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Technological Transitions and Educational Policies

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TECHNOLOGICAL TRANSITIONS AND EDUCATIONAL POLICIES

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ABSTRACT. This paper presents an out-of-equilibrium model to explain cross-country differences in the capacity to absorb new skill-biased technologies. The usual mainstream viewpoint stressing the role of labour markets will be re-examined in a context characterized by a sequential structure of both the process of production and the skill formation, whose interaction brings about coordination failures harming the viability of the innovation process. In this light, educational policies play a crucial role in restoring the required coordination. The robust results of the simulations show that educational policies appear to be important both in rigid and in flexible systems. In the former case, educational policies financed by taxation allow the system to escape a low productivity final equilibrium. In the latter, they contrast the financial constraint associated to a large decrease in the unskilled wage. Altogether, a moderate degree of rigidity seems the most appropriate institutional environment to reach the targets of viability and of a full exploitation of the technological potential.
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1. INTRODUCTION AND MOTIVATION

In the last three decades, due to the sharp changes in workers' conditions, the relation between labour market outcomes and technical change has gained a renewed interest among scholars and policy-makers alike. Several factors have been accounted for as an explanation of the joint emergence of labour market inequalities and of divergence in employment and productivity trends among rich countries, including technological change, globalization and institutional differences. The reversal in the pre-1970 convergence of GDP per capita and productivity of the main European economies (Germany, France, Italy) towards US levels has actually been ascribed to the different success in absorbing new IT-related technologies (see Scarpetta et al. 2000, Krueger and Kumar 2004). On the other hand, the skill-biasness of these technologies (Katz and Murphy 1992, Acemoglu 1998, Krusell et al. 2000, Aghion et al. 2002) has brought about a higher wage inequality in unregulated Anglo-Saxon countries, while lowering investments and increasing unemployment in regulated continental Europe.

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The emergence of different unemployment and productivity trends in response to common skill-biased technological shocks (Krugman 1994) is of particular interest in our analysis. In the mainstream literature, differential success in absorbing skill-biased technologies has been mainly attributed to differences in labour market institutions. In particular, flexibility of labour markets, i.e. low unemployment benefits, absence of firing costs and free wages fixing, is acknowledged as a strong incentive to favour innovative choices, growth and employment (Krugman 1994, Acemoglu 2003, Hornstein et al. 2007). As a matter of fact dismissal costs (employment protection) are believed to reduce the incentive for investment in risky, although very productive, technologies and to help retaining human resources in low productive sectors, characterised by less risky, routine innovations (Saint Paul 1997). In this view, the substantial skill premium brought about by flexible labour markets provides the right incentive to invest in general human capital, which is more easily transferable and enables workers to operate more efficiently with new technologies (Krueger and Kumar 2004). Adequate labour market conditions appear then as the crucial factor favouring the right coordination of household investments in skills and of firm investments in new technologies.

However, the theoretical focus on labour market differences alone falls short in explaining why Scandinavian countries, characterized by rigid labour market institutions, have been able to fully reap the benefits of the new skill-biased technologies. In the mainstream literature, an interesting step forward is the paper of Krueger and Kumar 2004 where the interaction of labour market and educational policies shape the incentive to accumulate different types of human capital. Moving from the Nelson and Phelps (1966) claim that new technologies require general rather than specific education, they show how distortive educational policies might interact with differences in labour market policies, hence explaining the observed differences in the rates of accumulation of general human capital between Germany and the US. Accordingly, the comparative advantage of the US and Scandinavian countries over the central EU area is partially attributed to an educational system that enhances the incentives of investing in college education with respect to specific and vocational training[1].

In this paper we seek to investigate the way in which differences in educational policies, and the interaction with different labour market institutions, affect the outcome of a skill-biased technological transition. The effects of the interaction between labour markets and educational policies will be considered by focussing on the feedbacks of wage inequality—mainly determined by technology and labour market institutions—on final demand and on human capital accumulation throughout the emergence of financial constraints at the household level. The dynamic coordination of investments in human and physical capital turns out to be affected both by the evolution of the incentives to invest in it, as the standard view would suggest, and by the evolution of the financial constraint at the households and firms' level. Note that these constraints are particularly relevant under three, rather realistic, hypotheses: 1. the assumption of cash-in-advance,

[1]In addition, counterfactual evidence supporting this explanation is provided by a comparative analysis of the dynamics of the total factor productivity in two countries with similar labour market institutions—UK and US—and a similar pattern of ICT investments, but different endowments of college graduates. In the nineties, the country with the larger college cohort, i.e. US, maintained a higher rate of growth of productivity with respect to the country with a smaller graduate cohort, i.e. UK, the similarity in the other characteristics notwithstanding (Basu et al. 2004).

implying that costs and proceeds are not automatically synchronized; 2. the assumption of imperfect capital markets, as is often the case in the literature on human capital, e.g. Galor and Zeira 1993; 3. the explicit consideration of a construction phase both of skills and physical capital, whose time dimension favours the emerging of constraints both at the households and firms level.

We will analyse the factors that shape the critical phase of a skill-biased technological transition from a steady state to another, and investigate the role of educational policies and labour market flexibility for the viability of this transition, by making use of an out-of-equilibrium model that embodies the abovementioned hypotheses. The complexity involved in the transitional analysis calls for non-analytical solutions whose robustness is checked through a detailed sensitivity analysis. The robust results of the simulations of the model show that educational policies appear to be important both in rigid and in flexible systems, but for different reasons. In the former case, educational policies financed by taxation speed up skill formation and thereby allow the system to escape a low productivity final equilibrium. In the latter, educational policies reduce the emergence of financial constraints at the household level associated to a large decrease in the unskilled wage. Altogether, a moderate degree of rigidity seems the most appropriate institutional environment to reach the targets of viability and of a full exploitation of the technological potential. It will also be shown that the level of the tax required to fully reap the benefits of the skill-biased transition is increasing in the degree of labour market flexibility. Finally, the model identifies a possible mechanism through which, in the case of rigid labour markets, a physiological productivity slowdown that characterizes the first phase of a technological transition might become permanent as a consequence of bad policy choices.

The paper is organized as follows. Section 2 describes the out-of-equilibrium perspective on innovation and skill formation. Section 3 presents the model. Section 4 investigates the outcomes of the transition and checks the robustness of the main results. Section 5 concludes.

2. INNOVATION AND SKILL FORMATION: AN OUT-OF-EQUILIBRIUM PROCESS

The 'right' choice of technology, that is, the choice of innovative technologies, and the incentives favouring it, are at the centre of the stage in the mainstream literature, which supports the view that rigid labour markets hinder this choice. However, this implies a view of production and technology according to which the productive capacity expression of a technology and its adequate utilisation (the gains of technology) are the automatic (immediate or delayed) result of a simple choice. A production theory of this kind, however, is consistent only with an equilibrium context. Only in equilibrium, in fact, it is possible to relate inputs and output on the basis of a relation defined ex ante by technical conditions, and determine returns and productivity as the expression of these conditions. In other words, once you are able to realise the conditions for the choice of the highly productive technology you have the results of this choice. Co-ordination problems, which might hamper the effective appropriation of the potential returns of new technologies, are excluded by assumption.

However, a radical innovation necessarily implies a restructuring of productive capacity, and thus a breaking of the regular behaviour of the economy. Only by relaxing the assumption that the system remains in equilibrium during a technological transition allows taking into account the dissociation in time of costs and proceeds that is the expression of the coordination problems raised by the attempted change. And only by re-establishing the coordination, both at the micro and the macro levels, that is necessary to ensure the viability of the innovative process, it will be possible to actually obtain the economic returns of innovation. This depends in turn on being able to re-establish a balanced structure of productive capacity and to eliminate the market imbalances and skill mismatches involved. This is a necessary condition for the viability of the innovation process and the possibility to reap the advantages associated to new technologies. In this light, technology no longer appears as the precondition of the process of innovation but as the result of the latter, interpreted as an (essentially economic) co-ordination process (Amendola and Gaffard 1998).

