz's (1984) framework, we assume that workers contribute one unit of labor if they do not shirk, or nothing otherwise.

To became oligopolists, firms must first devote resources to R&D in order to discover a more advanced production process capable of reducing manufacturing costs. Once successful in R&D, firms choose price $\tilde{p}$ to maximize their instantaneous flow of profits $\pi(t) = \left(\tilde{p} - \hat{w}(t)/\lambda^{j(i,t)}\right)\tilde{x}$, where $\hat{w}(t)/\lambda^{j(i,t)}$ is marginal cost and $\tilde{x}$ is sales. As each industry leader operates with a downward-sloping price schedule given by [6], firms that have just succeeded in innovation can keep their rivals from earning a positive profit from production by setting a price equal to the marginal cost of the most efficient follower:[5]

$$\tilde{p} = \frac{\hat{w}(t)}{\lambda^{j(i,t)-1}}. \tag{8}$$

By setting price [8] industry-leaders capture the entire industry market by forcing all the followers to dismiss their production facilities and exit the industry. Plugging [8] into price schedule [6], each industry leader performs a different flow of sales equal to:

$$\tilde{x} = \lambda^{j(i,t)-1}\frac{Y(t)}{\hat{w}(t)} \tag{9}$$

[5] Observe that the limit pricing behavior summarized by [8] is source of asymmetry in the size of firms. As will be verified in Section 2.3, such a characteristic does not affect the symmetric structure of the steady-state equilibrium.

but earns the same flow of profit equal to:

$$\pi(t) = \left(1 - \frac{1}{\lambda}\right) Y(t). \tag{10}$$

Combining [7] and [9], it is easy to check that each representative manufacturing industry-leader employs the same measure of workers:

$$L_x(t) = \frac{Y(t)}{\lambda \hat{w}(t)}. \tag{11}$$

which also equals the industry-wide labor demand.

In order to capture the impact that creative destruction has on the industry employment, we assume that only $(1-\phi) L_x(t)$ of the workers employed by the previous incumbent -where $\phi \in (0,1)$- are able to adapt to the new technology, while the remaining $\phi L_x(t)$ workers are not able to adapt and need to enter the unemployment spell to "retool". We interpret parameter ϕ as a measure of the knowledge mismatch due, for instance, to changes in the internal organization of the new incumbent. In this vein, an increase in ϕ can be interpreted as an increase in the negative effect that creative destruction has on the industry employment. The higher ϕ, the higher the flow of dismissed workers leaving the industry because of innovation.

Plugging [11] into [5], the level of per capita GDP of the economy is easy gained and reads:

$$\ln y(t) = \ln A(t) + \ln\left[\frac{L_x(t)}{N(t)}\right], \tag{12}$$

where $y(t) \equiv Y(t)/N(t)$ is per capita GDP and $A(t) \equiv \exp\left\{\int_0^1 \ln\left[\lambda^{j(i,t)}\right] di\right\}$ is a productivity index measuring the average productivity of the economy.

Differentiation of [12] with respect to time gives:

$$\gamma_y \equiv \frac{\dot{y}}{y} = \frac{\dot{A}(t)}{A(t)} + \left(\frac{\dot{L}_x}{L_x} - n\right). \tag{13}$$

According to [13], the growth rate of per capita GDP, γ_y, equals the growth rate of average productivity, $\dot{A}(t)/A(t)$, plus a term, $\dot{L}_x/L_x - n$, that tells us how the share of manufacturing employment out of population, $L_x(t)/N(t)$ changes over time.

2.3 Research and development and the productivity growth

Technological progress consists of process innovation. There is free entry into each R&D race, so firms may target their research effort at any of the continuum of leading-edge production processes. Labor is the only input used in R&D and all firms have the same R&D technology. Any firm j that hires $\ell_j(i,t)$ units of R&D labor in industry i at time t is able to introduce the next process innovation $j(i,t)+1$ with instantaneous probability (or Poisson arrival rate):

$$I_j(i,t) = \frac{\ell_j(i,t)}{\alpha K(i,t)}, \tag{14}$$

where $\alpha > 0$ is an exogenous parameter measuring the productivity of R&D workers and $K(i,t)$ is a measure of the R&D difficulty of industry i at instant t.

The $K(i,t)$ term in the denominator of [14] is not new to the endogenous growth literature and is used to get around the "scale effect" critique of Jones (1995). We assume that as the size of the economy increases over time, R&D difficulty increases as well and innovating becomes more and more difficult. In order to simplify the analysis, we assume that R&D difficulty does not change between industries and equals $K(i,t) = \kappa N(t)$, where $\kappa > 0$ is an exogenous parameter governing R&D difficulty growth.[6]

Now, let us consider a firm's choice of industry in which to target its R&D effort. The prize for a research success in an industry is a flow of profits that will last until the next success is achieved in the same industry. Let $v(i,t)$ denote the expected discounted profit for winning a R&D race in industry i at time t. By hiring $\ell_j(i,t)$ units of R&D labor for a time interval dt, firm j expects to realize $v(i,t)$ with probability $I_j(i,t)\,dt$. Thus, at each point in time t, firm j will choose its R&D employment ℓ_j in order to solve:

$$\max_{\ell_j} \left\{ v(i,t) \frac{\ell_j(i,t)}{\alpha\kappa N(t)} - \hat{w}(t)\,\ell_j(i,t) \right\}.$$

The first order condition for an interior solution gives the following free-entry condition:

$$v(i,t) \begin{cases} \leq \alpha\kappa N(t)\,\hat{w}(t) & \text{if} \quad I(i,t) = 0 \\ = \alpha\kappa N(t)\,\hat{w}(t) & \text{if} \quad I(i,t) > 0 \end{cases}, \tag{15}$$

If $v(i,t) < \alpha\kappa N(t)\,\hat{w}(t)$, then the marginal cost of R&D exceeds the marginal benefit and it is profit-maximizing for firms to devote no labor to R&D. In contrast, if $v(i,t) > \alpha\kappa N(t)\,\hat{w}(t)$, then the marginal benefit of R&D exceeds the marginal cost and it is profit-maximizing for firms to devote infinite resources to R&D. Only if $v(i,t) = \alpha\kappa N(t)\,\hat{w}(t)$ holds for all i can a symmetric equilibrium exist where the innovation rate $I(t)$ is positive, finite and the same for all firms in all industries.

