The Conundrum of Recovery: Growth or Jobs?

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Elias Dinopoulos† University of Florida

Wolf-Heimo Grieben‡ University of Konstanz

Fuat Şener* Union College

Abstract: We analyze the growth, employment and welfare effects of labor market policies that governments design to fight unemployment, including the "tax cuts for new hires" bill of the Obama administration. We address these issues within a fully-endogenous Schumpeterian growth model with search unemployment, stochastic matching, and rent protection activities. The rates of vacancy creation and job destruction are endogenously determined. We find that tax cuts for new hires increase the rate of growth and the unemployment rate. Moreover, they most likely reduce welfare when systemic risk premia on financial markets are high, as was the case during the 2007-2009 financial crisis.

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† University of Florida, Department of Economics, Gainesville, FL 32611-7140, USA; e-mail: elias.dinopoulos@warrington.ufl.edu.

‡ Department of Economics, University of Konstanz, 78457 Konstanz, Germany; e-mail: heimo.grieben@uni-konstanz.de. Part of this work was done while Wolf-Heimo Grieben was visiting scholar at the economics department of Columbia University, New York, and Stockholm School of Economics. We thank them for their hospitality. This work was supported by a grant from the Ministry of Science, Research and the Arts of Baden-Württemberg, Germany (Az: 21-655.042-5-2/1) to Wolf-Heimo Grieben.

* **Corresponding Author**. Department of Economics, Union College, Schenectady, New York, 12308 USA; e-mail: senerm@union.edu; phone: (518) 388-7093; fax: (518) 388-6988.

1 Introduction

The recent financial and economic crisis raised once again the question of how governments can stimulate the creation of jobs (Blinder, 2009) and more generally whether or not they can identify and implement effective recovery policies. The OECD (2010, p. 12 and p. 73) reports, among other policies, on attempts to encourage private sector hiring through tax cuts for new job openings in the U.S., France, Ireland, Portugal, and Spain.[1] In a recent symposium on the financial crisis, Caballero (2010, p. 96) argues that given that crises seem to be inevitable ex-ante, macroeconomists should put more emphasis on finding appropriate policy responses.

Following the spirit of Caballero we investigate the effects of policy on growth and job creation. In particular, we address the following questions. What are the effects of policy instruments on involuntary unemployment and endogenous growth? Which policies univocally stimulate the rate of growth and reduce the unemployment rate? Which policies present trade-offs between job-creation and growth (recovery conundrum)? What are the welfare implications of these policies? What is the nature of welfare-maximizing policies?

We address these questions within a dynamic general-equilibrium model of Schumpeterian growth and search unemployment with the following main features.[2] First, growth is endogenously driven by the deliberate innovation efforts of entrepreneurial firms. Successful innovators have access to technologies with lower costs of production. The arrival of innovations is governed by a stochastic Poisson process and generates fully-endogenous growth of labor productivity and output. Each successful innovator enjoys temporary monopoly power and

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[1] See also BusinessWeek from 17 March 2010 on the $18 billion jobs bill of the Obama administration, available under http://www.businessweek.com/news/2010-03-17/legislation-offering-tax-cuts-for-new-hires-clears-congress.html.

[2] The term "Schumpeterian growth" refers to endogenous growth generated through the process of creative destruction as described by Schumpeter (1934).

profits which fuel investments in R&D and Rent-Protection Activities (RPAs) to be explained below.

Second, successful innovators face labor market frictions. They must go through a stochastic search process to find, organize, and train workers before they start producing at full capacity. This matching process between firms and workers involves the creation, maintenance, and management of costly (resource using) vacancies.[3] Firms optimally choose the amount of vacancies based on profit-maximization considerations. The arrival of job-matches follows a stochastic Poisson process. The endogenous arrival of new technologies coupled with search-based labor market frictions give rise to endogenous job creation and destruction.

Third, in our model incumbent firms undertake RPAs to discourage the innovation efforts of potential competitors and to prolong their tenure as monopolists. These activities comprise of expenditures on patent enforcement, trade secrecy, lobbying to influence the judicial and legislative system securing property rights etc.[4] In the present model, RPAs play two important roles: they remove the counterfactual scale-effect property from the model and result in fully-endogenous growth which responds to public policies;[5] and they can dilute, even reverse, the expansionary impact of job-creating policies on economic growth. In other words, a policy that reduces unemployment and channels more resources into investment might retard economic growth by stimulating RPAs more than R&D activities. Consequently, RPAs con-

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[3] Costly vacancy creation, stochastic matching, and inclusion of RPAs are three central features that differentiate our work from the earlier Schumpeterian unemployment-growth models such as Aghion and Howitt (1994), and Şener (2000, 2001). A stochastic matching rate implies that the matching time is not predictable, and costly vacancy creation implies that incentives for vacancy creation affect this matching time in equilibrium.

[4] RPAs have been introduced to the literature by Dinopoulos and Syropoulos (2007). The models of Grieben and Şener (2009), and Sener (2008) also adopt the RPA approach. See these papers and the references therein for detailed empirical evidence on RPAs.

[5] This distinguishes our paper from Aghion and Howitt (1994) that is still subject to the 'Jones critique' (see Jones 1995a,b, and Segerstrom 1998). Fully-endogenous growth models have recently received more empirical support than semi-endogenous growth models, see e.g. Ha and Howitt (2007), Madsen (2007, 2008), Ang and Madsen (2010). For arguments in favor semi-endogenous growth, see Jones (2005).

stitute one of the main ingredients of the recovery conundrum: jobless growth or stagnant job-creation.

Finally, the paper abstracts from modeling explicitly the nature and causes of financial frictions such as informational asymmetries in financial markets, credit constraints, housing-market bubbles, fiscal and monetary policies, etc. Here we follow a modeling shortcut by assuming the existence of an exogenous aggregate systemic risk that results from the possibility of defaults on returns from savings. This shortcut simplifies the analysis, sharpens the intuition of the main results, and increases the model's applicability to a variety of situations independently of the underlying financial frictions that generated them. We identify financial turmoil as an environment with substantial systemic risk. Using this setting, we analyze in a simple way the impact of the 2007-2009 financial crisis.

The model generates a unique steady-steady equilibrium which entails the simultaneous presence of involuntary, search-based, unemployment and Schumpeterian growth. In the steady state equilibrium each firm's expected life duration is finite and consists of three sequential distinct phases. During the R&D phase, the size of each firm is indeterminate, that is each firm is infinitesimally small. When the new process innovation is discovered, the firm becomes a young technology leader, captures an exogenous and small share of its market, and enters the vacancy-creation process: it advertises new positions, interviews prospective workers, develops distribution systems, trains and organizes its workers and its suppliers. This process is stochastic and once it is completed, the firm enters its "adult" phase. During its adult phase the firm captures the whole market, it is targeted by potential innovators, and it is engaged in RPAs to delay the emergence of a new technology leader. Finally, the firm enters its old or mature phase. During this phase, the firm becomes a technology follower competing against a technology leader. As an old firm, it still captures a large part of the market, it does not engage in any RPAs and waits to be replaced by the new technology leader. The duration of each sequential phase during the life-cycle of each firm is stochastic and endogenous.

The assumptions that there is a continuum of industries and that each technology leader is targeted by firms engaged in R&D only during its adult phase generate two types of industries in the economy, that we call type A and type B industries. Type A industries are populated with adult technology leaders that have captured the entire market and engaged in RPAs. These industries are targeted by prospective innovators. Type B industries are populated by young technology leaders and old technology followers. In each type B industry a young technology leader tries to replace an old technology follower by creating more jobs through costly vacancies and stochastic matching. In other words, type A industries are "growth-oriented" and engage in investment activities, whereas B type industries are "employment-oriented" and engage in vacancy creation. In other words, young / small firms create jobs in our model whereas old / mature firms destroy jobs.[6]

The model inherits several macroeconomic steady-state properties associated with fully-endogenous growth models: per-capita consumption expressed in units of labor, wages, markups, the rate of unemployment, and the rate of growth remain constant over time; manufacturing labor productivity, manufacturing output, and per capita consumption expressed in units of output all grow at the rate of endogenous growth; and the appropriately defined price index declines at the rate of Schumpeterian growth.

Despite the presence of labor-market frictions, the model does not exhibit transitional dynamics.[7] The main reason for this property is that there is "bulk" matching between firms and workers (as opposed to gradual one-to-one matching). The absence of transitional dynamics

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6 This prediction is consistent with a recent empirical study by Haltiwanger et al. (2010). They argue that firm age is more important than firm size in the process of job creation and destruction. Using U.S. data, they report that during 1992-2005 firm startups accounted for about 3 percent of employment but almost 20 percent of gross job creation. The fastest growing firms were young firms under the age of five. According to the study, large and mature firms (over 500 employees, more than 10 years old) employed about 45 percent of private-sector workers and accounted for only about 35 percent of job creation but about 40 percent of job destruction.

7 The absence of transitional dynamics is a common property of Schumpeterian growth models. See, for example, Grossman and Helpman (1991, chapter 4), and Dinopoulos and Syropoulos (2007) among others. We conjecture that introducing human and physical capital accumulation in the present model will generate transitional dynamics.

simplifies the welfare analysis and permits a short-run interpretation of the main results. We highlight this interpretation by assuming that the level of population is fixed. The absence of transitional dynamics implies that, unless corrective policies are implemented, a financial crisis can have permanent adverse effects on unemployment and growth. In other words, the model can generate permanent (as opposed to transitional) recessions.

In our model, policies affect employment through their impact on both the rate of Schumpeterian job destruction and the rate of vacancy creation.[8] The net effects of these policies on innovation and Schumpeterian growth depend on whether they stimulate R&D activities of entrepreneurs more than RPAs of incumbent firms. More specifically we analyze the effects of six policies: three job-creation policies consisting of a production subsidy for young technology leaders, a tax on (old firms) technology followers which is proportional to the number of workers fired and aims at employment protection, and a subsidy given to young technology leaders that reduces the cost of maintaining and posting of job vacancies; two pro-growth investment-related policies that take the form of a subsidy on R&D or a tax on RPAs; and changes in the systemic risk of default that can be traced to financial-market events and/or government policies.

The analysis generates several novel results. We find that policy instruments such as changes in the production subsidy offered to young firms residing in type B industries (equivalent to Obama's recent "tax cut for new hires"), changes in the R&D subsidy rate, changes in the tax on RPAs, or changes in the level of employment protection, all imply a tradeoff between growth and employment (Propositions 1 and 2). These policies constitute the *conundrum* of recovery. They generate a positive relationship between growth and unemployment: jobless growth or stagnant employment. Hence, when only one of these policy in-

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[8] On this account our paper complements the related work of Mortensen (2005) who assumes costless vacancy creation. This implies that firms do not choose optimally the number of job vacancies and hence Mortensen's model does not allow for policies to affect employment through a vacancy-creation mechanism.

struments is applied, the government misses either the employment or the growth objective. By implementing our model numerically, we find that for a wide range of plausible parameter values, the welfare-maximizing subsidy to young firms that offer new vacancies is negative (even more so when systemic risk in the financial market is high, like during the 2007-2009 financial crisis), and that the welfare-maximizing level of firing costs aiming at direct employment protection is zero.