The human resource plays a crucial role in this process. In particular, the role of the human resource, as well as the working of labour markets (flexibility/rigidity, wages policy, employment protection. . .) must then be looked in the perspective of the viability of the innovation process. In this light learning appears as the main contribution of the human resource to the process of construction/restructuring of productive capacity, by helping to re-establish the co-ordination between the accumulation of the physical capital and that of the human capital, broken by the skill-biased requirements of the new technologies.

The focus on the process of learning–rather than on price mechanisms, aimed at bringing about equilibrium between demand and supply of labour–points to the problem of the co-ordination between the accumulation of the physical and the human capital, that is even more relevant in relation to general purpose technologies, given their strong and particular skill-bias. To be sure, dealing with these changes implies a high level of general education that supplies adaptable skills (University degrees, PhDs...) rather than vocational training (mainly based on experience) traditionally important for the provision of specific skills (Gould 2002).

The sensibly higher costs and the longer time to obtain a degree compared to vocational qualifications is likely to bring about a significant breaking of coordination between the process of accumulation of physical capital and that of the human resource. The latter must therefore be intensified and accelerated.

However, co-ordination problems are exacerbated by the fact that, in line with standard human capital theory (Becker 1975), firms find it difficult to appropriate investments in general human capital, which is easy transferable across industries and firms. Thus investments in training supported by the direct bargaining of entrepreneurial associations and unions, becomes less effective in solving emerging coordination failures as long as these institutions tend to promote the development of a know-how enhancing the productivity of incumbents' plants, rather than favouring the adoption of radically new technological designs (Baumol 2004).

It has been maintained that skill premia favoured by labour market flexibility may provide the appropriate incentives to accumulate general human capital. On the other hand, consistently with a significant empirical evidence (e.g. Haveman and Wolfe 1995), unskilled households face higher opportunity costs for investing in general education, hence requiring higher skill premia to upgrade. However, in the absence of perfect capital markets for borrowing against future income (Galor and Zeira 1993), poor families living on unskilled wages can not afford the fixed costs—living costs and tuition fees—of long educational programs. For example, Acemoglu and Pischke (2001) estimated a large and significant impact of household income on enrolment decision across three cohorts of US high school graduates. This effect is even magnified if technical change tends to trigger an initial productivity slowdown that amplifies the reduction of the unskilled wage. In sum, whether unemployed or less-rich, unskilled workers might face a liquidity constraint (or a higher opportunity cost) that makes them unable (or unwilling) to afford the long-term investment to attain a college degree, notwithstanding the incentive of high expected skill premia.

Active educational policies appear then as the way to overcome both the lack of incentives—typical of regulated systems—and the emergence of borrowing constraint—typical of unregulated ones. Here we focus on higher education subsidies in order to emphasize the possible interesting trade-offs that emerge by considering the interaction of educational policies and labour market institutions.

In this perspective, the differential path of accumulation of higher (general) education with respect to the US observed in many central European countries appears as the result of lower expected returns of investments in university education in these countries, due to the interaction of a passive tuition-free system and of rigid labour markets. On the contrary, an aid-based system, besides offsetting the decrease in the individual capacity to invest in education, also enhances the incentive to actually carry out this investment. A historical inspection of the U.S. policy experience suggests that the huge, and anti-cyclical , increase in student aids in the 70s is in tune with this explanation allowing to remove the financial constraint of many low-middle income households (Heller 2006). Among the policy measures that, since the end of the 60s, were taken in order to contrast the U.S. decline in high-technological sectors (Cozzi and Impullitti 2008), the sharp increase of investment in higher education has prepared the ground for the boom of the ICT revolution.

The out-of-equilibrium analysis carried out in this paper enables us to stress the importance of educational subsidies especially in the critical initial phase of technological transitions where the worsening of the macroeconomic performance, brought about by a diversion of resources towards construction activities, is likely to be a source of path dependency. In particular, in the perspective proposed it will be possible to critically re-examine the dominant conclusion as to the reasons of the transatlantic divergence– the difference in employment and productivity performances between the U.S. and the main European economies, casting doubts, in particular, on the belief that rigid labour markets are the main culprit of this divergence.

The model expounded in the next section provides the basis for the simulation analysis whose results are presented in section 4.

3. MODEL

This model represents an extension of the baseline model of Amendola and Gaffard (1998). With respect to that model, here the accumulation of human capital is endogenised and educational policies are explicitly considered.

The evolution of the economy is sketched out by a sequence of finite periods. Three types of agents are considered: a representative firm, skilled and unskilled workers. All exchanges between them are intermediated by a financial asset, call it 'money': the resources to carry out production and to sustain consumption are therefore financial resources, not physical output. The firm organizes production and pays profits at the end of each final production period as a constant fraction of the output sold. Two types of workers, skilled and unskilled, supply inelastically each a unit of labour at the beginning of the period. Wages are paid ex-ante and entirely spent within the period. In turn, profits are entirely spent during the next period. Population grows at a constant rate n and both types of workers have children with an identical fertility rate. In the initial steady state, technical change is absent, hence the economy grows at the rate n. At time $t > 0$, a skill-biased technological shock pushes the system out-of-equilibrium. The way in which the system adjusts to this shock is analysed in the simulations of section 4.

3.1. **The Neoaustrian technology.** In the representative firm production is carried out by means of fully vertically integrated processes of a Neo-Austrian type (Hicks 1973)[2], using a heterogeneous primary input (labour). An elementary process of production considers explicitly the time profile of inputs and outputs and is represented by an input matrix defined on time and skills and an output vector defined only on time. The input matrix is:

$$\mathbf{A} = \begin{bmatrix} \mathbf{a}_u^j \\ \mathbf{a}_s^j \end{bmatrix}. \tag{3.1}$$

Vectors $\mathbf{a}_s^j$ and $\mathbf{a}_u^j$ represent the requirement of skilled s and unskilled u labour, respectively. Each element of these vectors denotes the specific requirement of labour in the successive stages of the construction phase of productive capacity (from 1 to n^c) and, following it, of the utilization phase (from n^c+1 to n^c+n^u) during which the productive capacity generates an output.

The output vector is:

$$\mathbf{b} = \left[b^j\right], \tag{3.2}$$

with $b^j = 0, \forall j = 1, ..., n^c$ and $b^j = b > 0, \forall j = n^c + 1, ..., n^c + n^u$.

At each given moment t the productive capacity is subject to aging, i.e. $x^j(t) = x^{j-1}(t-1)$, and is represented by the intensity vector:

$$\mathbf{x}(t) = \left[\mathbf{x}^c(t), \mathbf{x}^u(t)\right], \tag{3.3}$$

whose elements are the number of processes in the construction c and in the utilization u phase active at time t. The activity of construction and utilization of productive capacity determines the vector of labour demand, whose elements are the demand for each type of skills respectively, i.e. $\mathbf{L}^D(t) = \mathbf{A} \cdot \mathbf{x}(t)'$.

[2]A Neo-Austrain representation of the production process, which allows to take explicitly into account the phase of construction of productive capacity, is best suited to deal with the restructuring of this capacity through which an out-of-equilibrium process like innovation takes place, and which is obscured by the equilibrium assumption behind the standard 'production function' representation of production and technology.

In the Neo-Austrian framework, a skill-biased technology implies a relative increase in the requirement of skilled labour with respect to unskilled labour. Clearly, when technology is allowed to change, the matrix **A** is also indexed by time.