2.4 The productivity growth

At each instant t, there is a measure one of industries where manufacturing production takes place. Each industry improves its production technology randomly, with transition probabilities that depend on the Poisson arrival rates equal to [14]. Following Grossman and Helpman (1991), at each instant t the average productivity of the economy is given by: $\ln A(t) = \left[\int_0^t I(s)\,\mathrm{d}s\right] \ln\lambda$; differentiation of $\ln A(t)$ with respect to t gives:

$$\frac{\dot{A}(t)}{A(t)} = I(t)\ln\lambda. \tag{16}$$

According to [16], a raise in the rate of innovation of the economy leads to a raise in the growth rate of productivity. In addition, a raise in the size of innovation λ raises productivity growth. Plugging [16] into [13] yields

$$\gamma_y \equiv \frac{\dot{y}}{y} = I(t)\ln\lambda + \left(\frac{\dot{L}_x}{L_x} - n\right). \tag{17}$$

[6]The specification adopted for $K(i,t)$ can be justified by saying that R&D difficulty is proportional to the size of global market because of the existence of organizational costs related to product distribution (Dinopoulos and Segerstrom (1999)) or the existence of costs to protect firm's intangible assets from misappropriations (Dinopoulos and Syropoulos (2006)).

According to [17], at each instant t the growth rate of per capita GDP depends on both the innovation intensity of the economy, $I(t)$, plus a term informing us how the share of manufacturing employment, $L_x(t)/N(t)$ changes over time.

2.5 The stock market

To finance R&D, firms issue equity claims on the flow of profits generated by the innovation. Claims on particular firms are risky assets which current valuation is given by the stock market. At each point in time t, investors must solve a portfolio allocation problem among shares in a variety of profit-maximizing firms and among riskless bonds. As there is a continuum of industries and the returns to engaging in R&D races are independently distributed across firms and industries, the risk attached to every single equity is idiosyncratic and each investor can diversify risk by holding a diversified basket of stocks.

Over a time interval dt, the shareholder receives a dividend $\pi(i,t)\,dt$, and the value of the firm appreciates by $\dot{v}(i,t)\,dt$ in each industry. Because each quality leader is targeted by firms conducting innovative R&D, the shareholder suffers a loss of $v(i,t)$ if further innovation occurs. This event occurs with probability $I(i,t)dt$, whereas no innovation occurs with probability $1 - I(i,t)dt$. Efficient financial markets make the expected rate of return from holding a stock of a quality leader equal to the riskless rate of return $r(t)dt$ that can be obtained through complete diversification.

As in our model $r(t) = \rho$ always holds, no arbitrage condition into capital market requires:

$$\frac{\pi(i,t)}{v(i,t)} + \frac{\dot{v}(i,t)}{v(i,t)} = \rho + I(i,t). \tag{18}$$

Plugging [10] into [18] and combining the result with [15] yields:[7]

$$\hat{\omega}\alpha\kappa = \frac{(1-1/\lambda)\,\hat{y}(t)}{\rho + I(1-\ln\lambda) - n}, \tag{19}$$

where $\hat{y}(t) \equiv y(t)/A(t)$ is the productivity-adjusted per capita GDP and $\hat{\omega} \equiv \hat{w}(t)/A(t)$ is the productivity-adjusted efficiency-wage of the economy.

It is worth-noting that in our model $\hat{\omega}$ is always constant. To see this, recall that $\ln P(t) \equiv \int_0^1 \ln[p(i,t)]\,di$ is the numeraire of the model. Taking logs and integrating between 0 and 1 Eq. [8], we get $\int_0^1 \ln[\lambda\hat{w}(t)]\,di - \int_0^1 \ln\left[\lambda^{j(i,t)}\right] di = 0$, which in turn can be rewritten as $\ln[\lambda\hat{w}(t)] = \ln A(t)$. We can thus conclude that at each instant t (not only in the steady state equilibrium) efficiency-wage $\hat{w}(t)$ grows at rate $I\ln\lambda$ and that $\hat{\omega}$ does not change over time.

According to [19], the profits earned by each leader $(1-1/\lambda)\,\hat{y}(t)$ are appropriately discounted using the interest rate $\rho - n$ plus the instantaneous probability $I(1-\ln\lambda)$

[7] Observe that, based on [15], we have used:

$$\frac{\dot{v}(i,t)}{v(i,t)} = \frac{\dot{N}(t)}{N(t)} + \frac{\dot{A}(t)}{A(t)} = n + I\ln\lambda.$$

of being driven out of business by further innovation.[8]. As Eq. [19] holds for every i, in the rest of the paper we focus on a symmetric structure in which both R&D difficulty and innovation rate do not vary across industries.

2.6 Labor market rigidity and the equilibrium unemployment

In this section we carefully describe how equilibrium unemployment changes over time. Our goal is that of summarizing the state of the labor market through a differential equation governing the time evolution of the equilibrium unemployment.