We identify two recovery policies that univocally stimulate the rate of growth and reduce the rate of unemployment: a subsidy that reduces the cost of vacancy creation *ex-ante* (i.e. prior successful matching) rather than *ex-post* (i.e., after successful matching); and a reduction in the systemic risk which reduces the financial risk premium and the default rate. These policies results in no tradeoff between employment and growth objectives (Proposition 2).

Viewed through the lenses of current macroeconomic approaches, our model belongs to the class of *Neo-Schumpeterian macroeconomics*, because it combines fully-endogenous Schumpeterian growth and Schumpeterian unemployment. Both features are based on the process of creative destruction described in the writings of Joseph Schumpeter. As such it differs from real business cycle (RBC) models in several important aspects. First, instead of relying on neoclassical growth theory that features exogenous productivity shocks, our model incorporates fully-endogenous total factor productivity growth. Second, instead of generating voluntary unemployment through a leisure-work tradeoff as does the RBC approach to macroeconomics, our model generates involuntary state-of-the-art equilibrium search unemployment of the type advanced by the Diamond-Mortensen-Pissarides (DMP) literature. The Neo-Schumpeterian approach to macroeconomics differs from other current approaches to macroeconomics that belong to the "periphery", using Caballero's (2010) terminology. Unlike these approaches, which highlight the role of informational frictions but relies on a partial-equilibrium framework, we maintain a dynamic general-equilibrium perspective, temporary monopoly power, and the assumption of rational expectations, all of which are prominent features of endogenous growth theory.

The main elements of the growth component of the present model are borrowed from Dinopoulos and Syropoulos (2007). This study abstracts from unemployment considerations which constitute the main concerns of the present paper. In addition, we would like to highlight three main differences between the approach of the present paper to modeling search unemployment and the standard DMP literature. First, while the DMP literature relies on the neoclassical growth model and exogenous idiosyncratic shocks to generate labor turnover and unemployment, the present model employs an endogenous job-destruction mechanism that is linked to endogenous technological innovation. Second, instead of gradual worker-specific matches, we consider a stepwise matching process: a successful innovator immediately captures a small portion of the market and then goes through another step which involves bulk matching to drive the incumbent out of the entire market. Thus, unlike the studies of Aghion and Howitt (1994) and Mortensen (2005), in the present study the matching rate itself contributes to the endogenous job-destruction process. Third, unlike Mortensen (2005) or any other macro-labor study we are aware of, the present paper combines a matching-in-bulks feature with costly vacancy creation. This combination makes unnecessary the use of bargaining between each worker and firm. Therefore we can maintain the assumption of perfectly competitive labor markets, and the wage can be used as the numéraire in accordance with the endogenous growth theory.[9]

[9] In Mortensen (2005), the bargaining solution between each firm and each worker substitutes the firm's choice of profit-maximizing vacancies. Notice also that with matching in bulks, the individual applicant has no bargaining power. We consider this feature to be realistic since most unemployed workers are not organized in labor unions and thus coordination among job applicants does not occur in practice. Notice also that, as stated by Hall (2010, p.19), standard matching models with bargaining are inconsistent with the empirical finding that in economic downturns with high unemployment, the negotiated wage rate does not decline despite the obvious improvement in the employer's bargaining power.

The remainder of the paper is organized as follows. Section 2 describes the elements of the model. Section 3 derives the equilibrium conditions and implements our model numerically. Section 4 analyzes and intuitively discusses the employment and growth effects of several individual policies that are applied one at a time. Section 5 provides our welfare analysis. Section 6 concludes.

2 The Model

We incorporate job-matching frictions to an endogenous growth model with process innovations. The economy consists of a continuum of industries with measure one. In a certain fraction of industries, technology leaders with full monopoly power serve the market by employing low-skilled workers. These industries are targeted by outside entrepreneurs who compete in R&D races by employing high-skilled workers. The arrival rate of innovations is endogenously determined. The winner of the R&D race becomes the new technology leader and gains access to the technology of producing the same product with less resources. The new leader immediately captures a small share of the product market. The previous technology leader now becomes the technology follower. While the leader enjoys partial monopoly power, the follower firm supplies the remaining market. To capture the entire market the technology leader must create vacant positions and match them with low-skilled workers. Once the matching process is complete, the technology leader fully replaces the technology follower and thus realizes full monopoly power. The technology follower exits the market completely, and its low-skilled workers join the unemployment pool. This creative destruction process coupled with search frictions gives rise to Schumpeterian unemployment. Moreover, technology followers become the new entrepreneurs who again compete in R&D races. Hence, the fraction of industries that experiences innovation is also endogenously determined.

Technology leaders with full monopoly power are targeted by outside entrepreneurs and they invest in rent protection activities (RPAs) to safeguard their technology and prolong the duration of their monopoly power. These RPAs remove the scale effects property and generate fully-endogenous long-run growth.

Labor is the only factor of production. The labor force consists of low-skilled and high-skilled workers, with the proportion of the former given as $1 - s$ and that of the latter given as $s \in (0, 1)$. Low-skilled workers can be employed in manufacturing only, whereas high-skilled workers can be employed in either R&D or RPAs.[10]

2.1 Consumer Behavior

The economy consists of a continuum of identical and infinitely-lived households whose measure is equal to one. The size of each household is denoted by N and remains constant. Given the unit measure of household, the size of the aggregate population also equals N. [11] Each household member inelastically supplies one unit of labor per period. Therefore we exclude by assumption the work-leisure trade off which has been used routinely in the RBC literature to generate voluntary unemployment. The representative household maximizes the infinite horizon utility

$$H = \int_0^\infty e^{-\rho t} \log h(t) dt, \tag{1}$$

where $\rho > 0$ is the subjective discount rate. The subutility function *log* $h(t)$ is defined as

$$\log h(t) \equiv \int_0^1 \log y(\omega, t) d\omega, \tag{2}$$

where $y(\omega, t)$ is the per-capita demand for goods manufactured in industry ω at time t. The household's optimization can be viewed as a two-stage problem. The first is a static optimiza-

[10] By allowing for mobility of resources between R&D and RPAs, we endogenize the intensity of R&D activity and thus capture the essential feature of endogenous growth theory. This labor assignment is similar to Dinopoulos and Syropoulos (2007) and also Grieben and Şener (2009). The difference is that in these papers labor mobility between R&D and manufacturing is assumed, while the portion of labor devoted to RPAs is kept fixed. Here, we keep the portion of labor allocated to manufacturing fixed but allow for unemployment in this sector. This assignment provides an analytically tractable endogenous growth model with job-matching of low-skilled workers as discussed below.

[11] In an earlier version of the paper we allowed for positive population growth and showed that the main results and mechanisms remain intact. These calculations are available upon request.

tion problem in which each household allocates consumption expenditure to maximize $h(t)$ given product prices. Since goods enter the subutility function in a symmetric fashion, each household spreads its per-capita consumption expenditure $c(t)$ evenly across goods.[12] Thus, demand for each good equals

$$Y(t) = \frac{c(t)N}{P(t)}, \tag{3}$$

where $Y(t) = y(t)N$, and $P(t)$ is the market price of the purchased good at time t. From now, we drop the time index t where appropriate.

The second stage involves a dynamic optimization problem in which each household chooses the evolution of c over time. Substituting (2) into (1) and using Y from (3), one can simplify the household's dynamic problem to maximizing

$$\int_0^\infty e^{-\rho t} \log c \, dt$$

subject to the budget constraint $\dot{A} = W + (r - \chi)A - cN$, where A denotes the asset holdings of the household, and W is the household's expected wage income. r is the rate of return obtained from a diversified asset portfolio that allows the investor to avoid idiosyncratic firm-level risk. That portfolio is still subject to systemic risk at the aggregate level. This is captured by the risk premium term $\chi \geq 0$, which implies a depreciation of the household assets by χ percent. That is, in normal times $\chi = 0$. In crisis times, households expect a default on χ percent of all financial investments, without being able to identify risky investments ex-ante.[13] This implies that the systemic-risk-adjusted rate of return on a fully diversified (idiosyncratic-

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[12] Each household consists of a large number of members who engage in income transfers such that each member enjoys the same level of consumption regardless of individual earnings. This implies the absence of effective uncertainty in individuals' income and consumption emanating from idiosyncratic firm-level risk.

[13] We include this risk premium as a convenient shortcut to capture the perceived risk of financial intermediaries going bankrupt, without explicitly modeling such institutions and money in our setting. We then examine the effects of a financial crisis by considering an increase in the risk premium χ. Note that it is not required that default on investments actually happens – the mere expectation of it suffices to produce a positive risk premium, reflecting mistrust that Akerlof and Shiller (2009) have identified as one of the main causes of economic depressions.

risk-free) portfolio is $r - \chi$. The solution of the dynamic optimization problem gives the Keynes-Ramsey rule, amended by the risk premium,

$$\frac{\dot{c}}{c} = r - \chi - \rho \,. \tag{4}$$

Since the labor supply per worker and the wage rate will be constant in the steady state, equation (4) implies a constant per-capita consumption expenditure[14] and $r = \rho + \chi$ in equilibrium. Hence, the return on the fully-diversified portfolio r must now compensate for the systemic risk faced by households. This raises r beyond the time preference rate ρ when $\chi > 0$.

2.2 Creative Destruction Cycle and Matching

The economy consists of a continuum of structurally identical industries indexed by $\omega \in [0, 1]$. In each industry, production technology improves through stochastic arrival of process innovations. Production of goods is characterized by constant returns to scale. Every time a process innovation arrives, the unit labor requirement in production is divided by a constant parameter $\lambda > 1$. We assume that there are frictions in the low-skilled labor market such that producer firms and low-skilled workers must go through a time-consuming search process before forming job matches. We assume that high-skilled workers can find employment instantly without going through a job-matching process. Hence only low-skilled workers are subject to turnover and face the consequence of unemployment.[15]

Let I denote the endogenous and stochastic (Poisson) arrival rate of process innovations in a given industry. Let $m \in (0, \infty)$ denote the number of process innovations observed in a

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[14] Nevertheless, the price index $P(t)$ declines over time whenever innovation takes place as will be shown later.

[15] This is a commonly used assumption in the literature. See, among others, the dynamic growth settings of Şener (2001, 2006) and the static model of Davis (1998) in which the authors also differentiate between high-skilled and low-skilled labor and assume that only low-skilled labor is subject to unemployment. This assumption captures in a simple way the well-established unemployment differential between high-skilled and low-skilled workers (see e.g. Nickell and Bell, 1995 and 1996, for descriptive evidence on seven major OECD countries) without foregoing analytical tractability. Moreover, since vacancy creation is costly, it will later turn out that the assumption of costly high-skilled labor matching would conflict with free entry of R&D firms which implies zero expected profits from doing R&D in equilibrium.

given industry between time t_0 and t. Consider an industry at time t in which a *technology leader* who has access to the m^{th} technology supplies the entire market as a *full monopoly*. Entrepreneurs target their innovation efforts at this industry. Innovation success implies that a new technology leader emerges with access to the $(m+1)^{\text{th}}$ technology. The new leader firm has an average cost that is λ times *lower* than the existing monopolist.