3.2. **Decisions: Production and Investments.** At the beginning of each period, the representative firm faces a financial constraint. $W(t)$ are the funds available to finance production processes, subject to the constraint:

$$W(t) = (1-\mu)\cdot y(t-1) + f(t) + h_f(t-1), \tag{3.4}$$

where $y(t-1)$ are the past period's money proceeds and μ is the fixed fraction of consumption out of profits, $h_f(t-1)$ are the idle money balances involuntarily accumulated in the past, and $f(t)$ are the external financial resources, either subsidies or credit. In particular, the external financial resources are such that: $f(t) = \min\left[f_S(t), f_D(t)\right]$, where $f_D(t)$ is the demand of external funds determined according to the actual investments and production plans, and $f_S(t)$ is the money supplied by the central authority, which we assume growing at the steady state rate n. Together with the characteristic of the technology, the wage fund $W(t)$ determines the desired demand of labour of each type.

While the emergence of a financial constraint depends on the decisions of the monetary authority, a human constraint might emerge for two reasons: full employment, or excess demand of at least one essential skill. A human resource constraint more stringent than a financial resource constraint forces the firms to accumulate involuntarily idle balances: $h_f(t) = \max\left[0, W(t) - \omega(t)\right]$ where $\omega(t)$ is the wage fund constrained by available human resources.

In both cases in which a stringent constraint emerges, firms are forced to scrap part of the productive capacity. This choice obviously depends on the technical coefficients defined in the matrix **A**. If the requirements of labour are non-negative in each phase of production, the optimal choice is clearly to scrap first the younger processes which are burdened by costs but not yet bring about revenues.

The decision of how much to produce in each period depends on expectations on final demand. The firm adapts its capacity with respect to the expected final demand , $\widehat{D}(t)$, which is made to depend on past trends in money proceeds. In the case of an excess of capacity with respect to the expected final demand, the vector of processes in the phase of utilization, $\mathbf{x}^U(t)$, is scaled down uniformly by a partial utilization of the productive capacity inherited from the past:

$$q(t) = \tau(t)\cdot \sum_{j=1}^{n^c+n^u} b^j \cdot x^j(t), \tag{3.5}$$

where the rate of utilization $\tau(t)$ depends on the expected final demand[3].

[3] $\tau(t) = \min\left(1, \frac{\widehat{D}(t)-\xi\cdot(o(t)-\widehat{o}(t))}{\sum_{k=1}^{n^c+n^u} b_k\cdot x_k(t)}\right)$ where $o(t)$ and $\widehat{o}(t)$ are respectively the real stocks actually put back on the market and the desired level of real stocks, which is equal to zero in equilibrium and, out-of equilibrium, is equal to a weighted average of the past levels of real stocks; $\xi \in (0,1]$ is a parameter

As a consequence, the new investments carried out (the rate of starts of new production processes) will be the minimum between desired investments–which, for simplicity, are assumed to grow at the steady state rate n [4]–and the part of the available financial resources not required to carry out current production.

3.2.1. *Demand and Supply.* The supply of final output $S(t)$ in each period is equal to the output produced in the period plus the real stocks, if any, accumulated in case of an excess supply in the previous periods and put immediately back on the market.

The effective demand for final output, $D(t)$, reflects our assumptions on the consumption decisions of the various agents:

$$D(t) = \frac{\omega(t) + \pi(t) + h^h(t-1)}{p(t)}, \tag{3.6}$$

where $\omega(t)$ is the 'constrained' wage fund (see above) entirely spent on consumption; $\pi(t) = \mu \cdot y(t-1)$ is consumption out-of-profits which is a constant fraction μ of money proceeds $y(t-1)$ at time $t-1$ and is entirely consumed in period t; and $h^h(t-1)$ are the idle balances accumulated by households in previous periods, emerging if there is an excess of demand in the final good market.

3.3. **Markets.** While production and investment decisions are updated during each period if plans cannot be fully realized, prices change only at the junction between periods as a consequence of the disequilibrium in the respective markets. The price of the final good in each period will then be:

$$p(t) = \max\left[p(t-1)\left(1 + \nu_p\left(\frac{D(t-1) - S(t-1)}{S(t-1)}\right)\right), c(t)\right], \tag{3.7}$$

where ν_p is the reaction coefficient expressing the degree of flexibility of the market. Furthermore, we exclude the possibility that, in period t, prices decrease below the unitary cost, $c(t)$, which is a function of the wages and of the technology.

Likewise, wages react to disequilibria in the labour market. The reaction coefficient ν_h captures the degree of labour market rigidity, within the range of two polar cases: a purely market-based determination of wages, i.e. $\nu_h \to \infty$, and an institutionally driven rule, $\nu_h = 0$.

$$w_h(t) = w_h(t-1)[\nu_h \cdot \Psi_h(t-1) + 1], \tag{3.8}$$

where $\Psi_h(t-1) = \frac{L_h^D(t-1) - L_h^S(t-1)}{L_h^S(t-1)}$, $L_h^D(t-1)$ and $L_h^S(t-1)$ are respectively the demand and the supply of labour of type h at time $t-1$. Wage rigidity can be the consequence

that captures the elasticity of the degree of utilization to unexpected changes in the desired level of real stocks.

[4]This is obviously a limitation of the model. The assumption of more realistic decision rules, with, e.g., the rate of start directly depending on the expected final demand, tends to generate the well-known instability of post-keynesian growth models. However, simulations available on request show that, within a certain range, our results are robust if we consider a decision rule for the rate of start which is a linear combination of the trend and the demand-related component.

of many factors, ranging from union monopoly power to efficiency wages, from market incompleteness to fairness considerations (see Howitt 2002). The parameters ν_h turn out to be very important in the following discussion. We further assume that there is a lower bound for the unskilled wage that equals the basic wage: $w_u(t) = \underline{w}(t)$.

3.4. **Endogenous formation of skills.** We assume that becoming skilled is equivalent to attain an educational program, which lasts for one year and costs ϱ per person, and that skilled workers can perform unskilled jobs while the opposite is not true. Moreover, individuals have equal innate abilities, but they differ as regard to preferences towards leisure and the time profile of income revenues. That is, given the wage premium equal to the difference between the skilled and the unskilled wage, $w_s - w_u$, only a fraction ϕ of individuals is well disposed to attend an educational program giving up incomes during the educational period. The higher the wage premium, the higher the fraction ϕ. For sake of simplicity, we further assume that ϕ is equal to the normalized wage premium as long as the unskilled wage remains above a minimum wage. More formally:

$$\widetilde{\phi}(t) = \begin{cases} \frac{w_s(t)-w_u(t)}{w_s(t)+w_u(t)} & if \quad w_u(t) > \underline{w}(t) \\ 1 & if \quad w_u(t) = \underline{w}(t) \end{cases} \tag{3.9}$$

Since in this work we will mainly interpret $\underline{w}(t)$ as a basic or subsistence wage, it is natural to maintain that $\underline{w}(t)$ changes with prices g_p: $\underline{w}(t) = \underline{w}(t-1) \cdot (1+g_p)$. It is easy to show that this functional specification is more sensible to a decrease of the unskilled wage than to an increase in the skilled one. This implies that human capital investments have a precautionary element (Gould 2002), being a reaction to the risk of deterioration of the unskilled level of well-being.

As to firms' decisions, in the case in which a stringent liquidity constraint emerges, individuals' decisions to invest in human capital can not be realized. Provided that the cost of education is equal to the basic wage plus the fee, an unskilled offspring can financially support education only if the unskilled wage is at least equivalent to the cost of education plus the minimum requirement for parents' subsistence: $w_u(t) \geqslant c_e(t) + \underline{w}(t) = 2 \cdot \underline{w}(t) + \varrho$.

If the liquidity constraint is stringent, i.e. $w_u(t) < 2 \cdot \underline{w}(t) + \varrho$, an unskilled worker, who at the new wage premium wants to shift, is able to become skilled only if the cost of education is subsidized (with the amount of the individual subsidy equal to the difference $w_u(t) - (2 \cdot \underline{w}(t) + \varrho)$).