Define the economy-wide mass of workers currently in employment at time t by $L(t)$. From the previous Sections, we know that each industry leader employs the same measure of workers [11], while the representative R&D firm employs the same measure of researchers equal to $\alpha\kappa I(t) N(t)$. With a measure of industry equal to one, the demand side of the labor market can be summarized by the following equation:

$$\ell(t) = \alpha\kappa I(t) + \frac{\hat{y}(t)}{\lambda\hat{\omega}}, \tag{20}$$

where $\ell(t) \equiv L(t)/N(t)$ is the employment-population ratio of the economy, $\alpha\kappa I(t)$ is the share of R&D workers in total employment and $\hat{y}(t)/\lambda\hat{\omega}$ is the share of productivity-adjusted manufacturing workers in total employment.

Let us analyze how $\ell(t)$ changes over time. Consider first the demand for labor of R&D firms. In the steady state, the successful firm get a patent on the discovery and dismiss all the workers. Since each R&D firm is of measure zero, we conclude that the mass of workers freed by each R&D firm has no impact on aggregate R&D employment. However, when a shock hits the equilibrium innovation rate of the economy, this rationale does not hold and R&D sector gives his contribution to either job creation or job destruction. In fact, R&D employment changes due to changes in the steady state rate of innovation I. Differentiate $\alpha I\kappa$ with respect to time gives $\alpha\dot{I}\kappa$, which is a measure of how R&D employment changes due to a change in I. If $\dot{I} < 0$, R&D sector destroys employment when moving to an equilibrium to another, while the opposite holds if $\dot{I} > 0$.

Consider now the demand for labor of manufacturing firms. At each instant t, the share of manufacturing workers in total employment is $\hat{y}/\lambda\hat{\omega}$. In standard Schumpeterian models with full employment, once an innovation occurs all the employees of the previous industry leader are instantaneously laid-off because of creative destruction. In contrast, in this model we have assumed that the innovator keeps a fraction $(1-\phi)$ of the workers employed by the previous incumbent and dismisses the remaining ϕ. As a result, the flow of workers into the unemployment pool due to the knowledge mismatch reads $(\hat{y}/\lambda\hat{\omega})\,\phi I$.

Once in unemployment, the probability that a worker could get a job at each instant t depends on an exogenous parameter measuring the rigidity of the labor market, $\mu > 0$, plus the rate of job creation generated by innovation φI.[9] The parameter μ can be

[8] The presence of the $(1-\ln\lambda)$ term in the denominator of [19] is akin to the *crowding-out effect* found by Aghion and Howitt (1998, ch. 3). In order to maintain a positive business stealing effect, in the remainder of the paper we assume $1-\ln\lambda > 0$, which in turn implies $\lambda < 2,71828$.

[9] The presence of the φI term in the unemployment outflow captures the positive effect that innovation has on employment. Since innovators keeps only a fraction $(1-\phi)\,\hat{y}/\lambda\hat{\omega}$ of the previous firm workforce,

interpreted as a measure of the difficulty of getting a job due to the lack of either job-placement services or labour market programmes. The increase in μ can be interpreted as an increase in labor market flexibility, while the decrease in μ can be interpreted as an increase in labor market rigidity. Consequently, the flow of workers out of the unemployment spells due to the manufacturing firms hiring is $[\mu + \varphi I(t)](1-\ell)$.

Summing up, the differential equation governing the time evolution of total employment is given by:

$$\dot{\ell} = \alpha \dot{I} \kappa + [\mu + \varphi I(t)](1-\ell) - \phi I(t) \frac{\hat{y}}{\lambda \hat{\omega}},$$

where the $\alpha \dot{I} \kappa$ term on the right-hand side is the flow of workers either hired - if $\dot{I} > 0$- or fired -if $\dot{I} < 0$ - by R&D sector, the $[\mu + \varphi I(t)](1-\ell)$ term denotes the flow of workers hired by manufacturing firms, and the $\phi I(t) \hat{y}/\lambda\hat{\omega}$ term denotes the flow of workers fired by manufacturing firms because of knowledge mismatch.

Define the equilibrium rate of unemployment by $u \equiv 1-\ell$. Differentiation of u with respect to time gives $\dot{u} = -\dot{\ell}$, which reads

$$\dot{u} = \phi I \frac{\hat{y}}{\lambda \hat{\omega}} - \alpha \dot{I} \kappa - (\mu + \varphi I) u. \tag{21}$$

Eq. [21] is the law of motion of the equilibrium rate of unemployment we were looking for.

3 The steady state equilibrium

In this section we analyze the steady state property of the model. The equilibrium conditions of the model are summarized by the aggregate NSC, [4], the no-arbitrage/research equation, [19], the differential equation governing the time evolution of the aggregate rate of unemployment, [21], the aggregate labor demand [20], and the differential equation governing the growth rate of real GDP, [17]. The four endogenous variables are: the productivity-adjusted efficiency wage $\hat{\omega}$, the level of per capita GDP in efficiency units $\hat{y}$, the steady state rate of unemployment u, and the steady state rate of innovation I.

Definition 1 *We define the steady state equilibrium as the situation to which,* (i) *the rate of innovation of the economy is constant over time (i.e.,* $\dot{I} = 0$*)* (ii) *the flow in equals the flow out of unemployment (i.e.,* $\dot{u} = 0$*),* (iii) *the productivity-adjusted wage rate is constant over time and such that no worker choose to shirk,* (iv) *GDP per capita* y *grows at the same rate as average productivity, i.e.* $\dot{\hat{y}} = 0$.

Let "*" refers to steady state values. Since a stable innovation rate requires $\dot{I} = 0$, the rate of job turnover of the economy - i.e. the sum of job creation $\eta^* = [\mu + \varphi I^*] u^*$ and job destruction $\delta^* = \phi I^* \hat{y}^*/\lambda\hat{\omega}^*$ - is easy gained and reads:

$$\eta^* + \delta^* = (\mu + \varphi I^*) u^* + \phi I^* \left(\frac{\rho - n + I^*(1-\ln\lambda)}{\lambda - 1} \right). \tag{22}$$

where [19] has been used to substitute for $\hat{y}^*/\lambda\hat{\omega}^*$.