To start production, the new leader must first match with production workers. We assume that following innovation success, the leader can immediately hire a small amount of workers without engaging in costly search. In this way, it captures a fraction $\phi \in]0, 1[$ of the consumer demand and thereby establishes *partial monopoly* in the market. This forces the follower to lay off a corresponding amount of workers.[16] To capture the rest of the market the leader must engage in costly search by posting or advertising vacant positions. While the leader firm is engaged in search, the follower continues to supply a fraction $1 - \phi$ of the market.[17] Once the leader becomes successful in job-matching, the follower exits the market, and all of its remaining workers join the unemployment pool. Further innovation in the industry triggers again the above creative-destruction cycle. Hence, at any point in time, technology leaders with partial monopoly power seek to fill their vacant positions and unemployed workers aim to match with vacant positions.

Let V represent the level of economy-wide vacancies and U stand for the level of economy-wide unemployment. In the spirit of the labor search literature, we assume that the arrival of successful job matches follows a stochastic process whose intensity is given by the matching function $M(U, V)$. The matching function is concave, homogenous of degree one and increasing in its both arguments.

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[16] One can view this as the technology leader instantaneously hiring a share ϕ of the existing full monopolist's workers. For these workers, switching to the technology leader makes sense because they can escape the impending unemployment risk.

[17] This step-wise replacement mechanism is in the spirit of Dinopoulos and Waldo (2005, pp. 141-142) where a successful innovator instantaneously captures a small share of the market and then consumers gradually switch from the previous-generation product to the state-of-the-art quality product.

Let $\theta = V/U$ denote a measure that captures the tightness of the labor market. Dividing $M(U, V)$ by V yields the matching rate of vacancies $q(\theta) = M(U/V, 1) = M(1/\theta, 1)$. Similarly, dividing $M(U, V)$ by U yields the job-finding rate of unemployed workers $p(\theta) = M(1, V/U) = M(1,\theta)$. Note that $q(\theta)$ and $p(\theta)$ are stochastic Poisson arrival rates, unlike the corresponding deterministic rates in Aghion and Howitt (1994), hence we have stochastic matching.[18] It follows that the expected length of an unemployment spell is $1/p(\theta)$. Observe that $\partial q(\theta)/\partial\theta < 0$, that is, as the level of vacancies per unemployed worker increases, it becomes more difficult for firms to fill their vacant positions. On the other hand $\partial p(\theta)/\partial\theta > 0$, that is, as the level of vacancies per unemployed worker increases, unemployed workers can find jobs more easily. The transition rates $p(\theta)$ and $q(\theta)$ satisfy $p(\theta)U = q(\theta)V = M(U, V)$.[19] This matching scheme implies that the vacant positions of searching firms are matched at the rate of $q(\theta)$.

2.3 Industrial Structure

We assume that in each industry the next-generation technology $m+1$ can be targeted for innovation only after the entire market demand is satisfied with the latest available technology m. This implies that at each point in time, there are two possible industry configurations which we refer to as type A and type B industries. In type A industries, there is a technology leader with full monopoly power that can use the m^{th} technology serving the entire market, and entrepreneur firms target their R&D at the $(m + 1)^{\text{th}}$ technology. In Type B industries, there is a technology follower with the m^{th} technology serving a fraction $1 - \phi$ of the market, and a new technology leader with the $(m + 1)^{\text{th}}$ technology, serving a fraction ϕ of the market

[18] See Pissarides (2000, chapter 6) and Aghion and Howitt (1998, section 4.5) for alternative stochastic matching models, where it is also the case that not all contacts between workers and open vacancies lead to successful matches.

[19] Further, the matching function has the following properties: $M(0, V) = M(U, 0) = 0$, $\lim_{x\to 0} \partial M/\partial x = +\infty$, and $\lim_{x\to\infty} \partial M/\partial x = 0$, $x \in \{U, V\}$.

and thereby exerting partial monopoly power. At the same time the new technology leader is searching workers to drive the technology follower completely out of business.[20]

Let n_A and $n_B = 1 - n_A$ represent the fraction of type A and type B industries, respectively. Since the arrival rate of innovations is I, a typical type A industry switches to industry type B with instantaneous probability Idt. Therefore, the expected flow of industries from type A into type B is $n_A Idt$. Consider then a typical industry B. If a new technology leader successfully completes its hiring process, then this type B industry switches to a type A industry. Since the probability of this event is $q(\theta)dt$, the flow of industries from type B into type A is $(1-n_A)q(\theta)dt$. Consequently, the net flow of industries into the A sector is $dn_A = (1-n_A)q(\theta)dt - n_A Idt$, which implies

$$\dot{n}_A = q(\theta)(1-n_A) - In_A . \tag{5}$$

Figure 1 below illustrates the resulting industry configuration.

Insert here: Figure 1 (Industrial Structure)

2.4 Product Markets

Consider a technology leader firm in a type A industry that has access to the state-of-the-art m^{th} technology and has completed its matching process. For this firm, the marginal (and average) cost of manufacturing per unit of final goods is $\frac{\kappa}{\lambda^m} w_L$, where $\kappa > 0$ is a constant labor productivity parameter which we henceforth normalize to one without loss of generality. The parameter $\lambda > 1$ measures the size of process innovations, and w_L is the wage rate of low-skilled labor. Hence $1/\lambda^m$ measures the amount of low-skilled labor required per unit of output.

[20] Since the $(m+1)^{\text{th}}$ technology is not yet fully implemented for production, there are no entrepreneurs that can be hit by the $(m+2)^{\text{th}}$ technology.

The leader firm competes with a follower that is one step down in the technology ladder, i.e. which produces with the $(m-1)^{\text{th}}$ technology and has a unit cost of $\frac{1}{\lambda^{m-1}}w_L$. The leader can use this cost advantage to engage in limit pricing and sustain monopoly power in the market. More specifically, the leader can charge a price $P(t)$ that is slightly below the marginal cost of the follower, $\frac{1}{\lambda^{m-1}}w_L - \varepsilon$, where ε is an infinitesimal positive amount. The follower can at best price at marginal cost; however, this does not suffice to generate a positive demand for the follower's product. In equilibrium, the leader charges $P(t) = \frac{1}{\lambda^{m-1}}w_L$, has a unit cost of $\frac{1}{\lambda^{m}}w_L$ and faces the entire market demand $cN/P(t)$. Note that real per-capital expenditure $c/P(t)$ increases in the steady-state equilibrium as new process innovations materialize and cause a decline in $P(t)$. Thus, in a type A industry, the monopoly profits of the leader firm from product sales are:

$$\pi^A = \frac{cN}{w_L/\lambda^{m-1}}\left[\frac{w_L}{\lambda^{m-1}} - \frac{w_L}{\lambda^m}\right] = \frac{cN(\lambda-1)}{\lambda}. \tag{6}$$

The producer's demand for manufacturing labor equals [21]

$$Z \equiv \frac{cN}{\lambda w_L}. \tag{7}$$

Hence, the incumbent's profit flow and labor demand are independent of m, the number of cumulative innovations used for production at time t, but dependent on λ, the marginal technological difference between the monopolist and the follower.

While the type A industry quality leader earns monopoly profits, it simultaneously invests in RPAs of level X. For this purpose, the incumbent hires high-skilled labor at a wage rate of w_H. The cost of performing X units of RPAs is $w_H\gamma X$, where γ is the unit labor requirement of

[21] To calculate labor demand, multiply total production $cN/P(t)$ with the unit labor requirement $1/\lambda^m$, where $P(t) = w_L/\lambda^{m-1}$.

such activities. Hence, the type A industry leader's profit flows net of rent protection costs equal:

$$\pi_{net}^{A} = \pi^{A} - w_H \gamma X \ . \tag{8}$$

Consider now a transformation of the type A industry to type B industry through successful innovation. In this industry, there are two producing firms: the technology leader (innovator) who supplies a portion ϕ of the market and the follower (previous leader) who supplies the remaining portion $1 - \phi$. The profit flows of the leader and the follower are then equal to $\phi\pi^B$ and $(1- \phi)\pi^A$, respectively. In order to determine π^B, note that in type B industries, the technology leader with $(m+1)^{\text{th}}$ technology competes with the previous leader who has access to the m^{th} technology. Thus, the leader can charge a price $P(t)$ that is slightly below the marginal cost of the follower $\frac{w_L}{\lambda^m} - \varepsilon$, where $\varepsilon \to 0$. The follower can at best price at marginal cost; however, this does not suffice to generate a positive demand for the follower's product. In equilibrium, the leader charges $P(t) = \frac{w_L}{\lambda^m}$, faces a market demand $\phi cN/P(t)$, and has a unit cost of $\frac{w_L}{\lambda^{m+1}}\left(1-\sigma_L^B\right)$, where $0 < \sigma_L^B < 1$ ($\sigma_L^B < 0$) is the type B leader firm's production subsidy (tax) rate. This firm does not invest in RPAs since its technology is not (yet) targeted by entrepreneurs. Thus, in a type B industry, the monopoly profits of the technology leader with $(m+1)^{\text{th}}$ technology are:

$$\phi\pi^{B}(t) = \phi \frac{cN}{w_L/\lambda^m}\left[\frac{w_L}{\lambda^m} - \frac{w_L}{\lambda^{m+1}}(1-\sigma_L^B)\right] = \frac{\phi cN\left[\lambda-(1-\sigma_L^B)\right]}{\lambda} . \tag{9}$$

Note that $\pi^A = \pi^B$ for $\sigma_L^B = 0$.

In type B industries, the technology follower with the m^{th} technology can still retain its profit flows in a portion $(1-\phi)$ of the market due to incomplete matching by the new technology leader. In this portion of the market, the technology follower competes with another follower who has access to the $(m-1)^{\text{th}}$ technology. The pricing and profit flow derivations follow the same steps as before. Thus, the technology follower earns $(1-\phi)\pi^A$ as profit flows.

2.5 Innovation

There are sequential and stochastic R&D races in type A industries to discover the next generation process innovation. The instantaneous probability of success (Poisson arrival rate) I_j by firm j is given by

$$I_j = \frac{R_j}{D} \qquad \text{with} \qquad D = \delta X \ , \tag{10}$$

where R_j represents the innovation intensity of a typical entrepreneur j, and D measures the difficulty of conducting R&D. We model R&D difficulty D as a flow variable, where X is the level of RPAs undertaken by the technology leader in a type A industry, and δ measures the effectiveness of these RPAs.