3.5. **The Educational Policy.** We assume that educational policies are financed by a tax in order to keep the government budget balanced. For sake of simplicity, we consider only a tax on firms' idle balances, which are a direct consequence of the emergence of a stringent human constraint. This tax meets the requirement of being flexible. In fact, once a skill mismatch occurs, firms involuntarily accumulate idle balances that are automatically reinvested if, and when, the human constraint is relaxed. While the skill mismatch is gradually reabsorbed, idle balances are gradually decumulated and the effect of the policy disappears. The supply of educational funds is then equal to:

$$K_e^S(t) = \iota \cdot h_f(t-1), \tag{3.10}$$

where ι is the tax rate.

The emergence of idle balances–as in the opposite case the credit rationing–signals a break in the complementary accumulation of human and physical capital. In this model, changes in the level of the tax reestablish this complementarity: a task assured in other similar models by monetary policy (Amendola and Gaffard 1998) or, in the standard literature, by a continuous optimization process (e.g. Galor and Moav 2006). Together with the parameters capturing the degree of labour market rigidities, the level of the tax captures institutional features in this framework. Given the supply of education funds, the effective amount of funds mobilized in each period is:

$$K_e(t) = \min(K_e^D(t), K_e^S(t)), \tag{3.11}$$

where $K_e^D(t)$ is the aggregate demand of subsidies[5]. By assuming that subsidies mainly cover living expenditures, the educational policy modifies the level of final demand:

$$D(t) = \frac{\omega(t) + \pi(t) + h^h(t-1) + \min(K_e^S, K_e^D(t))}{p(t)}. \tag{3.12}$$

In the next section, we will present the results of the simulation analysis.

4. Simulation analysis

We consider initial steady states where the financial constraint for unskilled workers is not binding, i.e. $w_u(0) - \underline{w}(0)$ is large enough (recall that this distance determines the capacity of accumulating human capital). This is a realistic assumption looking at western countries before the ICT shock. To simplify matters, we assume that technical change is exogenous and consists of a single shock[6]. This is skill-biased and also forward-biased, that is: an increase in the requirements of skilled workers occurs in the construction phase (R&D, design, etc.) and is more than compensated by a decrease in the requirement of unskilled workers, mainly concentrated in the utilization phase. The robustness of the results of our analysis will be checked with respect to more or less strong technological shocks and to different institutional configurations, defined by the parameters capturing labour market rigidities (ν_s, ν_u) and educational policies (ι).

Section 4.1 discusses the issue of the viability of the skill-biased transition, while section 4.2 analyses the outcomes in terms of final productivity. In section 4.3, we introduce the educational policy.

4.1. **Viability.** The viability of the technological transition is crucially affected by the initial distance between the unskilled and the basic wage. In the case of a relatively high initial distance, the system reaches a new steady state characterized by a higher level of income per-capita. The transition to the new equilibrium is characterized by a phase of cyclical fluctuations that are brought about by the interplay of disequilibria

[5]In particular, three groups demand subsidies: 1. the unskilled offspring if $w_u(t) < 2 \cdot \underline{w}(t) + \varrho$, 2. the unskilled workers that at the new wage premium want to acquire skills, 3. the offspring of unemployed workers.

[6]The case in which technical change takes place as a sequence of small shocks rather than as a once-for-all shock would require a considerable amount of additional structure since, in this case, shocks could not be considered as completely unexpected and hence endogenous technological adoption should be considered. This is a challenge for future work.

in the labour and the final product markets, and are amplified by lags in the adjustment of skills and of the productive capacity (fig. 1). On the other hand, a system where initially the unskilled wage is too close to the basic wage has less chances to successfully carry on the technological transition. Following the skill-biased shock, the unskilled wage might decline below a critical level that enables unskilled households to self-finance education investments. Notwithstanding the high incentives to accumulate human capital, represented by the skill premium, the income effect prevails and hence human capital accumulation shrinks. As a result, skill mismatches are not reabsorbed, whereas unemployment and high wage inequality persist (fig. 2).

More formally put: the dynamical system characterized in section 3 has a bifurcation in correspondence to the initial level of $w_u(0) - \underline{w}(0)$. This implies that, given $w_u(0)$, it is possible to identify a cut-off level of the basic wage $\underline{w}^*(0)$ such that if $\underline{w}(0) \in \left[\underline{w}^*(0), \frac{w_u(0)}{2} - \varrho\right]$ the system is not viable, while if $\underline{w}(0) \in [0, \underline{w}^*(0))$ viability is ensured. In figure 2, repeated series of simulations gives a graphical interpretation of $\underline{w}^*(0)$, seen the locus separating the viable and the unviable regions.

Labour market parameters ν_s and ν_u affect the critical value $\underline{w}^*(0)$ to which corresponds a qualitative change in the behaviour of the system. In particular, consistently with previous works in the out-of-equilibrium literature (e.g. Amendola, Gaffard and Saraceno 2004), systems characterized by flexible labour markets face additional difficulties in carrying on successfully the transition. Since the initial decrease of the unskilled wage is larger in flexible labour markets, adjusting to skill-biased innovations is possible only when the unskilled parental capacity to finance education is large enough; otherwise, the cost of education can not be afforded by unskilled parents. To a certain extent, instead, rigid labour markets prevent that a large initial increase of inequality harms skill formation. To be sure, under the restriction that labour markets and the final product market are homogeneous $\nu_p = f^+(\nu_s)$[7], repeated long-run simulations show that the more rigid the labour markets, the larger the set of values of $\underline{w}(0)$ compatible with the system's viability and hence the higher can be the threshold value $\underline{w}^*(0)$ (fig. 3).

The shape of the relationship between $\underline{w}^*(0)$ and the degree of labour market flexibility remains robust to a quasi-montecarlo experiment where the long-run outcomes of 5000 randomly extracted configurations of the relevant parameters are analysed (fig. 4). More precisely, the percentage of viable cases more than halves when moving from extremely rigid to extremely flexible labour markets (tab.1, col. 1 and fig. 5). As an additional check, probit regressions permit to further disentangle the effect of the different factors affecting the viability of the transition. All coefficients are significant at .01% and of the expected sign in different specifications of the econometric relationship (tab. 2); in particular, higher skill-biasness, basic wage and degree of labour market flexibility all strongly reduce the probability that a transition is viable. By comparing the size of the coefficients, product market flexibility appears to be almost irrelevant for the viability;

[7]It is worthwhile noticing that rigidities in the skilled and the unskilled labour markets play an asymmetric role provided that the emergence of a stringent liquidity constraint depends essentially on the evolution of the unskilled wage, while the dynamic of the incentive effect is also related to the one of the skilled wage. As a matter of fact, simulations confirm that the more flexible the unskilled labour market, the harder the technological transition, whereas the opposite holds for the skilled labour market.

however, as it will be shown, this is not the case if we evaluate the transition in terms of final productivity.

4.2. **Productivity.** Among the viable cases, the outcomes of the transition can substantially differ in terms of final productivity. The convergence to the potential level of productivity of the new technology may not be ensured even when, in the long-run, skill mismatches are reabsorbed. A continuum of final steady states with different final productivities emerges since Keynesian feedbacks from demand expectations to productivity, via capacity utilization, interact with a sequential structure of production. More to the point, the initial productivity slowdown, brought about by the interaction of cash-in-advance constraints and of costly construction phases[8], can worsen final demand expectations, hence leading to capacity under-utilization.

Interestingly, we found that this effect is much stronger in rigid labour markets. Using the previous randomly generated dataset, the percentage of viable cases with a level of the final productivity ratio–i.e. the ratio between the effective and the final steady state productivity–above .95 increases with the degree of labour market flexibility (tab. 1 col. 2). Extremely rigid systems display both a significantly higher probability of being viable and a significantly lower probability of reaching a 'high productivity' final steady state. Note that, in rigid labour markets, there is a slower initial skill formation due to a lack of incentives (fig. 6). This protracts the initial output decline and might generate a lower final demand, even when skill mismatches are reabsorbed. Overall, the unique institutional configuration able to meet both the target of a viable transition and that of a high productivity final steady state seems to be the one associated with moderate degrees of rigidity (fig. 7).