According to [22], the steady state rate of job turnover, $\eta^* + \delta^*$, is higher: (i) the higher the flexibility of the labor market μ, (ii) the higher the knowledge mismatch

the only way to bridge the gap of their workforce is that of resorting to the labor market and hire the remaining $\phi\hat{y}/\lambda\hat{\omega}$ workers they need to start producing.

generated by each new technology vintage, ϕ, (iii) the higher the impact of innovation on job creation, φ, (iv) the higher the steady state innovation rate, I^*, (v) the higher the steady state unemployment rate, u^*, (vi) the higher the subjective discount rate of consumers adjusted for the growth rate of population, $\rho - n$, and (vii) the lower the size of innovation, λ.

From [21], it is easy to check that a steady state equilibrium implies:[10]

$$u^* = \left(\frac{\phi I^*}{\mu + \varphi I^*} \right) \left(\frac{\hat{y}^*}{\lambda \hat{\omega}^*} \right). \tag{23}$$

Steady-state unemployment [23] positively depends on the steady state rate of innovation I^*. The presence of the $(\hat{y}^*/\lambda\hat{\omega}^*)$ term on the right-hand side of [23] makes the equilibrium unemployment rate to depend on current manufacturing employment through variables $\hat{y}^*$ and $\hat{\omega}^*$. A permanent change in the fraction of workers into manufacturing, $\hat{y}^*/\lambda\hat{\omega}^*$, leads to a permanent change in the equilibrium unemployment of the economy.

Finally, by plugging [19] into [20] and [23], the steady state of the economy is fully described by the following pair of equations:

$$u^* = \alpha\kappa \left(\frac{\phi I^*}{\mu + \varphi I^*} \right) \left(\frac{\rho - n + I^* (1 - \ln \lambda)}{\lambda - 1} \right). \tag{24}$$

and:

$$1 - u^* = \alpha\kappa \left(\frac{\rho - n + I^* (\lambda - \ln \lambda)}{\lambda - 1} \right). \tag{25}$$

Eq. [24] is globally increasing in (I, u) space (U-curve) and Eq. [25] is globally decreasing in (I, u) space (L-curve). As a result, the steady state equilibrium of the model (point A in Figure 1) is completely pinned-down by these two equations.

To verify that point A in Figure 1 is indeed a steady state, we have to solve for the two remaining endogenous variables, $\hat{\omega}$ and $\hat{y}$, and show that property (iv) of Definition 1 is also satisfied. Given $I^*$and initial condition $A(0)$, the definition of $A^*(t)$ determines the time path of index $\int_0^1 \ln \lambda^{j(i,t)} \mathrm{d}i = I^* t \ln \lambda$. Next, given I^*, u^* and $A(t)$, Eqs. [4] and [19] determine $\hat{\omega}^*$ and $\hat{y}^*$ respectively.

To show that in the steady state per capita GDP grows proportionally to the steady state rate of innovation, recall that in the steady state manufacturing employment grows at the same rate as population (i.e. $\dot{L}_x/L_x = n$); accordingly, resorting to Eq. [17] we obtain:

$$\gamma_y^* = I^* \ln \lambda,$$

meaning that in the steady state y grows at the same rate as average productivity.

All these results can be summarized as follows.

Proposition 1 *For the case of a shirking model with labor market rigidity and innovation-based growth, a steady state equilibrium as that defined by Definition 1 exists and is unique.*

[10] Observe that $u^* < 1$ implies $\hat{y}^*/\lambda\hat{\omega}^* < (\mu + \varphi I^*)/\phi I^*$. Since $\hat{y}^*/\lambda\hat{\omega}^* \in (0, 1)$, this result holds when I^* is not too high.

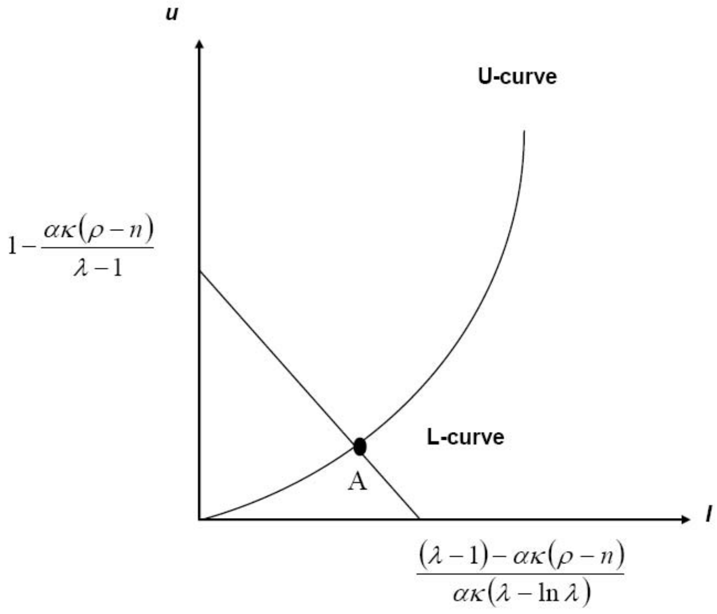

Figure 1: The steady-state equilibrium

Starting from a steady state equilibrium, in the next section will analyzes the extent of a labor market reform aimed at reducing labor market rigidity.

4 Reducing labor market rigidity

In this section we study the impact that ALMPs have on labor market rigidity, equilibrium unemployment and productivity. In particular, we are interested in studying the steady state effects of labor market policy shocks aiming at (i) reducing the knowledge mismatch generated by each technology vintage, (ii) increasing the job-finding rate of the economy.