Since the I_j's are independently distributed across firms and industries, the Poisson arrival rate for innovation at the industry level equals

$$I = \sum_j I_j = \frac{R}{D} \qquad \text{with} \qquad R = \sum_j R_j \ . \tag{11}$$

2.6 Stock Markets

There exists a stock market that channels households' savings to firms. Let V_{RD} represent the value of an entrepreneur firm engaged in R&D. Let V_L^B represent the value of a technology leader producing in a type B industry and simultaneously searching workers.

Consider now the determination of V_{RD}. Over a small time interval dt, with probability $I_j dt$, the entrepreneur firm successfully innovates and realizes a gain equal to $V_L^B - V_{RD}$, which requires R&D expenditure $w_H(1-\sigma_R)\beta R_j$, where $0 < \sigma_R < 1$ ($\sigma_R < 0$) is the R&D subsidy (tax) rate, and $\beta > 0$ is the unit labor requirement of R&D. With probability $(1 - I_j dt)$, success does not materialize, and the stockholders realize a change in valuation given by $\dot{V}_{RD}$. In the absence of stock market arbitrage opportunities, the expected rate of return generated by the entrepreneur must be equal to the systemic-risk-adjusted rate of return on a fully diversified (idiosyncratic-risk-free) portfolio, $r - \chi$:

$$I_j dt\left[V_L^B - V_{RD}\right] - w_H\left(1-\sigma_R\right)\beta R_j dt + (1 - I_j dt)\dot{V}_{RD} dt - \chi V_{RD} dt = \left(r-\chi\right)V_{RD} dt \;. \quad (12)$$

Free-entry in R&D drives the value of the entrepreneur V_{RD} down to zero. Taking limits as $dt \to 0$ and using (10), this yields

$$V_L^B = \beta\delta w_H\left(1-\sigma_R\right)X \;. \quad (13)$$

Consider now the valuation condition for a technology leader in a type B industry that has access to the $(m+1)^{th}$ technology. This firm supplies a fraction ϕ of the market by employing ϕZ units of labor and realizes the profit flow $\phi\pi^B$. At the same time it maintains $(1-\phi)Z$ vacant positions to capture the entire market as a type A producer. Denote with $\alpha > 0$ the cost of maintaining one unit of vacancy per unit of time.[22] Thus, over a short interval of time, the total cost of holding vacancies equals $\alpha(1-\phi)Zdt$. By incurring this cost, the searching firm has a matching probability of $q(\theta)dt$. If successful matching takes place, all of the vacant positions of the firm are filled. The technology leader in a type B industry then becomes the technology leader with full monopoly power in a type A industry, and the stockholders realize a capital *gain* of $V^A - V_L^B > 0$. With probability $[1 - q(\theta)dt]$, no matching occurs in the industry, in which case the stockholders realize a change in valuation given by $\dot{V}_L^B$. In the absence of stock market arbitrage opportunities, the expected rate of return generated by a type B technology leader must be equal to $r - \chi$:

$$\phi\pi^B dt + q\left(\theta\right)\left(V^A - V_L^B\right)dt - \alpha\left(1-\phi\right)Zdt + \left[1-q\left(\theta\right)dt\right]\dot{V}_L^B dt - \chi V_L^B dt = \left(r-\chi\right)V_L^B dt \;. \quad (14)$$

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[22] We model vacancy maintenance cost as a fixed cost following the standard search unemployment literature. Alternatively, in a general equilibrium spirit, one can assume that firms must employ labor to maintain vacancies. But then one must assume that such labor be matched with the searching firm instantly, a mechanism which will essentially resurrect the fixed vacancy cost assumption.

Taking limits as $dt \to 0$ yields

$$V_L^B = \frac{\phi\pi^B + q(\theta)V^A - \alpha(1-\phi)Z}{q(\theta) + r - \dot{V}_L^B / V_L^B}. \tag{15}$$

Consider now the valuation of a monopolist producer in a type A industry V^A. Over a small time interval dt, its stockholders receive the net profit flow $\pi_{net}^A dt = (\pi^A - w_H\gamma X)dt$ as dividends. With probability Idt, further process innovation takes place in the industry. In this event, the monopolist becomes the follower producer in the type B industry with the valuation V_F^B. The stockholders of the monopolist experience a capital *loss* of $V^A - V_F^B > 0$. In addition, the monopolist has to lay off ϕZ manufacturing workers, for each of whom a firing cost $f > 0$ has to be paid. With probability $(1 - Idt)$, no further innovation occurs in the industry, in which case the stockholders realize a change in valuation given by $\dot{V}^A$. In the absence of stock market arbitrage opportunities, the expected rate of return generated by the monopolist in a type A industry must be equal to $r - \chi$:

$$\left(\pi^A - w_H\gamma X\right)dt - I\left(V^A - V_F^B + f\phi Z\right)dt + \left(1 - Idt\right)\dot{V}^A dt - \chi V^A dt = \left(r - \chi\right)V^A dt. \tag{16}$$

Taking limits as $dt \to 0$ yields

$$V^A = \frac{I\left(V_F^B - f\phi Z\right) + \pi^A - w_H\gamma X}{I + r - \dot{V}^A / V^A}. \tag{17}$$

Consider finally the valuation of a follower producer in a type B industry V_F^B. Over a short time interval dt, the stockholders of the follower receive $(1-\phi)\pi^A dt$ as dividend payments. With probability $q(\theta)dt$, the technology leader becomes successful in matching and forces the follower out of the market. In this event, the stockholders of the follower experience a capital *loss* of V_F^B. In addition, the follower firm has to lay off the remaining $(1-\phi)Z$ manufacturing workers and pay a firing cost f for each of these. With probability $1-q(\theta)dt$, no matching occurs in the industry, in which case the stockholders realize a change in valuation given by $\dot{V}_F^B$.

In the absence of stock market arbitrage opportunities, the expected rate of return generated by the technology follower must be equal to $r-\chi$:

$$\left(1-\phi\right)\pi^{A}dt-q(\theta)\left[V_{F}^{B}+f\left(1-\phi\right)Z\right]dt+\left[1-q(\theta)dt\right]\dot{V}_{F}^{B}dt-\chi V_{F}^{B}dt=\left(r-\chi\right)V_{F}^{B}dt\,. \quad (18)$$

Taking limits as $dt \to 0$ yields

$$V_{F}^{B}=\frac{\left(1-\phi\right)\left[\pi^{A}-fq\left(\theta\right)Z\right]}{q(\theta)+r-\dot{V}_{F}^{B}/V_{F}^{B}}\,. \quad (19)$$

2.7 Job Vacancies

In type B industries technology leaders hold vacancies in order to attract workers. To engage in search, a technology leader pays a vacancy maintenance cost of $\alpha(1-\phi)Z$, where α is a vacancy-cost parameter and $(1-\phi)Z$ is the additional vacancies needed if the firm completely takes over the market. Note that the market size Z is endogenous, such that the number of vacancies created per firm $(1-\phi)Z$ will respond to changes in vacancy creation incentives. By bearing the vacancy costs, the firm faces a probability $q(\theta)$ of being successfully matched, in which case the firm is transformed from being a leader in type B industry to being a leader in a type A industry with full monopoly power. This implies a realization of the additional return $V^{A}-V_{L}^{B}$. In general equilibrium, when *all* leader firms in type B industries engage in costly search, profit opportunities from vacancy creation must be fully exploited; thus, the vacancy creation (VC) condition is

$$q(\theta)\left(V^{A}-V_{L}^{B}\right)=\alpha(1-\phi)Z \qquad \textbf{VC}, \quad (20)$$

where the LHS is the expected returns from searching and the RHS is the costs of vacancy maintenance. This knife-edge condition is later used to pin down the labor market tightness $\theta \equiv v/u$ in equilibrium.

2.8 Optimal Rent Protection Activities

Monopolist firms in type A industries who face the threat of innovation undertake RPAs X to prolong their incumbency. They optimally choose X at each point in time to maximize the LHS of (16), the expected returns from their stocks. Using (11) and (10), we note that $I(X) = R/(\delta X)$ Setting the derivative of the LHS of (16) with respect to X to zero, using $dI(X)/dX = -I/X < 0$ and taking limits as $dt \to 0$, we derive the optimal *RPA condition* as:

$$w_H \gamma X = I\left(V^A - V_F^B + f\phi Z\right) \qquad \textbf{RPA}, \tag{21}$$

which implies that the expenditure on RPAs increases with the threat of innovation, I, and the capital loss incurred in case successful innovation materializes, $V^A - V_F^B + f\phi Z$.

2.9 Labor Markets

In this model, low-skilled workers can be in two possible states: employed or unemployed. In type B industries, every time a technology leader becomes successful in matching, the follower firm exits the market and lays off its low-skilled workers. The fraction of industries that experience replacement is $q(\theta)(1-n_A)$. In each type B industry, the amount of workers employed by the follower is $(1-\phi)Z$. Thus, the flow of workers into the unemployment pool due to firm replacement during a small time period dt equals $q(\theta)(1-n_A)(1-\phi)Zdt$.[23] The flow of workers out of the unemployment pool during dt is driven by successful job finding of unemployed workers, which equals $p(\theta)Udt$. Consequently, the equation of motion for the level of unemployment U is given by

$$\dot{U} = q(\theta)(1-n_A)(1-\phi)Z - p(\theta)U\ .^{24} \tag{22}$$

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[23] It should be noted that there are additional flows into and out of unemployment that exactly cancel out. In type A industries, with instantaneous probability I, an entrepreneur successfully innovates and the incumbent monopolist loses a fraction ϕ of the market and lays off ϕZ units of labor. This creates an inflow into the unemployment pool of size $In_A\phi Z$. However, this is exactly nullified by the instantaneous hiring of the same size by successful entrepreneurs in type A industries.

[24] Note that the equation of motion for V is the same as (22). In a fraction n_A of industries with probability I, new firms create new vacancies in some amount V^{new}. Given the total matching at each point in time as $pU = qV$, it follows that $\dot{V} = In_A V^{NEW} - qV$. Imposing $\dot{V} = 0$ for the steady state gives $V^{NEW} = qV/(In_A)$. Substituting into this expression the stock of vacancies V from equation (23)

At each point in time, technology leaders in type B industries maintain vacant positions to hire workers. The fraction of such industries is equal to $1 - n_A$, and in each industry the level of vacant positions is equal to the expected labor demand $(1-\phi)Z$. Thus, the economy-wide vacancy rate defined with respect to low-skilled workers $v \equiv V/[(1-s)N]$ equals

$$v = \frac{(1-n_A)(1-\phi)Z}{(1-s)N}. \tag{23}$$

In the labor markets, supply must equal demand for labor in equilibrium. For low-skilled and high-skilled labor, this implies, respectively:

$$(1-u)(1-s)N = Z\left[n_A + (1-n_A)\phi + (1-n_A)(1-\phi)\right] = Z, \tag{24}$$

$$sN = n_A(\gamma X + \beta R), \tag{25}$$

where $u \equiv U/[(1-s)N]$ is the unemployment rate of low-skilled workers. Note from (25), together with $R = I\delta X$ from (11) and (10), that the high-skilled labor demand ratio of R&D relative to RPAs is equal to BI with $B \equiv \beta\delta/\gamma$. Hence, given fixed high-skilled labor supply sN, an increase in the innovation rate I implies that R&D labor input goes up while RPA labor input goes down.