It is worth noticing that the negative effect of demand expectations tends to be stronger when prices are prevented from declining up to the point where the level of demand can entirely absorb the higher potential supply. In rigid price settings, it is the degree of capacity utilization which is forced to accommodate for quantity disequilibria bringing about, in the long run, a lower level of real wages and of overall spending capacity[9]. It follows that higher competition in the product market should improve final productivity especially in systems with rigid labour markets. This is actually the case: the estimated impact of price flexibility on productivity is positive and strongly significant everywhere, but in rigid and moderately-rigid labour market configurations it is two to four times higher than in more flexible ones (tab. 3). The effect of a greater product market flexibility is magnified in moderately-rigid labour markets where a "reform" of product market has a larger impact on productivity than a "reform" of labour markets. Finally, figures 8-11 show that, in rigid labour markets, both the level of the final productivity ratio and its cumulated value–i.e. the cumulated of all the ratio experienced

[8]A fall in output and the appareance of technological unemployment due to the phase of construction of productive capacity during which inputs are required but output not yet accrues, is analysed and proved in the literature on the "machinery effect" and the "productivity paradox" (Hicks 1973, Amendola and Gaffard 1998, Amendola, Gaffard and Saraceno 2005).

[9]Notice the parallell with the models of Caballero and Hammour (1998) and Hornstein et al. (2007): rigid labour markets prevent wages from declining at the begininning of the transition, but this ends up damaging the working-class in the long-run. Simulations available upon request show that workers' real wages decline in the case of rigid labour and product markets.

during the transition–tend to improve by increasing the coefficient of product market regulation from 0.1 to 0.3[10].

A straightforward interpretation of our findings shows that the final outcome of the transition can be a 'lower steady state' insofar as markets, included the final one, are too rigid. On the other hand, slower changes in wages, brought about by rigid labour markets, appear to enable a successful transition even if the unskilled wage is relatively close to the basic level, and thus the social capacity of accumulating human capital tends to deteriorate much faster. As a result of these contrasting forces, extreme institutional configurations tend to hinder the diffusion of the new technology.

4.3. **Policy Analysis.** It has been shown that, due to the emergence of a binding financial constraint for unskilled households, market forces alone might not be able to restore a balanced accumulation of human and physical capital. In this situation, subsidizing education is the main candidate policy in order to ensure a viable technological transition. The role of public policies turns out to be of paramount importance in the initial phase of the transition in which counter-cyclical policy interventions should be designed in order to mitigate the potentially harmful effect of the output decrease, which is magnified here by the effect of skill-biased technologies on unskilled wages.

In order to analyse the effect of the educational policy–financed through a tax on firms' idle balances, that is: funds subtracted to the financing of the production process due to some binding constraint on productive resources–we let the tax to vary in the interval $(0, 0.9)$ and draw randomly the other parameters so as to obtain a new artificial sample of 22050 observations. The first important result is that, for initially unviable systems, there exists an appropriate internal level of the policy that maximizes the probability of re-establishing the co-ordintation between investments in physical and human capital (tab.4 and fig.12). If taxes are relatively low, the educational policy does not allow relaxing the financial constraint at the household level. On the other hand, excessive taxes reduce the free funds of firms and hence the capacity to adjust investments when macroeconomic conditions improve.

Particularly interesting for the explanation of cross-country differences in the capacity to absorb skill-biased shocks is assessing the effect of the educational policy in different labour markets. For the unviable cases, the table in figure 12 shows that the level of the tax which maximizes the probability of being viable tends to increase with the degree of labour market flexibility. Put differently, the *minimum* tax rate required to assure the viability of the transition increases with the degree of flexibility–as more flexible systems are more likely to be unviable. This points to a set of "optimal" institutional configurations in which labour market rigidities and the public spending in education are, to a certain extent, substitutes. In particular, the adverse effect of labour market flexibility on skill formation can be reduced by increasing educational expenditures (fig.

[10]This result is to a certain extent consistent with the empirical evidence provided by Fiori et al. (2007). Using a panel of Oecd countries over the period 1980-2002, they show that, if the final market is more competitive and characterized by lower entry barriers, the unemployement rate tends to decrease more in rigid labour markets than in flexible ones. Therefore, accounting for the interactions of market imperfections leads to the conclusion that labour and final market deregulation are in a certain sense 'substitutes'. Here a similar conclusion holds for the relation between the final level of productivity and income per capita, on the one hand, and the interaction of market imperfections, on the other.

13). In the US, the large increase in student aids during the 70s might have prevented that the observed reduction in the unskilled real income brought about a lower enrollment rates and educational attainments of this group. Although not directly, this policy supported the large scale diffusion of skill-biased technologies during the 90s.

The educational policy turns out to be important also in rigid systems. A tax on idle balances allows to contrast the decline of aggregate demand, sustaining a higher degree of capacity utilization both in the short- and in the long-run. In the short-run, idle funds are used to finance subsidies for education that represent additional consumption expenditures. In the long-run, as the demand of educational funds gradually decreases and the skill mismatch is reabsorbed, these funds are automatically reinvested in physical capital. To quantify the effect of the policy, we estimate the impact on productivity of a the tax for different labour market configurations under the restriction of homogeneity of product and labour markets $\nu_p = f^+(\nu_s)$. In line with previous analyses, the impact on productivity is maximized in moderately-rigid labour markets whereas, in very rigid labour markets, subsidies to education have a much smaller impact than labour market reforms (tab. 5).

This latter scenario seems to reinforce our explanation of why central European countries fail to reap the full gains of the ICT revolution. Grounding on an equal income distribution and on its public educational system–factors that in principle tend to favour skill formation–large European economies tend to ignore the fact that, even in more socially protected systems, some individuals are harmed by the transition and require targeted policy measures that make them able to afford the cost of higher education.

5. CONCLUSIONS

This work is a first attempt to address by means of a heterodox approach some of the most relevant issues for labour market inequalities, skill-biased technical change and productivity dynamics. In particular, our analysis has provided new insights on the explanation of the cross-country divergence in the capacity to absorb skill-biased technologies. Moreover, unlike in the standard literature on the productivity paradox (e.g. Greenwood and Yorukoglu 1997), the length and the persistency of low productivity levels has emerged as a consequence of policy failures and particular institutional configurations.

Our model has proved to be consistent with Krueger and Kumar (2004) explanation of the transatlantic divergence since, in most cases, the transition to the new technology is viable only if an increase in public investments in general and higher education compensates for a decreasing capacity of investing in education among the unskilled workers. In particular, an out-of-equilibrium analysis enables us to stress the importance of educational policies especially in the critical initial phase of the technological transition. In the U.S., counter-cyclical policy interventions such as student aids and investments in higher education were probably essential in the 70s to contrast the initial decrease of unskilled wages induced by the joint effect of the ICT revolution and of several adverse shocks, like the oil crisis.

Moreover, looking at the interaction between educational policies and labour market institutions, policy interventions appear important both in rigid and in flexible systems, but for different reasons. In the former case, educational policy speeds up skill formation and thereby allows the system to escape a low productivity final equilibrium. In the latter, educational policy reduces the high degree of economic turbulence which in flexible systems tends to characterize both the phase of the transition and the final attractor. Altogether, a moderate degree of rigidity seems the most appropriate institutional environment to reach the targets of viability and of a full exploitation of the technological potential.

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Appendix A

Range of parameters for the robustness analysis: the size of technological shocks measured as the input/output ratio varies between [1,1.4]; the degree of skill-biasness between [.99,1.84]; the degree of flexibility in labour markets between [.05,.82]; the degree of product market flexibility between [.1, .4]; the initial basic wage, given the unskilled wage, between [.16,.467]. In random experiments, all parameters are extracted from uniform distributions. Further information about the descriptive statistics of our samples are available upon request by the authors.