For the sake of exposition, the reminder of this section only offers a graphical exposition of the comparative statics results. The interested readers can find the complete proofs and computational details in Appendix B.1.

4.1 Reducing the knowledge mismatch

In this Section we analyze the steady state impact of some ALMPs aimed at reducing the degree of knowledge mismatch generated by each new vintage technology. These ALMPs are generally defined as those labor market policies directed to promoting continuing upgrading of the workforce's human capital as well as lifelong learning of all individuals. Their goal is that to offset the steady state negative impact of the creative destruction, thereby making a larger share of workers immediately employable by the new technology leaders. In our model, these ALMPs can be studied through a permanent drop in parameter ϕ.

Figure 2 shows how the economy reacts to a reduction in ϕ. The L-curve does not change while the U-curve shifts to right. According to the figure, as the steady state

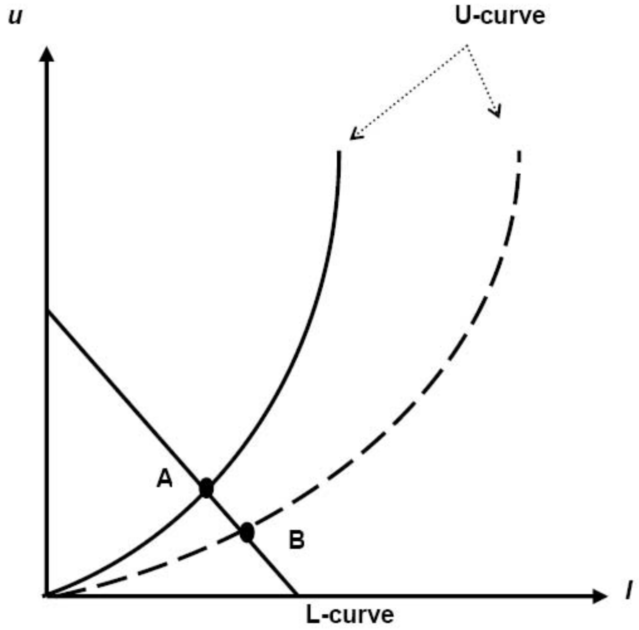

Figure 2: Reducing the mismatch of innovation

equilibrium moves from point A to point B in the figure, the rate of innovation, I^*, increases, the equilibrium rate of unemployment, u^*, decreases, and the share of workers in manufacturing, $\hat{y}^*/\lambda\hat{\omega}^*$, increases (via Eq.[19]). This result allows us to conclude that a negative relationship between productivity growth (due to the increase in the innovation rate) and labor market rigidity exists. However, the steady state effects on the two remaining steady state variables, $\hat{y}^*$ and $\hat{\omega}^*$, are not clear-cut and turn out to depend on how decreased ϕ impacts the steady state job turnover $\eta^* + \delta^*$. Appendix B.1 provides a formal demonstration of why a permanent drop in ϕ has mixed effects on both the steady state rate of job creation and job destruction.

We summarize all these results in the following proposition.

Proposition 2 *A permanent drop in ϕ leads to:*

1. *An increase in the steady state innovation rate of the economy I^*, a decrease in the equilibrium unemployment rate of the economy u^*, and an increase in the steady state share of workers engaged in manufacturing, $\hat{y}^*/\lambda\hat{\omega}^*$;*

2. *No clear-cut effects on the steady state rate of job turnover, $\eta^*+\delta^*$, the productivity-adjusted per capita GDP, $\hat{y}^*$, and the productivity-adjusted efficiency-wage, $\hat{\omega}^*$.*

Proof. See Appendix B.1 ■

According to Proposition 2, ALMPs can help the economy to increase both manufacturing employment and per capita GDP growth rate. This result contrasts with the standard, full-employment ladder-quality models result, which predicts a trade-off between manufacturing employment and growth. In fact, in the standard Schumpeterian model of growth with full-employment, a raise in the steady-state innovation rate can be achieved only at the expense of manufacturing employment. In our model labor this is not the case because of the presence of unemployment, which represent a resources waste for the economy. By making the labor market more flexible, ALMPs reduces the waste of resources associated with unemployment and creates better conditions of innovation investment and growth.

The economic intuition of the increase in the steady-state innovation rate is given by the no-arbitrage/research equation, [19], that can be rewritten as follows:

$$\alpha\kappa = \frac{(\lambda - 1)\,\frac{\hat{y}^*}{\lambda\hat{\omega}^*}}{\rho + I^*\,(1 - \ln\lambda) - n}. \tag{26}$$

When ϕ falls, the share of manufacturing employment increases; i.e. $\hat{y}^*/\lambda\hat{\omega}^* \uparrow$. The increase in $\hat{y}^*/\lambda\hat{\omega}^*$ raises the numerator of the the right-hand side of [26] because the market size of each intermediate producer increases in the new steady-state. This generates a mismatch between the benefit and the cost of innovating. To reestablish the equilibrium, the rate of innovation I^* must increase.

Observe that the raise in $\hat{y}^*/\lambda\hat{\omega}^*$ does not help us to understand how $\hat{y}^*$ and $\hat{\omega}^*$ change in the new steady state. For instance, it is equally possible that either $\hat{y}^*$ and $\hat{\omega}^*$ decrease in the new steady state, with $\hat{\omega}^*$ decreasing more than $\hat{y}^*$, or $\hat{y}^*$ and $\hat{\omega}^*$ increase, with $\hat{\omega}^*$ increasing less than $\hat{y}^*$. What we can say is that in the new equilibrium the economy reacts by increasing its manufacturing production as well as innovation intensity and nothing else. Observe also that $\dot{I} > 0$ makes a share of unemployed workers to move from unemployment to R&D. As a result, in the new steady state equilibrium the permanent fall of the equilibrium unemployment resulted into a raise of both manufacturing and R&D employment.