Substituting for Z from (24) into (22) and using the definitions of u and v, we obtain the equation of motion for the low-skilled unemployment rate u as

$$\dot{u} = q(\theta)(1-n_A)(1-\phi)(1-u) - p(\theta)u, \tag{26}$$

where $q(\theta)(1-n_A)(1-\phi)$ is the economy-wide *job-destruction rate*, and $p(\theta)u$ is the economy-wide *job-finding rate* in our model. From (26), using (23) to substitute V/Z for $(1-n_A)(1-\phi)$, $V = v(1-s)N$, (24) to substitute for Z, and the matching function identity condition $p(\theta)u = q(\theta)v$, we get $\dot{u} = 0$, which holds both in and out of the steady-state equilibrium. Thus in this model with perfect foresight in matching, there are no transitional dynamics for unemployment.

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and noting $(1-n_A)/n_A = I/q$ from $\dot{n}_A = 0$ in (5), we obtain $V^{NEW} = (1-\phi)Z$, and thus $\dot{V} = In_A(1-\phi)Z - pU$. Using $In_A = (1-n_A)q$, this boils down to (22), which completes the proof of the claim.

3 Steady-State Equilibrium

We normalize the low-skilled wage rate to one, $w_L \equiv 1$.[25] In the Referees' Appendix R.2 (available upon request) we show that the economy immediately jumps to the steady-state equilibrium and does not exhibit transitional dynamics.[26] At the steady-state equilibrium, the endogenous variables of the model w_H, u, v, n_A, c, V^A, V_L^B, V_F^B, π^A, π^B, and X remain constant. With c constant, it follows from equation (4) that $r = \rho + \chi$. We henceforth denote the steady-state values by *.

As is demonstrated in Appendix A, the steady-state equilibrium is characterized by the following three equations (see the Appendix B for existence and uniqueness proof):

$$q(\theta) = \frac{\alpha(\rho+\chi)}{\lambda - 1 - \dfrac{\phi}{1-\phi}\left[\dfrac{2\left(\lambda-1+\sigma_L^B\right)}{(\rho+\chi)(1-\sigma_R)B} + \sigma_L^B\right]} \qquad \textbf{VC}(\boldsymbol{q}), \tag{27}$$

$$\begin{aligned} B(1-\sigma_R) &= \frac{V_L^B}{I^*\left(V^A - V_F^B + f\phi Z\right)} \\ &= \frac{\phi\left(\lambda-1+\sigma_L^B\right)\left[q(\theta)+\rho+\chi\right](2I+\rho+\chi)}{I(\rho+\chi)\left[q(\theta)+\phi(\rho+\chi)\right]\left[f(\rho+\chi)+\lambda-1\right]} \end{aligned} \qquad \textbf{RP}(\boldsymbol{I}, \boldsymbol{q}), \tag{28}$$

$$\frac{q(\theta)I^*}{I^*+q(\theta)}(1-u)(1-\phi) = p(\theta)u \qquad \textbf{CD}(\boldsymbol{u}, \boldsymbol{v}, \boldsymbol{I}^*). \tag{29}$$

The **vacancy-creation (VC)** equation (27) is the reduced form of (20) and expresses $q^*(\theta)$ in terms of the parameters. Given $\partial q(\theta)/\partial\theta < 0$ from the matching function, (27) pins down a

[25] The alternative is to normalize consumption expenditure per capita $c \equiv 1$, which makes the determination of the low-skilled wage rate w_L explicit. From (7), $Z \equiv cN/(\lambda w_L) = N/(\lambda w_L)$, and (24), it follows $w_L = 1/[\lambda(1-u)(1-s)]$, i.e. w_L is residually determined for given u. Since it turned out that proceeding this way significantly complicates the presentation of the steady-state equilibrium without providing any new insights, we chose $w_L \equiv 1$ as our numéraire.

[26] Introducing human or physical capital accumulation to our model would generate transitional dynamics. This generalization lies beyond the scope of our paper since our focus is on short-run recovery policies and their welfare effects.

unique level for $\theta^* = (v/u)^*$. Note that $p^*(\theta)$ can be recovered from the matching identity $p(\theta) = (v/u)q(\theta)$.

The **relative-profitability (RP)** equation (28) is solely in terms of I and $q(\theta)$. The LHS is the cost of R&D relative to RPAs, and the RHS is the expected returns from R&D relative to RPAs. Observe that the RHS is decreasing in I and decreasing in q, given $0 < \phi < 1$. Thus, once q^* is determined, equation (28) pins downs a unique level for I^*.

The **creative destruction (CD) condition** (29) combines (26) with the industry flow equation (5) with $\dot{n}_A = 0$ and $\dot{u} = 0$ imposed. The LHS of (29) represents the rate of labor flow into the unemployment pool, and the RHS represents the rate of labor flow out of the unemployment pool. With q, p^* and I^* determined, the CD condition (29) and the expression for $\theta^* = (v/u)^*$ from the VC equation (27) together pin down unique levels for u^* and v^*.

We now illustrate the steady-state equilibrium graphically in (u, I) space. Equation (28) implicitly defines a unique level of I^* in terms of the parameters of the model. It is captured by a horizontal line in (u, I) space, as is shown in Figure 2a below. The CD relationship with q^* substituted from (27) implies an upward sloping curve in (u, I) space, as shown in Figure 2a below.[27] An increase in I speeds up the arrival rate of next-generation firms and thereby increases the fraction of type B industries $1 - n_A = I/(I + q^*)$, which are subject to replacement. This raises the aggregate job-destruction rate $q(\theta)(1 - n_A)(1 - \phi)$ and increases the worker flow into unemployment. Consequently, the unemployment rate u increases.[28]

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[27] Solving (29) for I and differentiating this expression twice with respect to u shows that $\partial^2 I / \partial u^2 > 0$ iff $q(\theta^*)(1-u)(1-\phi) > p(\theta^*)u \iff I^* > 0$. This reveals that the CD curve is indeed convex for $I^* > 0$ as shown in Figure 2a.

[28] In (u, v) space, this curve is usually referred to as the Beveridge curve in the DMP literature, and in line with empirical evidence, it is unambiguously downward sloping: first, an increase in the v/u ratio raises the job-finding rate $p(\theta)$, which reduces unemployment and hence works towards a negatively sloped Beveridge curve. Second, a higher v/u ratio decreases the matching rate $q(\theta)$ and thus the rate of creative destruction, thereby also contributing to a negatively sloped Beveridge curve. We note this as an improvement over the DMP literature where the slope of the Beveridge curve is ambiguous (see e.g. Mortensen and Pissarides 1994, p. 403, Pissarides 2000, p. 47, or Caballero 2007,

With I^*, q^*, θ^*, and u^* determined, the remaining endogenous variables can be obtained in a recursive fashion. The level of v^* follows directly from θ^* and u^*. The level of $n_A{}^*$ follows from imposing $\dot{n}_A = 0$ in (5). Substituting $R = I\delta X$, which follows from (10) and (11), into (25) yields X^*. Substituting $u*$ into (24) gives Z^* and thereby c^*, π^{A*} and π^{B*}. With π^{B*} and X^* pinned down, w_H is derived from (A.2). The rate of consumer utility growth in this economy is

$$g^* = I^* n_A^* \log\lambda = \frac{I^* q^*(\theta)\log\lambda}{I^* + q^*}, \qquad (30)$$

see the Referees' Appendix R.1 (available upon request) for a complete derivation.

Solving in (30) for the innovation rate I as a function of the growth rate g, substituting this into (28) and (29) yields, after simplifying and with (27) still determining $q^*(\theta)$, an alternative representation of the steady-state equilibrium in (g, u) space that will be useful for our later comparative-static policy analysis:

$$g = \frac{\log\lambda}{\dfrac{1}{q(\theta)} + \dfrac{B(1-\sigma_R)\left[\lambda - 1 + f(\rho+\chi)\right]\left[q(\theta) + \phi(\rho+\chi)\right]}{\phi\left(\lambda - 1 + \sigma_L^B\right)\left[q(\theta) + \rho + \chi\right]} - \dfrac{2}{\rho+\chi}} \qquad \mathbf{RP}(\boldsymbol{g}, \boldsymbol{q}), \quad (31)$$

$$g = \frac{p(\theta)\log\lambda}{(1-\phi)\left(\dfrac{1}{u} - 1\right)} \qquad \mathbf{CD}(\boldsymbol{u}, \boldsymbol{v}, \boldsymbol{g}^*). \quad (32)$$

In (g, u) space, equation (31) restates the RP condition (28) as a horizontal line, and equation (32) restates the CD condition (29) as a convex upward-sloping curve, as is illustrated in Figure 2b.

Here: Figure 2 (steady-state equilibrium)

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pp. 127-128). This is because in that setting, a higher v/u ratio implies a higher opportunity cost of employment which raises the job-destruction effect of the (exogenous) productivity shocks and thereby works towards a positively-sloped Beveridge curve.

We now implement our model numerically, which will allow to quantify the comparative-static policy analysis that follows in section 4. The choice of our benchmark parameter values as shown in Table 1 is justified as follows: The size of innovations, λ = 1.25, measures the gross mark up (the ratio of the price to the marginal cost) enjoyed by innovators and is estimated as ranging between 1.05 and 1.4 (see Basu 1996 and Norrbin 1993). The subjective discount rate ρ is set at 0.06 to reflect a real interest rate of 6 percent. This is within the range suggested by Mehra and Prescott (1985) as the average real return on the US stock market over the century prior to their study (7 %) and the value of 3 % used by Dinopoulos and Segerstrom (1999). The matching function is Cobb Douglas as in Blanchard and Diamond (1989) with $M(U, V) \equiv AV^{\eta}U^{1-\eta}$ and $\eta = 0.6$, such that $q = A(1/\theta)^{0.4}$ and $p = A\theta^{0.6}$. The benchmark value for the vacancy-creation costs α = 0.2 is very close to the choice (0.213) in Shimer (2005). Other benchmark parameters ϕ = 0.01, A = 0.13, $B \equiv \beta\delta/\gamma = 1$ and $\gamma = 1$ are chosen with the objective to generate reasonable values for endogenous variables, in particular to generate a growth rate $g = n_A I \log\lambda$ around 0.5%, following Denison (1985), and an unemployment rate around 8%. The proportion of high-skilled workers s is set at 0.01 to generate a wage differential $w_H/w_L \equiv w_H$ that is significantly greater than 1. Note also that our definition of "high-skilled" workers is very narrow, since it comprises only those working in R&D and RPAs. N = 1 and w_L = 1 are convenient normalizations, and setting $\sigma_L^B = \sigma_R = f = \chi$ = 0 serves as a useful, distortion-free reference case.