The benchmark values of the technological parameters for the single run simulations are: $a_s^c = 2.4965$; $a_s^u = 1.6644$; $a_u^c = 6$; $a_u^u = 4$; $\widetilde{a}_s^c = 1.07 \cdot a_s^c$; $\widetilde{a}_s^u = 1.6644$; $\widetilde{a}_u^c = 5.3$; $\widetilde{a}_u^u = 2.6$; $b = \widetilde{b} = 15$; $n_c = 2$, $n_u = 2$, where $\widetilde{\ }$ refers to the new values of the technological parameters. The productivity index is the ratio between input used and output sold. A case is defined as '*Unviable*' if the unemployment rate reaches the level of 0.4.

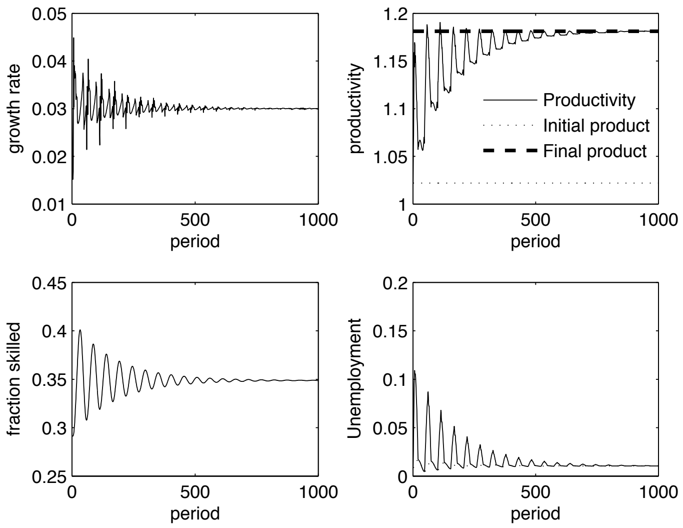

FIGURE 1. viable

Viability and Productivity	1. Viable Cases	2. Viable cases with a final prod. ratio>.95 on viable only	3. Viable cases with a final prod. ratio>.95 on all
Lm flex	%	%	%
[0.05, 0.11)	74.0%	5.7%	4.3%
[0.11, 0.24)	61.7%	23.1%	14.8%
[0.24, 0.43)	46.7%	65.4%	31.5%
[0.43, 0.63)	39.2%	88.1%	35.3%
[0.63, 0.75)	33.3%	94.0%	31.3%
[0.75, 0.82]	30.5%	75.4%	23.0%
all	46.7%	57.3%	26.7%

TABLE 1. Summary: viability and product.