4.2 Increasing the job-finding rate

Consider now a labor market reform aimed at increasing the steady state job-finding rate of the economy. These ALMPs are generally defined as those labor market policies directed to training and rehabilitation; information, counseling, and financial support to find a job. Formally, such measures can be studied through a permanent increase in either μ or φ.

Figure 3 shows how the economy reacts to a permanent increase in either μ (chart a) or φ (chart b). From a graphical point of view, both reforms give to the same steady state results of the previous Section. In the new steady state (point C in both charts), the rate of innovation I^* increases, the equilibrium rate of unemployment u^* decreases, and the share of workers in manufacturing, $\hat{y}^*/\lambda\hat{\omega}^*$, increases (via Eq.[19]). This result allows us to conclude that a negative relationship between productivity growth and labor market rigidity holds even for the case of this type of reforms. In contrast to previous Section though, the impact on the rate of job destruction is much more clear-cut. Indeed, from [22] it is easy to verify that a permanent increase in either μ or φ permanently increases job destruction δ^*. However, the long-run impact on job creation is still ambiguous and does not help us to shed light on how ALMPs can impact job turnover as a whole (see Appendix B.2 and B.3).

We can thus establish the following Proposition.

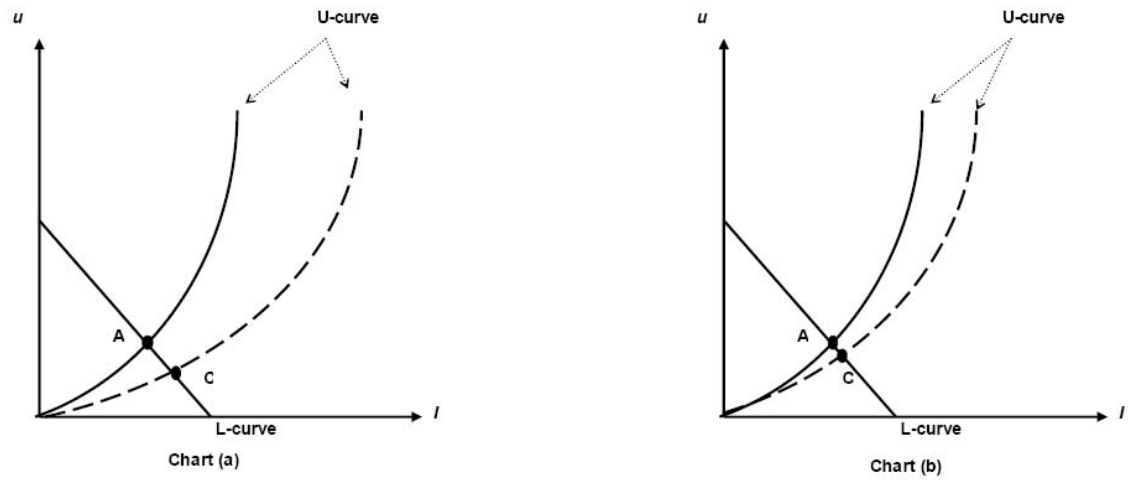

Figure 3: Increasing the job finding rate. Chart (a): an increase in μ; Chart (b): an increase in φ.

Proposition 3 *A permanent increase in either μ or φ leads to:*

1. *A permanent increase in the steady state innovation rate of the economy I^*, a permanent decrease in the equilibrium unemployment rate of the economy u^*, and a permanent increase in manufacturing employment, $\hat{y}^*/\lambda\hat{\omega}^*$;*

2. *A permanent increase in the steady state rate of job destruction δ^*, but to no clear-cut conclusion regarding the steady state rate of job turnover $\eta^* + \delta^*$.*

Proof. See Appendix B.2 and B.3. ■

Since Proposition 3 establishes almost the same results of Proposition 2, the same considerations of the previous section hold. Observe once again that the model does not help us to understand how $\hat{y}^*$ and $\hat{\omega}^*$ change in the new steady state.

5 Conclusions

In this paper we have studied the steady state impact of various reforms aimed at reducing labor market rigidities. In doing so, we have build a scale-invariant, innovation-based growth model with efficiency-wages in the spirit of Shapiro and Stiglitz (1984). On the positive point of view, the model shows a negative relationship between productivity growth and labor market rigidity. On a policy point of view, the model points out how the use of ALMPs can increase manufacturing employment and spur long-run productivity growth.

In particular, we found that labor market policies directed to reduce the knowledge mismatch generated by each innovation as well as improving job finding increases steady state rate of innovation, decrease the equilibrium unemployment rate and increase the steady state share of manufacturing employment. We also found that the steady state impact of such reforms on the rate of job turnover, per capita GDP and the equilibrium efficiency-wage is mixed. The economic explanation of all these steady state results relies on the presence of moral-hazard in the employer-employee relationship that makes the productivity growth of the economy (via its innovation intensity) very sensitive to the level of the efficiency-wage offered by manufacturing firms.

Appendix A
Derivation of the NSC

This Appendix provides the analytical details of the derivation of NSC [4]. Define the value function by $V(a,z)$. The Bellman equation takes the following structure:

$$rV(a,z) = \max_{c,\varepsilon}\left\{c(t) - \varepsilon\chi + E\left[\frac{dV(a,z)}{dt}\right]\right\}$$

subject to:

$$da = [(r-n)a + z - c]\,dt$$

and

$$dz = -(w-b)\,dq_w + (w-b)\,dq_b.$$

Based on Sennewald and Wälde (2006) and Sennewald (2007), the change of $V(a,z)$ is given by

$$\begin{aligned} dV(a,z) &= V_a[(r-n)a + z - c]\,dt + [V(a,z+b-w) - V(a,z)]\,dq_w + \\ &\quad [V(a,z+w-b) - V(a,z)]\,dq_b \end{aligned} \tag{A.1}$$

where $V_i \equiv \partial V(a,z)/\partial i$ with $i = \{a,z\}$.