Here: Table 1 (Numerical steady-state equilibrium and comparative-static exercises)

The other columns that capture the numerical results of changing parameters relative to the benchmark will be referred to in the following section when discussing policy experiments individually.

4 Comparative Steady-State Analysis: The Tradeoff Between Growth and Employment

4.1 The Impact of The Financial Crisis 2007-2009

As reported by e.g. Hall (2010, pp. 12-13), one key element of the financial crisis 2007-2009 was the dramatic increase in credit spreads (difference between private borrowing rates and long-term treasury bond rates), reflecting inter alia the expected default of many financial assets and coming along with an hitherto unprecedented increase in the number of banks going bankrupt. Here, we are not asking for the reasons behind these events, but analyze the effects of an increase in the risk premium χ on employment, vacancy creation, and growth.

An increase in χ increases the RHS of (27) for a sufficiently low ϕ, which we assume to be the case, and hence q^* increases, which reduces the relative R&D-RPA profitability. Intuitively, the rise in χ lowers the returns from job-creation $V^A - V_L^B$, and thus vacancy creation slows down, and v/u ratio declines. This leads to a rise in q^*.[29] An increase in χ also reduces the absolute rewards from *both* R&D (V_L^B) and RPAs, $V^A - V_F^B$.[30] We concentrate on the limiting (and realistic) case $\phi \to 0$ to ensure that almost all low-skilled workers have to undergo the search and matching process before being hired. The Referees' Appendix shows that for sufficiently small values of ϕ, the fall in R&D rewards is larger than the fall in RPA rewards.

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[29] Actually, the higher χ reduces both V^A and V_L^B for a sufficiently low level of ϕ (holding the profit flows constant). It turns out that the decline in V^A (the expected discounted rewards of being fully matched) is larger than the decline in V_L^B (the expected discounted rewards at the status quo, while being partially matched). See the Referees' Appendix R.3, available upon request, for details of the derivation.

[30] A higher χ reduces both V^A and V_F^B. It turns out that the decline in V^A (the value enjoyed by maintaining full incumbency) is larger than the decline in V_F^B (the value realized upon falling technologically behind). Thus, the rewards from RPAs decline. See the Referees' Appendix R.3, available upon request, for details of the derivation.

Hence the RHS of (28) goes down. The RP curve shifts down and innovative activity I declines.

Next, we investigate the impact on the CD curve. A higher q^* increases the aggregate job destruction rate $qI/(I + q)$, implying an increased labor flow into unemployment. At the same time, the fall in the job-finding rate p^* (induced by the lower $\theta \equiv v/u$ ratio) pulls less people out of unemployment. For a given I, both effects work to increase u and shift the CD curve to the right, as is shown in Figure 3.

Here: Figure 3 (steady-state effects of an increase in financial default risk)

With RP shifting down and CD shifting to the right, I^* clearly decreases whereas the net effect on u^* is ambiguous. With q^* increasing but I^* decreasing, the net effect on g^* as given in (30) is ambiguous. The Referees' Appendix shows that for sufficiently low values of ϕ, a higher χ reduces g^*,[31] while the ambiguity on u^* cannot be resolved in general. However, our numerical simulations reveal that at sufficiently low innovation rates (induced e.g. by high χ values, and corresponding to low growth rates g^*), an increase in χ raises u^*, whereas at sufficiently high innovation rates an increase in χ reduces u^*. It follows that within this range, the vacancy rate unambiguously declines: the number of vacancies posted per firm $(1-\phi)Z^* = (1-\phi)(1-s)(1-u^*)N$ decreases due to a higher unemployment rate, and the mass of searching firms $1 - n_A^*$ decreases due to both a higher matching rate and a lower innovation rate. Thus, a systemic shock can be more detrimental to the economy in low growth times by not only reducing growth further but also by increasing unemployment. Figure 4 illustrates the (linear)

[31] Our finding that an increase in systemic risk reduces economic growth is empirically supported by Adrian et al. (2010). They "*define the macro risk premium as the component of GDP that is contemporaneously correlated with the various Treasury term spreads and credit spreads*", and "*obtain an estimate of the macro risk premium as the fitted value of a linear regression of GDP growth on these corporate bond spreads and Treasury spreads*" (p. 189). They find a strong negative correlation between GDP growth and this macro risk premium for the US during 1985-2009 (Figure 5, p. 190), and similar pictures emerge for Germany, Japan, and the UK (pp. 202-204).

growth and (nonlinear) unemployment effects of continuously rising values of $\rho + \chi$ for alternative values of λ, given that all other parameters take their benchmark values from Table 1.

Here: Figure 4 (growth and unemployment effects of continuously rising $\rho + \chi \in [0.035, 0.095]$ for alternative values of λ)

We now analyze alternative labor market and investment policies. Our goal is to identify those recovery policies that univocally stimulate the rate of growth and reduce the rate of unemployment.

4.2 An Increase in Production Subsidy to Searching Firms σ_L^B: Obama's "Tax Break For New Hires"

An increase in σ_L^B, the exclusive subsidy rate targeted to technology leaders in Type B industries, can be considered as being qualitatively equivalent to the recent "tax break for new hires" policy of the Obama administration. Earlier experience with a similar policy, the New Jobs Tax Credit (NJTC) enacted 1977, did not appear to be encouraging, as is explained by Burtless (2009). While he refers to ignorance of employers, risk of abuses (e.g., laying off workers to become entitled to the subsidy upon hiring new workers for the same jobs), windfall gains to firms planning to raise employment anyway, and etc. to explain the poor performance of "tax subsidies for marginal employment increases", our model offers a different explanation based on macroeconomic general-equilibrium effects. We proceed in two steps: first, we discuss the impact of an increase in σ_L^B on the equilibrium matching rate $q(\theta)$ using (27). Second, we graphically analyze in (u, I)-space of Figure 2a the induced shifts in the RP and CD curves and thereby determine the changes in u^* and I^*.

It follows immediately from (27) that an increase in σ_L^B increases the vacancy matching rate q^*. The mechanism is as follows. An increase in σ_L^B raises the profit flows of searching firms π^B in (9) and therefore V_L^B in (15). Hence the rewards from innovation increase. Maintaining the free-entry in R&D condition (13) requires an increase in the R&D difficulty-adjusted high-skilled wage rate $w_H X$. This in turn translates into higher rent-protection expenditures $w_H \gamma X$ for monopolists in type A industries and thus their valuation V^A in (17) decreases. Consequently, the returns from vacancy creation in (27) *decrease* and firms create *fewer* vacancies relative to unemployment.[32] In other words, $\theta \equiv v/u = (1 - n_A)(1 - \phi)Z/U$ decreases and thus $q^*(\theta)$ rises, an adjustment which restores the zero-profit condition in vacancy creation. We note that the job finding rate of workers $p^*(\theta)$ decreases given $\partial p(\theta)/\partial\theta > 0$.

It follows from (28) that an increase in σ_L^B has two competing effects on I. The direct impact is to raise the returns from innovation success relative to RPAs, as captured by the RHS of (28), and thereby stimulate innovative activity I.[33] The indirect impact works through the higher q^*. Given $\phi < 1$, a higher q^* reduces the relative R&D-RPA profitability as captured by the RHS of (28) and thus dampens innovative activity I.[34] The Referees' Appendix shows that for sufficiently low values of ϕ, the direct effect dominates the indirect effect. Thus $dI^*/d\sigma_L^B > 0$ and the RP curve shifts up. We henceforth restrict attention to this case.

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[32] Recall that the VC condition (27) is the reduced form of (20), $q(\theta)(V^A - V_L^B) = \alpha(1-\phi)Z$, and note that a change in σ_L^B affects only V^A (negatively) and V_L^B (positively) in this equation. The reason is that the Z terms embedded in V^A and V_L^B cancel out once the appropriate substitutions are made. See the derivation of the VC condition (27) in Appendix A for details.

[33] More precisely, an increase in σ_L^B raises π^B in (9) and hence the rewards from innovation V_L^B in the R&D free-entry condition (13), which shows up in reduced form on the RHS of (28). See Appendix A, equations (A.1) and (A.2), for the complete derivation.

[34] An increase in q^* has no effect on the reduced form of the R&D free-entry condition, see Appendix A, equation (A.2). However, it affects the returns from RPAs as captured by the RHS of (21) $I\left(V^A - V_F^B + f\phi Z\right)$. First, a higher q^* raises the replacement rate of followers in type B industries, hence V_F^B decreases. Second, the decline in V_F^B reduces V^A via (17) because V_F^B is the valuation of monopolists in type A industries if they get replaced. The first effect increases the RPA returns whereas the second effect reduces them. Given $\phi < 1$, total differentiation of the reduced form of (21) [see Appendix A, equation (A.4)] implies a net increase in RPA returns. Thus, a higher q^* reduces the profitability of R&D relative to RPAs for a given I.

Next, we investigate the impact on the CD curve. First, a higher q^* increases the rate at which technology laggards in type B industries are replaced. At the same time a higher q^* lowers the fraction of type B industries $1 - n_A = I/(I + q)$. Since these effects are combined in the $qI/(I + q)$ term, it is easy to see that the former effect dominates the latter. As a result, the aggregate job-destruction rate increases and hence the labor flow into unemployment. Second, a lower p^* decreases the job-finding rate of workers, reducing the labor flow out of unemployment. For a given I, both effects work to increase the unemployment rate u and shift the CD curve to the right.

Here: Figure 5 (steady-state effects of an increase in σ_L^B)

With RP curve shifting up and the CD curve shifting to the right, we observe that both I^* and u^* clearly increase. It follows that given the increase in u^*, the decrease in v/u required to raise $q^*(\theta)$ for restoring the zero-profit condition in vacancy creation (27) can come about through either a decrease in v^*, or through an increase in v^* by less than u^*. With the increase in u, clearly the number of vacancies posted per firm $(1-\phi)Z^* = (1-\phi)(1-s)(1-u^*)N$ declines. We show in the Referees' Appendix that for sufficiently low values of ϕ, the mass of searching firms $1 - n_A$ increases. The higher innovation rate I accelerates the emergence of tech leaders and thus searching firms, which more than offsets the effect that the higher matching rate q reduces the mass of searching firms. With the mass of type B firms increasing but the number of vacancies per searching firm decreasing, the net effect on the vacancy rate is ambiguous. Our numerical simulations in Table 1 above imply that for plausible parameter values, the vacancy rate increases. Nevertheless, subsidizing young searching firms fails in terms of helping people escape unemployment. Note however that it stimulates growth g^* by raising both

q^* and I^*.[35] Hence, an increase in σ_L^B induces a positive correlation between unemployment and growth and thus belongs to the conundrum of recovery.