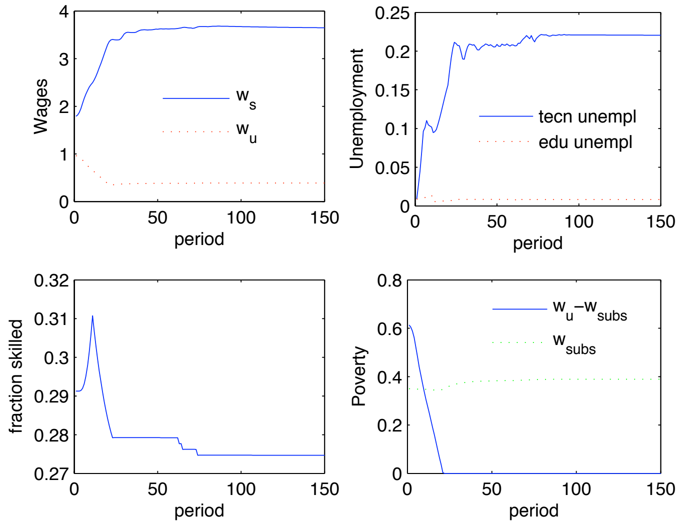

FIGURE 2. unviable

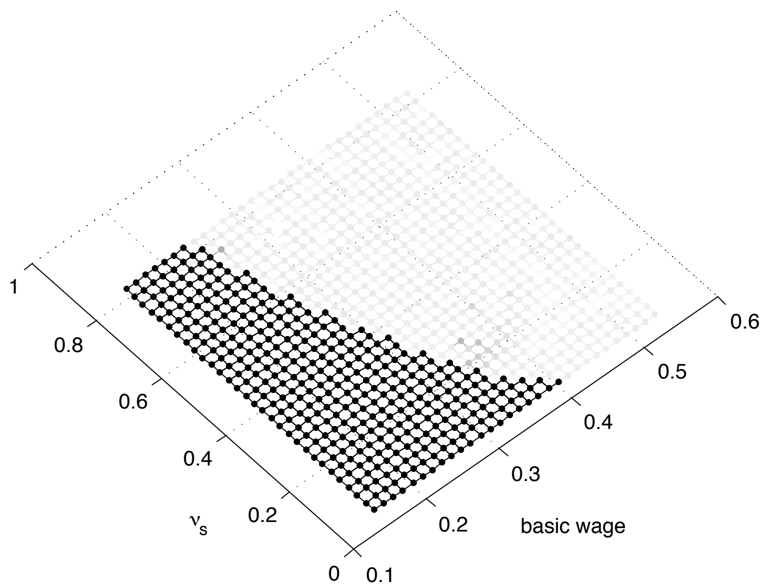

FIGURE 3. viable=dark points

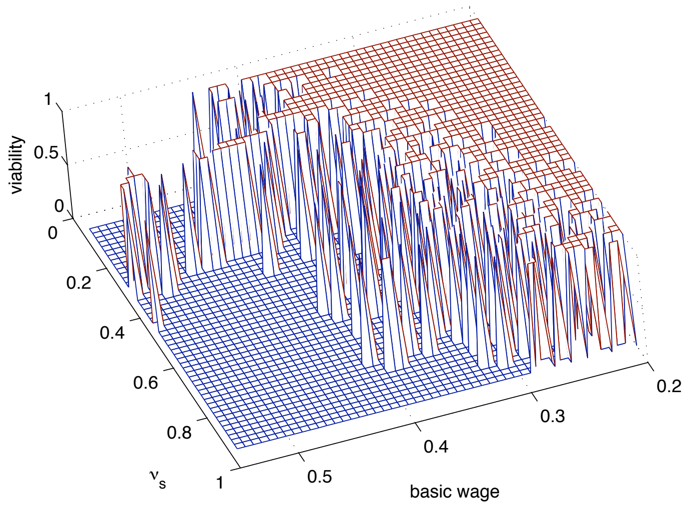

FIGURE 4. viable random shock

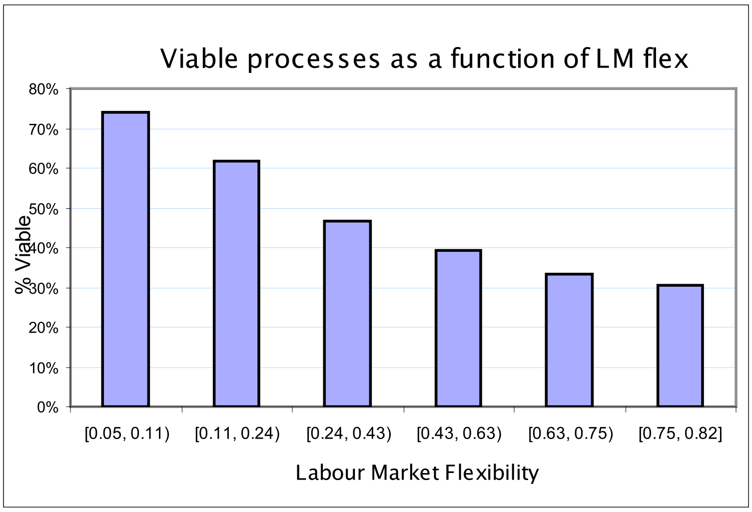

FIGURE 5. Viability and LM flex

Dependent Variable: Viable			
Probit Regression	Model 1	Model 2	Model3
wage bs	-1.344***	-3.891***	-4.866***
	(0.033)	(.181)	(.248)
pm flex	-0.051**	-0.169***	-0.200***
	(0.024)	(.041)	(.045)
lm flex	-0.639***	-1.842***	-2.348***
	(,027)	(.099)	(.133)
lm flex^2	0.160***	0.436***	0.869***
	(0.027)	(.051)	(.074)
tech shock	-0.446***	0.343***	0.382***
	(0.024)	(0.051)	(.058)
skill bias		-3.155***	-3.920***
		(.153)	(.207)
lm flex*wage bs			1.047***
			(.08)
constant	-0.326***	1.375***	-1.111***
	(0.036)	(0.01)	(.093)
obs	5000	5000	5000
Pseudo R2	0.481	0.831	0.863
Log pseudo lik.	-1792.4	-584.9	-472.3
Wald chi2	1813.47	517.55	420.17
* significant at 5%; ** at 1%; *** at 0.1%			
Robust standard errors in brackets			

Table 2. Determinants of Viability. Notation: bs= basic, pm and lm flex=product and labour market flexibility, tech shock= size of the shock, skill bias= degree of skill biasness.

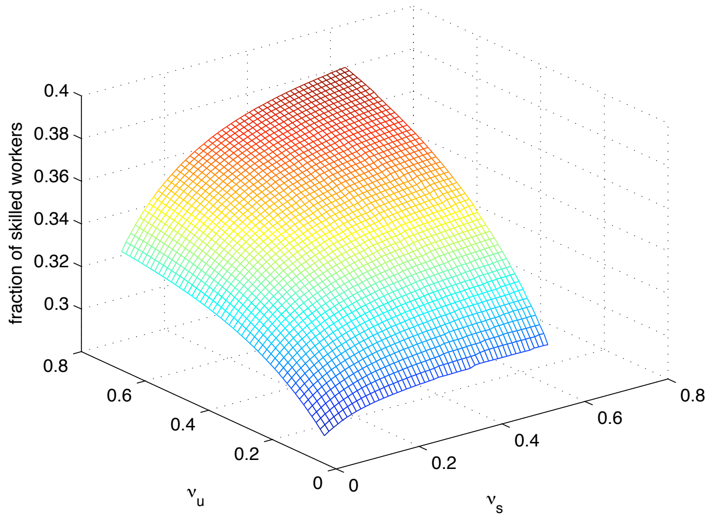

FIGURE 6. Fraction of skilled workers after 30 runs

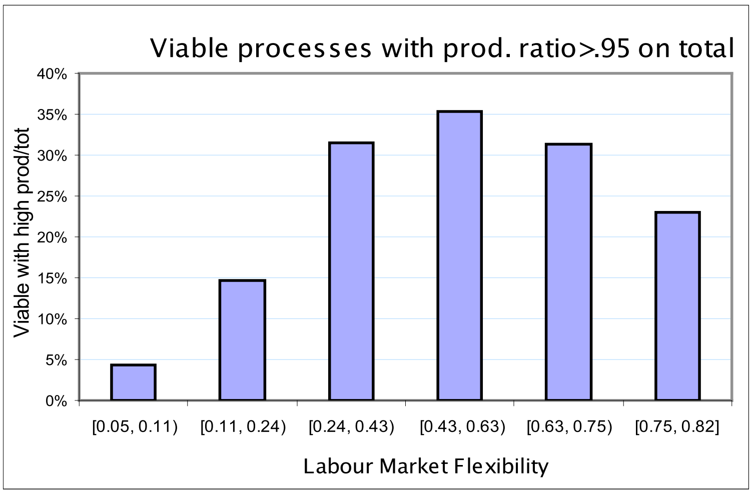

FIGURE 7. Viable cases with high final prod.

Dependent Variable: Final Productivity Ratio

only viable cases

quartile of lm flex	Rigid [.05,.24)	Moderately Rigid [.24, .44)	Moderately Flexible [.44, .64)	Flexible [.64, .83]	all
pm flex	0.172***	0.230***	0.097***	0.050***	0.149***
	(0.006)	(0.01)	(0.01)	(0.01)	(0.006)
lm flex	0.295***	0.189***	0.029*	-0.133***	0.125***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.003)
skill bias	0.066***	0.155***	0.052***	0.036***	0.066***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.006)
tech shock	-0.547***	-0.394***	-0.111***	-0.021	-0.333***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)
constant	1.375***	1.100***	1.009***	1.041***	1.167***
	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)
obs	913	561	471	383	2328
R-squared	0.85	0.72	0.27	0.16	0.61