Forming expectations on [A.1] gives:

$$\begin{aligned} E_t[dV(a,z)] &= V_a[(r-n)a + z - c]\,dt + \\ &\quad + [V(a,z+b-w) - V(a,z)][\delta(t) + (1-\varepsilon)q] + \\ &\quad + [V(a,z+w-b) - V(a,z)]\,\eta \end{aligned} \tag{A.2}$$

Insertion of [A.2] into the Bellman equation [A.1] gives:

$$rV(a,z) = \max_{c,\varepsilon}\left\{\begin{array}{c} c - \varepsilon\chi + V_a[(r-n)a + z - c]\,dt + \\ + [V(a,z+b-w) - V(a,z)][\delta + (1-\varepsilon)q] \\ + [V(a,z+w-b) - V(a,z)]\,\eta \end{array}\right\} \tag{A.3}$$

The first-order condition reads:

$$V_a = 1 \tag{A.4}$$

Eq. [A.4] makes consumption a function of the state variable, $c = c(a)$. As a result, replacing control variable by their optimal values $c(a)$, the maximized Bellman equation reads:

$$\begin{aligned} \rho V(a,z) &= c(a) - \varepsilon\chi + V_a[(r-n)a + z - c(a)] \\ &\quad + [V(a,z+b-w) - V(a,z)][\delta + (1-\varepsilon)q] + \\ &\quad + [V(a,z+w-b) - V(a,z)]\,\eta \end{aligned} \tag{A.5}$$

Each worker selects its effort level to maximize his expected life-time utility. This means comparison of the utility from shirking with the utility of not shirking. Define the present-discounted value of the expected income stream of an employed worker by $W \equiv V(a, w)$ and the present-discounted value of the expected income stream of an unemployed worker by $U \equiv V(a, b)$.

Consider first the case of an individual in the employment pool. For an employed worker the probability of getting a job is nil (i.e., $\eta = 0$) whereas that of loosing a job is positive and equal to $\delta + (1 - \varepsilon) q$. Plugging $r = \rho$ and first order condition [A.4] into [A.5], the present-discounted value of the expected income stream of an employed worker (regardless of her tendency to shirk) can be described by the asset equation:

$$\rho W = w - \varepsilon\chi + (\rho - n) a + [\delta + q(1 - \varepsilon)](U - W) \tag{A.6}$$

Define W_S as the expected life-time utility of a shirking worker (i.e., Eq. [A.6] when $\varepsilon = 0$), and W_{NS} as the expected life-time utility of a non-shirking worker (i.e., Eq. [A.6] when $\varepsilon = 1$). The worker will choose to shirk or not to shirk if and only if the NSC $W_{NS} \geq W_S$ holds.

In order to get the effort-enhancing wage rate of the economy, we compare the worker lifetime utility for $\varepsilon = 1$ and $\varepsilon = 0$ and obtain:

$$w \geq \hat{w} \equiv \rho U - (\rho - n) a + (\rho + \delta + q) \frac{\chi}{q}$$

Let's now analyze the case of an individual in unemployment spell. For an unemployed worker the probability of loosing a job is nil (i.e., $\delta + q(1 - \varepsilon) = 0$) while that of finding a job is positive and equal to η. The present-discounted value of the income stream can then be described by the following asset equation:

$$\rho U = b + (\rho - n) a + \eta (W - U) \tag{A.7}$$

Comparison of the lifetime utility of a non-shirking worker (i.e., Eq. [A.6] with $\varepsilon = 1$) with that of an unemployed worker (Eq. [A.7]) gives equation [4] of the text.

Appendix B

B.1: An increase in ϕ

Consider a steady state equilibrium as that described by the pair [24] and [25]. Differentiation of [24] and [25] with respect to u^* I^* and ϕ gives the following:

$$\Gamma \cdot \begin{bmatrix} \frac{du^*}{d\phi} \\ \frac{dI^*}{d\phi} \end{bmatrix} = \begin{bmatrix} \frac{\alpha I^*[\rho - n + I^*(1 - \ln\lambda)]}{(\lambda - 1)(\mu + \varphi I^*)^2} \\ 0 \end{bmatrix} \tag{B.1}$$

where the Jacobian reads:

$$\Gamma \equiv \begin{bmatrix} 1 & -\frac{\alpha\kappa\phi[\mu(\rho - n) + I^*(2\mu + \varphi I^*)(1 - \ln\lambda)]}{(\lambda - 1)(\mu + \varphi I^*)^2} \\ -1 & -\frac{\alpha\kappa(\lambda - \ln\lambda)}{\lambda - 1} \end{bmatrix}$$

The determinant of the Jacobian matrix reads:

$$|\Gamma| \equiv -\alpha\kappa \left\{ \frac{(\lambda - \ln\lambda)(\mu + \varphi I^*)^2 + \phi[\mu(\rho - n) + I^*(2\mu + \varphi I^*)(1 - \ln\lambda)]}{(\lambda - 1)(\mu + \varphi I^*)^2} \right\} < 0.$$

Using the Creamer rule yields:

$$\frac{du^*}{d\phi} = -\frac{1}{|\Gamma|}\frac{\alpha^2\kappa^2 I^*(\lambda - \ln\lambda)[\rho - n + I^*(1-\ln\lambda)]}{(\lambda-1)^2(\mu+\varphi I^*)^2} > 0$$

and

$$\frac{dI^*}{d\phi} = \frac{1}{|\Gamma|}\frac{\alpha\kappa I^*[\rho - n + I^*(1-\ln\lambda)]}{(\lambda-1)(\mu+\varphi I^*)^2} < 0$$

In (I, u) space, an increase in ϕ does not affect the L-curve while making the U-curve to shift to left.