Finally, we note that the following investment-targeted policies have qualitatively the same effects as an increase in σ_L^B: an increase in the R&D subsidy rate σ_R, or an increase in the tax rate on RPAs $\sigma_X > 0$, which could be incorporated by replacing B in (28) with $\hat{B} \equiv B/(1+\sigma_X)$. All these policies raise the relative R&D-RPA profitability and generate a faster innovation rate I^*. At the same time all reduce the profitability of vacancy creation and reduce the labor market tightness ratio $\theta^* \equiv v/u$. In the job market, the higher I^* and q^* raise the aggregate job-destruction rate and the lower p^* reduces the job finding rate. Hence both the rate of unemployment u^* and the rate of growth g^* increase (recovery conundrum). We summarize our results in

Proposition 1: *Starting from the unique interior steady-state equilibrium, the following policies all result in a higher steady-state growth rate g^* and a higher steady-state unemployment rate u^* among low-skilled workers:*

i.) *an increase in the searching firms' production subsidy rate $\sigma_L^B > 0$;*

ii.) *an increase in the R&D subsidy rate $\sigma_R > 0$;*

iii.) *an increase in the RPA tax rate $\sigma_X > 0$.*

4.3 An Increase in Firing Costs

An increase in the firing cost f exerts no effect on the VC condition (27). Hence, the vacancy matching rate q^* and thus $\theta^* \equiv v/u$ remain unchanged. At the same time, a higher f lowers the innovation rate I^* by reducing the profitability of R&D relative to RPA, as captured by the RHS of (28). This implies a downward shift of the RP curve in Figure 4 below. In the job

[35] Totally differentiating $g^* = (\log\lambda)I^*q^*/(I^* + q^*)$ with respect to I gives $dg/dI = (\partial g/\partial I) + (\partial g/\partial q)(dq/dI) > 0$. Given $\partial g/\partial I > 0$, $\partial g/dq > 0$ and $dq/dI > 0$, it follows that $dg/dI > 0$.

market a lower I^* reduces the aggregate job-destruction rate by reducing the fraction of technology laggards subject to innovation $1 - n_A$. Thus the unemployment rate u^* declines, as can be seen in Figure 6 below. Given that u^* falls and $\theta^* \equiv v/u$ remains unchanged, we conclude that v^* must decline in the same proportion as u^*. With the decrease in u^*, clearly the number of vacancies posted per firm $(1-\phi)Z^* = (1-\phi)(1-s)(1-u^*)N$ increases. Hence, this is more than compensated by the decline of the mass of searching firms $1 - n_A{}^* = I^*/(I^* + q^*)$ due to the decrease in I^* for constant q^*. Therefore, consistent with cross-country empirical evidence summarized e.g. by Boeri and van Ours (2008, p. 212), stricter employment protection captured by a higher f reduces both the economy-wide job destruction rate $q(\theta)(1-n_A)(1-\phi)$ determining the unemployment inflows, and the economy-wide job-finding rate $p(\theta)u$ determining unemployment outflows. With q^* unchanged, the lower I^* results in a lower steady-state growth rate $g^* = (log\lambda)I^*q^*/(I^* + q^*)$. Again, changes in f induce a positive correlation between growth and unemployment and thus belong to the conundrum of recovery.

Here: Figure 6 (steady-state effects of an increase in *f*)

4.4 A Decrease in Vacancy-Creation Costs α

A decrease in the vacancy-creation cost parameter α can be motivated as a policy aimed at subsidizing job creation more directly than "tax break for new hires" analyzed above in section 4.2. These costs of creating and filling vacancies consist of advertising the position in e.g. newspapers, paying a human resources department for dealing with new applicants, reimbursing outlays of applicants (e.g. traveling costs to the place of the job interview, hotel costs), and the like. A decrease in α can be operationalized by defining marginal vacancy creation costs $\alpha \equiv \hat{\alpha}\,(1-\sigma_V)$, and considering an increase in the vacancy-creation subsidy rate σ_V. Such a change implies an increase in the profitability of vacancy creation, which raises $\theta \equiv v/u$ and therefore reduces $q(\theta)$ in equation (27). Given $\phi < 1$, a lower q^* reduces the relative R&D-

RPA profitability as captured by the RHS of (28) and thus stimulates innovative activity I. In the Referees' Appendix we show that for sufficiently low ϕ, this translates into an upward shift of the RP curve (31) in (g, u) space, as is illustrated in Figure 7 below.

Next, we investigate the impact on the CD curve. A lower q^* reduces the aggregate job destruction rate $qI/(I + q)$, implying a decrease in the labor flow into unemployment. In the meanwhile, a higher p^* (induced by the higher $\theta \equiv v/u$ ratio) increases the job-finding rate of workers, helping more people escape unemployment. For a given I, both effects work to decrease the unemployment rate u. In (g, u) space, the increase in $p^*(\theta)$ implies a counterclockwise turn of the CD curve as is illustrated in Figure 7.

Here: Figure 7 (steady-state effects of a decrease in α)

With RP shifting up and CD turning counterclockwise, g^* clearly increases whereas the net effect on u^* is ambiguous. However, our numerical simulations in Table 1 above imply that for plausible parameter values, a lower α reduces u^*. It follows that the vacancy rate v^* increases both due to the higher I^* and due to the lower q^* (which implies that the mass of firms that offer vacancies increases unambiguously), as well as due to the lower u^*, which implies that the number of vacancies posted per firm, $(1-\phi)Z^* = (1-\phi)(1-s)(1-u^*)N$, increases as well.

We conclude that contrary to a production subsidy for searching firms $\sigma_L^B > 0$, subsidizing vacancy creation directly improves growth and employment *at the same time*, and changes in α induce a negative correlation between growth and unemployment (no recovery conundrum).[36] We summarize our results in

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[36] Regarding the empirical evidence, Mortensen (2005, p. 239) states that "[…] *there is no consensus regarding the sign of the correlation between growth and unemployment either across countries or across longer periods of time in the same country*", perhaps "[…] *because the two rates are simultaneous[ly] determined in market economies. If so, shocks to different common determinants in different countries and time periods can induce uncorrelated comovements on average*" (ibid, p. 240). This is in line with the predictions of our model for the various policy exercises that we consider.

Proposition 2: *Starting from the unique interior steady-state equilibrium, the following all result in a higher steady-state growth rate g^*:*

i.) *a decrease in firing costs f;*

ii.) *an increase in vacancy-creation subsidies σ_V;*

iii.) *a decrease in the financial risk premium χ.*

The following all result in a higher steady-state unemployment rate u^*:

iv.) *a decrease in firing costs f;*

v.) *a decrease in vacancy-creation subsidies σ_V;*

vi.) *an increase (a decrease) in the financial risk premium χ if the initial steady-state growth rate g^* is sufficiently low (high).*

5 Welfare Analysis (Preliminary)

The aim of this section is, first, to derive the welfare-maximizing levels of σ_L^B and *f*, and second, to identify recovery policies that are able to raise welfare when an unfavorable macroeconomic shock (like a significant increase in the risk premium χ) occurred. The instantaneous log utility per citizen is derived in Appendix R.1 (available upon request) as

$$\log h(t) = \log(c) - \left[n_A + (1-n_A)(1-\phi)\right]\log\lambda + n_A(\log\lambda)It .$$

Substituting this into the intertemporal utility function (1), and evaluating the integral yields the following expected discounted utility for a representative household:

$$H = \frac{1}{\rho}\left\{\frac{n_A I\log(\lambda)}{\rho} - \left[n_A + (1-n_A)(1-\phi)\right]\log(\lambda) + \log(c)\right\}. \tag{33}$$

Here, $n_A I\log(\lambda)$ is the dynamic component: in the continuum of type A industries with share n_A, labor-saving technical progress arrives at the innovation rate *I*. With each innovation, the goods price charged by type A quality leader firms declines by λ, which raises the real wage rate and hence the per-capita goods demand by the same amount. This in turn increases utility by log(λ). The static welfare component in (33) is the logarithm of purchased goods summed over all industries. This term accounts for the fact that a typical type B technology leader in industry ω captures a share ϕ of the market and charges the price $1/\lambda^{m(\omega)}$, where $\lambda^{m(\omega)}$ represents the top-innovated technology in industry ω, and the fraction of type B industries is $1 - n_A$. While technology followers, who serve the remaining share $1 - \phi$ of the market in a fraction $1 - n_A$ of the industries, and full-monopoly firms, who supply the complete market in a fraction n_A of the industries, charge the higher price $1/\lambda^{m(\omega)-1}$. Summed over industries, these relatively higher prices gives rise to a static welfare loss captured by the negative term $-[n_A + (1 - n_A)(1 - \phi)]\log(\lambda)$.

Using $n_A^* = q^*/(I^* + q^*)$, $c^* = Z^*\lambda/N$, and (24) to substitute for Z yields, after simplifying, the following expression for steady-state per-capita utility:

$$H^* = \frac{1}{\rho}\left\{\frac{\log(\lambda)}{\frac{I^*}{q^*(\theta)}+1}\left(\frac{I^*}{\rho}-\phi\right)-(1-\phi)\log\lambda+\log\left[\lambda\left(1-u^*\right)(1-s)\right]\right\}. \qquad (34)$$

We note that since our model does not display any transitional dynamics (see the Referees' Appendix R.2, available upon request, for proof), the following comparative-static exercise on the steady-state welfare effects of policy changes does not miss any transitional welfare effects. Differentiating (34) gives, after simplifying, the following first-order condition for the optimal σ_L^B level:

$$\frac{\partial H^*}{\partial \sigma_L^B} = \frac{1}{\rho}\left\{\frac{g^*}{\rho\left[I^*+q^*(\theta)\right]}\cdot\left[\overbrace{\frac{\partial I^*}{\partial \sigma_L^B}}^{>0}\cdot\frac{q^*(\theta)+\rho\phi}{I^*}+\overbrace{\frac{\partial q^*(\theta)}{\partial \sigma_L^B}}^{>0}\cdot\frac{I^*-\rho\phi}{q^*(\theta)}\right]-\frac{\overbrace{\partial u^*/\partial \sigma_L^B}^{>0}}{1-u}\right\}=0. \qquad (35)$$

Hence, on the one hand, an increase in the type B leader firm's production subsidy σ_L^B raises per-capita welfare by increasing the innovation rate (dynamic welfare gain) and by increasing the matching rate, which raises the proportion of Type A industries n_A where innovation takes place (another dynamic welfare gain). On the other hand, an increase in σ_L^B raises the unemployment rate and thereby reduces per-capita consumption expenditure (static welfare loss). Similarly, an increase in firing costs f results in a dynamic welfare loss by reducing the innovation rate, leaves the matching rate unaffected, and results in a static welfare gain by reducing the unemployment rate. The corresponding first-order condition for the optimal level of f is

$$\frac{\partial H^*}{\partial f} = \frac{1}{\rho}\left\{ \frac{g^*\left[q^*(\theta)+\rho\phi\right]}{\rho\left[I^*+q^*(\theta)\right]I^*} \cdot \overbrace{\frac{\partial I^*}{\partial f}}^{<0} - \frac{\overbrace{\partial u^*/\partial f}^{<0}}{1-u} \right\} = 0 . \tag{36}$$

Applying the numerical implementation from section 3, we can derive the welfare-maximizing levels of σ_L^B and f as functions of deep parameters of the model. Figures 8a-d show this for the case of σ_L^B (see the Mathematica Appendix, available upon request, for derivation).