* significant at 5%; ** significant at 1%; *** significant at 0.1%

Robust standard errors in brackets

TABLE 3. Determinants of productivity

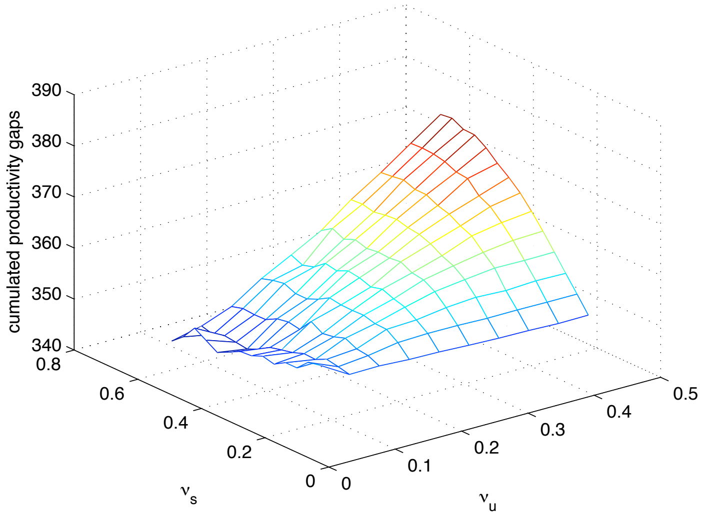

FIGURE 8. cumulated prod. if $\nu_p = .1$ after 400 runs

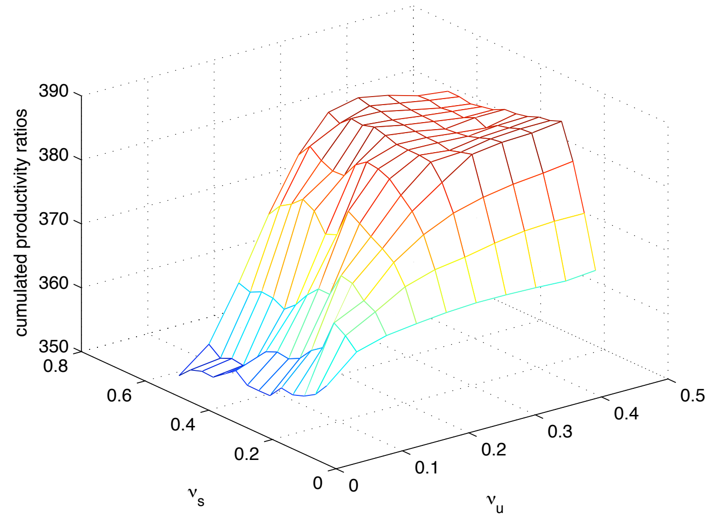

FIGURE 9. cumulated prod. if $\nu_p = .3$ after 400 runs

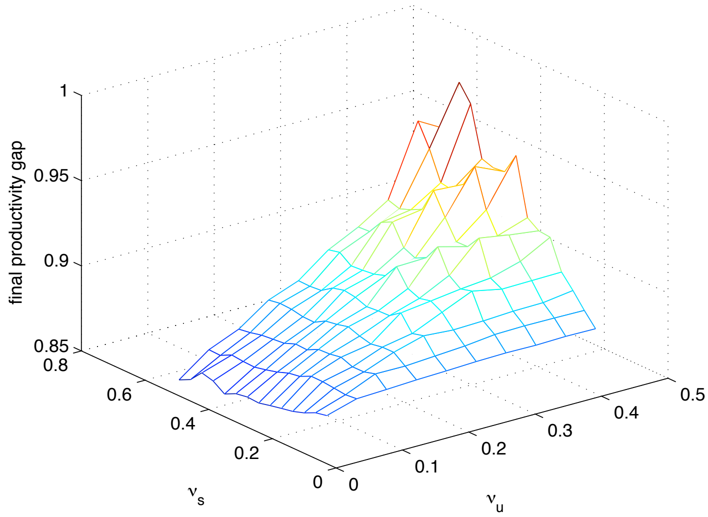

FIGURE 10. final prod. if $\nu_p = .1$ after 400 runs

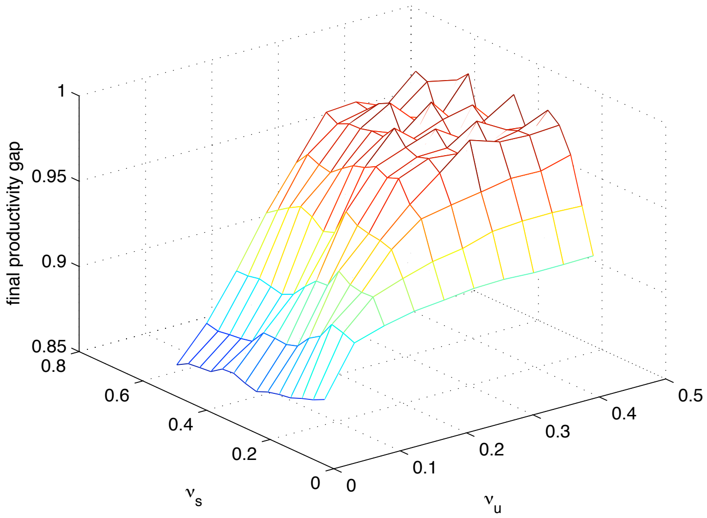

FIGURE 11. final prod. if $\nu_p = .3$ after 400 runs

Flex/Tax	tax							
flex	tax=0	<=0.1	(0.1,0.37]	(0.37,0.65]	(0.65,0.81]	(0.81,0.88]	>0.88	Total
<.12	0.0%	46.4%	68.1%	66.5%	53.7%	46.3%	56.1%	54.3%
[.12, 23)	0.0%	65.8%	64.6%	57.0%	43.1%	39.2%	33.3%	50.4%
[.23,.44)	0.0%	41.2%	62.0%	54.0%	45.3%	34.4%	32.0%	45.9%
[.44,.64)	0.0%	33.1%	56.0%	57.0%	46.5%	44.3%	39.5%	44.6%
[.64,.76)	0.0%	29.7%	56.0%	54.5%	58.6%	59.1%	54.8%	46.8%
[.76,.80)	0.0%	25.0%	54.0%	53.3%	54.9%	55.6%	55.6%	45.5%
[.80,.83)	0.0%	31.5%	53.3%	48.9%	50.0%	56.5%	47.8%	43.3%
Total	0.0%	37.3%	59.2%	55.1%	49.5%	46.0%	43.2%	46.4%
Obs. 10986, only initially unviable cases								

TABLE 4. Tax and LM flex, initially unviable

% Viable		
tax	all	unviable without the tax
0	50.5%	0.0%
<=0.1	60.0%	37.3%
(0.1,0.37]	76.8%	59.2%
(0.37,0.65]	74.6%	55.1%
(0.65,0.81]	70.4%	49.5%
(0.81,0.88]	67.8%	46.0%
>0.88	65.6%	43.2%
Obs.	22050	

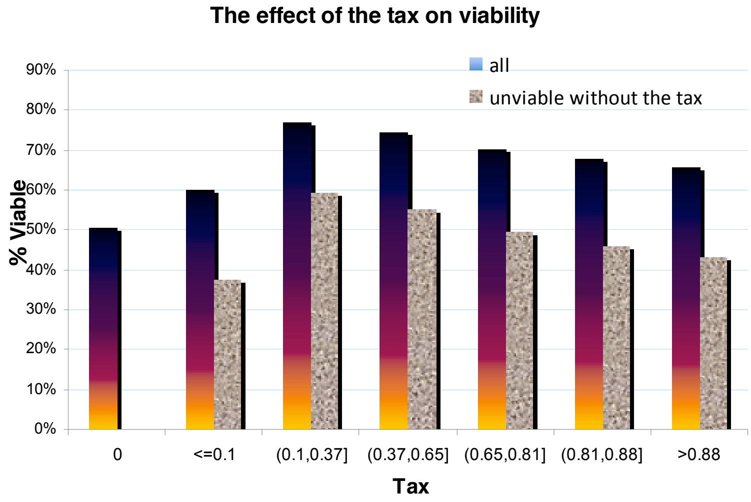

FIGURE 12. Viable as a function of the tax

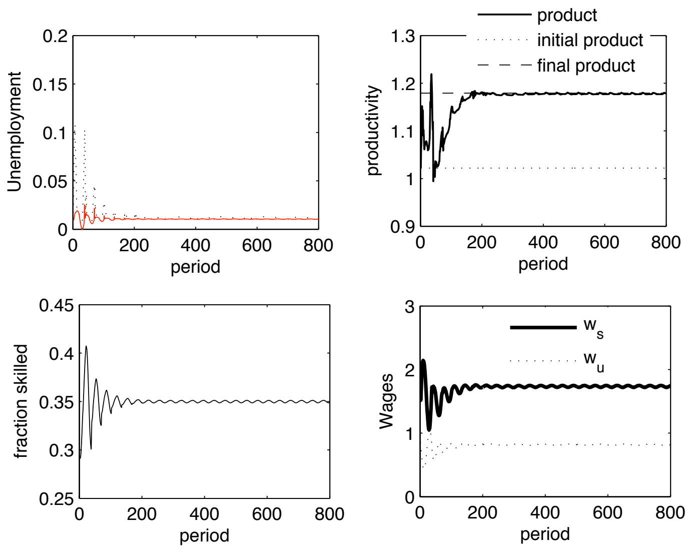

FIGURE 13. Example of dynamics in flex LM plus tax

Dependent Variable: Final Productivity Ratio					
only viable cases					
quartile of lm flex	Rigid [.05,.24)	Moderately Rigid [.24, .44)	Moderately Flexible [.44, .64)	Flexible [.64, .83]	all
tax	0.018***	0.121***	-0.004	-0.065***	0.024***
	(0.005)	(0.006)	(0.007)	(0.011)	(0.004)
tax^2	-0.059***	-0.132***	0.001	0.045***	-0.046***
	(0.005)	(0.006)	(0.008)	(0.012)	(0.005)
lm flex	0.256***	0.315***	-0.209***	-0.099***	0.083***
	(0.006)	(0.01)	(0.010)	(0.017)	(0.002)
skill bias	-0.036***	0.014***	0.074***	-0.022**	0.001
	(0.003)	(0.05)	(0.006)	(0.009)	(0.004)
tech shock	-0.379***	-0.126***	-0.036***	-0.011	-0.154***
	(0.007)	(0.01)	(0.011)	(0.019)	(0.008)
constant	1.356***	0.981***	1.031***	1.074***	1.089***
	(0.007)	(0.01)	(0.012)	(0.024)	(0.008)
obs	4704	3552	3640	3440	15336
R-squared	0.64	0.38	0.14	0.03	0.16

* significant at 5%; ** significant at 1%; *** significant at 0.1%
Robust standard errors in brackets

TABLE 5. Productivity and educational policy