Let now analyze the impact of an increase in ϕ on the steady state rate of job creation $\eta^* = (\mu + \varphi I^*)\, u^*$. Differentiating with respect to ϕ yields:

$$\frac{d\eta^*}{d\phi} = (\mu + \varphi I^*)\frac{du^*}{d\phi} + \varphi u^* \frac{dI^*}{d\phi}$$

As:

$$\frac{du^*}{d\phi} = -\frac{dI^*}{d\phi}\left(\frac{\alpha\kappa(\lambda-\ln\lambda)}{(\lambda-1)}\right),$$

the previous derivative boils down to:

$$\frac{d\eta^*}{d\phi} = \left\{\varphi u^* - (\mu+\varphi I^*)\left[\frac{\alpha\kappa(\lambda-\ln\lambda)}{(\lambda-1)}\right]\right\}\frac{dI^*}{d\phi}.$$

whose sign depends on the sign of the term in curly brackets which is ambiguous.

B.2: An increase in φ

Consider a steady state equilibrium as that described by the pair [24] and [25]. Differentiation of [24] and [25] with respect to u^* I^* and φ gives the following:

$$\Gamma \cdot \begin{bmatrix} \frac{du^*}{d\mu} \\ \frac{dI^*}{d\mu} \end{bmatrix} = \begin{bmatrix} -\frac{\phi\alpha\kappa(I^*)^2[\rho-n+I^*(1-\ln\lambda)]}{(\lambda-1)(\mu+\varphi I^*)^2} \\ 0 \end{bmatrix} \tag{B.2}$$

Using the Creamer rule yields:

$$\frac{du^*}{d\varphi} = \frac{1}{|\Gamma|}\frac{\phi(\alpha\kappa I^*)^2(\lambda-\ln\lambda)[\rho-n+I^*(1-\ln\lambda)]}{(\lambda-1)^2(\mu+\phi I^*)^2} < 0$$

and

$$\frac{dI^*}{d\varphi} = -\frac{1}{|\Gamma|}\frac{\phi\alpha\kappa(I^*)^2[\rho-n+I^*(1-\ln\lambda)]}{(\lambda-1)(\mu+\phi I^*)^2} > 0$$

In (I, u) space, an increase in φ does not affect the L-curve while making the U-curve to shift to right.

Let now analyze the impact of an increase in φ on the steady state rate of job creation $\eta^* = (\mu + \varphi I^*)\, u^*$. Differentiating with respect to φ yields:

$$\frac{d\eta^*}{d\varphi} = (\mu+\varphi I^*)\frac{du^*}{d\varphi} + \varphi u^*\frac{dI^*}{d\varphi} + I^* u^*$$

As:

$$\frac{du^*}{d\varphi} = -\frac{dI^*}{d\varphi}\left[\frac{\alpha\kappa(\lambda-\ln\lambda)}{\lambda-1}\right],$$

the previous derivative boils down to:

$$\frac{d\eta^*}{d\varphi} = \left\{ \varphi u^* - (\mu + \varphi I^*) \left[\frac{\alpha\kappa (\lambda - \ln \lambda)}{(\lambda - 1)} \right] \right\} \frac{dI^*}{d\varphi} + I^* u^*.$$

Once again, the impact on the steady state job turnover depends on the sign of the term in curly brackets which is ambiguous. So no clear-cut result emerges.

B.3: **An increase in** μ

Consider a steady state equilibrium as that described by the pair [24] and [25]. Differentiation of [24] and [25] with respect to u^* I^* and μ gives the following:

$$\Gamma \cdot \begin{bmatrix} \frac{du^*}{d\mu} \\ \frac{dI^*}{d\mu} \end{bmatrix} = \begin{bmatrix} -\frac{\phi\alpha I^* \phi[\rho - n + I^* (1 - \ln \lambda)]}{(\lambda - 1)(\mu + \varphi I^*)^2} \\ 0 \end{bmatrix} \tag{B.2}$$

Using the Creamer rule yields:

$$\frac{du^*}{d\mu} = \frac{1}{|\Gamma|} \frac{\phi (\alpha\kappa)^2 I^* (\lambda - \ln \lambda) [\rho - n + I^* (1 - \ln \lambda)]}{(\lambda - 1)^2 (\mu + \phi I^*)^2} < 0$$

and

$$\frac{dI^*}{d\mu} = -\frac{1}{|\Gamma|} \frac{\phi\alpha\kappa I^* [\rho - n + I^* (1 - \ln \lambda)]}{(\lambda - 1) (\mu + \phi I^*)^2} > 0$$

In (I, u) space, an increase in μ does not affect the L-curve while making the U-curve to shift to right.

Let now analyze the impact of an increase in μ on the steady state rate of job creation $\eta^* = (\mu + \varphi I^*) u^*$. Differentiating with respect to μ yields:

$$\frac{d\eta^*}{d\mu} = \varphi I^* \frac{du^*}{d\mu} + \varphi u^* \frac{dI^*}{d\mu} + u^*$$

As:

$$\frac{du^*}{d\mu} = -\frac{dI^*}{d\mu} \left[\frac{\alpha\kappa (\lambda - \ln \lambda)}{\lambda - 1} \right],$$

the previous derivative boils down to:

$$\frac{d\eta^*}{d\mu} = \left\{ \varphi u^* - \varphi I^* \left[\frac{\alpha\kappa (\lambda - \ln \lambda)}{\lambda - 1} \right] \right\} \frac{dI^*}{d\mu} + u^*.$$

Once again, the impact on the steady state job turnover depends on the sign of the term in curly brackets which is ambiguous. So no clear-cut result emerges.

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