Here: Figures 8a-8d (welfare-maximizing level of σ_L^B as a function of $\rho + \chi$, λ, α, or B)

In these Figures we show the dependence of the welfare-maximizing level of σ_L^B with respect to feasible ranges of ρ, λ, α, and B, while keeping all other parameters at their benchmark levels from Table 1, respectively. For these benchmark parameters, the welfare-maximizing level is at about $\sigma_L^B = -0.05$, while it becomes positive for sufficiently larger λ or B, and for sufficiently smaller α. In particular, Figure 8a shows that at sufficiently low levels of $\rho + \chi$ (i.e., at high growth rates), the welfare-maximizing level of σ_L^B is positive, such that a shift from a neutral policy $\sigma_L^B = 0$, to subsidizing searching firms $\sigma_L^B > 0$ raises welfare (the jump from point A to point B in Figure 8a). At sufficiently high levels of $\rho + \chi$ (i.e. at low growth rates), the welfare-maximizing level of σ_L^B is negative, such that a shift from $\sigma_L^B = 0$ to taxing the searching firms $\sigma_L^B < 0$ raises welfare (the jump from point C to point D in Figure 8a).[37] Hence our model suggests that during the 2007-2009 financial crisis with abundant mistrust and hence particularly high risk premium χ, a tax rather than a subsidy to firms creating vacancies would have been welfare improving, and thus could be identified as a meaningful recovery policy, whereas Obama's "tax cut for new hires" cannot. To put it differently, the case for subsidizing searching firms diminishes as risk premia increase and thus growth slows down.

As the Mathematica Appendix (available upon request) shows, the welfare-maximizing level of firing costs is $f = 0$ for a wide range of parameter values around our benchmark. Since this comprises both high and low risk premia, reducing firing costs is supported by our model as a helpful policy independently of the state of the economy.

Starting from our benchmark parameters, there are several possibilities to reduce unemployment and simultaneously to raise growth and welfare. First, additional numerical calculations (available upon request) show that there are combinations of the policy instruments $\sigma_L^B < 0$ and $\sigma_R > 0$ that can achieve these aims, while applying each of these policy instruments in isolation cannot (see Table 1). A second way is to subsidize vacancy creation ex ante through $\sigma_V > 0$ which reduces α (see section 4.4).[38] A third way is to reduce the financial risk premium χ (see section 4.1) through e.g. measures that help to rebuild confidence in banks etc.[39]

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[37] In section 4.1 we found that an increase in the risk premium χ unambiguously reduces g^*, but increases u^* only for parameter combinations that yield a sufficiently small g^*. Applying our parameter benchmark values from section 3, including $\rho = 0.06$, reveals that the critical $\tilde{\chi}$ beyond which any further increase in χ raises u^* is $\tilde{\chi} = -0.0083$. Moreover, as is obvious from Figure 8a, the welfare-maximizing σ_L^B becomes negative when χ exceeds some critical level $\hat{\chi}$. Again applying the benchmark parameters including $\rho = 0.06$ reveals that $\hat{\chi} = -0.00845$. It follows that for any reasonable $\chi > 0$ during the financial crisis 2007-2009, our model predicts that the increase in financial risk premia χ raised unemployment and called for a tax $\sigma_L^B < 0$ on searching type B leader firms.

[38] Differentiating (34) with respect to α gives, of course, an expression similar to (35), now including $\partial I^*/\partial\alpha < 0$, $\partial u^*/\partial\alpha > 0$, and $\partial q(\theta)^*/\partial\alpha > 0$. Although a lower matching rate $q(\theta)^*$ reduces the proportion of type A industries where dynamic welfare gains from innovations occur, the net effect for plausible parameter values is clearly an increase in steady-state welfare (see Table 1).

[39] Differentiating (34) with respect to χ yields an expression again similar to (35), now including $\partial I^*/\partial\chi < 0$, $\partial q(\theta)^*/\partial\chi > 0$, and $\partial u^*/\partial\chi$ with ambiguous sign. Again, for plausible parameter values,

6 Conclusion (Preliminary)

This paper takes a Schumpeterian perspective on growth and jobs. Economic growth stems from deliberate R&D efforts of entrepreneurs, which results in improvements in total factor productivity. Successful entrepreneurs must go through a search process to replace incumbent firms with obsolete technologies. This involves a costly vacancy creation and maintenance process. Firms successful in matching provide jobs for the unemployed, whereas incumbents that are replaced must lay off their workers. Unemployment thus stems from a creative destruction process coupled with search and matching frictions in the labor market.

We find that labor market and R&D policies affect the rate of innovation by altering the profitability of R&D relative to RPAs and also by altering vacancy creation decisions. Policy changes also affect the rate of unemployment by altering the rates of job creation and job destruction. We have shown that growth-stimulating policies like R&D subsidies or increased production subsidies to young firms searching for workers present tradeoffs. They indeed boost growth but also raise unemployment. In the meanwhile the tradeoffs disappear for some policies. For example, subsidizing vacancy creation directly (i.e., by reducing vacancy creation costs during the search process) results in higher growth and also lower unemployment.

We also investigate the impact of an increase in systemic risk in the financial markets. We find that an increase in risk premium decreases the rate of innovation and growth. However, the unemployment effect depends on the level of innovation. We find that at sufficiently low innovation rates, an increase in risk premium raises unemployment, whereas at sufficiently high innovation rates it reduces unemployment. Thus, in low growth times a systemic shock can have severe adverse effects on the economy not only by further dampening growth but also by increasing unemployment.

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the net steady-state welfare effect is positive (see Table 1).

In our welfare analysis, we find that production subsidies for successful innovators that offer vacancies reduce welfare for a wide range of plausible parameter values. Moreover, we have shown that the welfare-maximizing level of these subsidies is more likely to be negative (i.e., taxation) when systemic risk premia on financial markets are high, which was the case during the 2007-2009 financial crisis. Hence, we conclude that the "tax cut for new hires" offered by the Obama administration during the 2007-2009 financial crisis may be misguided as a way to reduce unemployment and to raise welfare. Alternative policies such as direct subsidization of vacancy maintenance can yield better outcomes by boosting both growth and welfare, and at the same time reducing unemployment.

Appendix A: Derivation of the Steady-State Equilibrium

We first determine I^* and $q^*(\theta)$. The first step is to substitute (20) into (15). Using $r = \rho + \chi$ and $\dot{V}_L^B / V_L^B = 0$, this implies

$$V_L^B = \phi\pi^B / (\rho + \chi) \ . \qquad \text{(A.1)}$$

Combining (A.1) with (13) gives the **free-entry in R&D condition**

$$w_H (1 - \sigma_R) \beta\delta X = \phi\pi^B / (\rho + \chi) \qquad \textbf{FE}.^{40} \qquad \text{(A.2)}$$

We substitute for $V^A - V_F^B$ from (21) into (16), and use $r = \rho + \chi$ and $\dot{V}^A / V^A = 0$. Taking limits as $dt \to 0$ and solving the resulting expression for V^A gives:

$$V^A = \frac{\pi^A - 2w_H\gamma X}{\rho + \chi} . \qquad \text{(A.3)}$$

We substitute V_L^B from (A.1) and V^A from (A.3) into the vacancy creation (VC) condition (20) by using (7) to substitute for Z, $w_L \equiv 1$, (A.2) for $w_H X$, (6) for π^A, and (9) for π^B. We solve

[40] From (A.1) and (A.2) we see that the assumption of some immediate costless matching of new quality leader jobs with production workers (i.e., $\phi > 0$) is necessary for having a meaningful model with a positive reward for innovating V_L^B, such that there exist entrepreneurs who continue to enter the R&D market until expected R&D profits are competed away.

the resulting expression for q to find the **VC(*q*)** condition (27) of the main text, where $B \equiv \beta\delta/\gamma$ is the resource requirement of R&D relative to RPAs.

Substituting V^A from (17) into the **RPA optimality condition** (21) using (19) for V_F^B, $r = \rho + RP$, $\dot{V}^A/V^A = \dot{V}_F^B/V_F^B = 0$, (7) to substitute for $Z = cN/(\lambda w_L) = \pi^A/[w_L(\lambda-1)]$, and $w_L \equiv 1$ gives:

$$w_H\gamma X = \frac{I\pi^A\left[q(\theta)+\phi(\rho+RP)\right]}{\left[q(\theta)+\rho+RP\right](2I+\rho+RP)}\left[\frac{f(\rho+RP)}{\lambda-1}+1\right] \qquad \textbf{RPA}. \qquad (A.4)$$

Dividing (A.2) by (A.4), using (6), (9) and $B \equiv \beta\delta/\gamma$ yields the **RP(*I, q*)** condition (28) of the main text.

Finally, we derive the "creative destruction" (CD) relationship. Setting $\dot{n}_A = 0$ in (5) and using the equilibrium values yields $n_A^* = q^*(\theta)/[I^* + q^*(\theta)]$. Substituting this into (26) for $\dot{u} = 0$ gives the creative destruction condition (29).

Appendix B: Existence and Uniqueness of the Steady-State Equilibrium

For $q^* > 0$, we need the denominator of (27) to be positive. This is our first parametric restriction:

$$\lambda - 1 - \frac{\phi}{1-\phi}\left[\frac{2(\lambda-1+\sigma_L^B)}{(\rho+\chi)(1-\sigma_R)B}+\sigma_L^B\right] > 0 \qquad (B.1)$$

Since q is strictly declining in $\theta \equiv v/u$, condition (B.1) ensures existence and uniqueness of θ^*, and hence of $q(\theta)^*$ and $p(\theta)^*$. Given this unique $q^* > 0$, to have a unique $I^* > 0$, we need two conditions. First, when $I \to 0$ the RHS of (28) should be above $B(1-\sigma_R)$. This condition holds automatically given that the RHS of (28) $\to \infty$ when $I \to 0$. Second, when $I \to \infty$, the RHS of (28) should be below $B(1-\sigma_R)$. This gives us our second parametric restriction:

$$B(1-\sigma_R) > \frac{2\phi\left(\lambda - 1 + \sigma_L^B\right)\left(q^* + \rho + \chi\right)}{(\rho + \chi)\left[q^* + \phi(\rho + \chi)\right]\left[f(\rho + \chi) + \lambda - 1\right]}, \tag{B.2}$$

with q^* given by (27). Since the RHS of (28) is strictly decreasing in I for given q^*, condition (B.2) ensures existence and uniqueness of I^*. We note that (B.1) and (B.2) jointly hold for sufficiently low levels of ϕ. The existence of a unique $u^* \in (0, 1)$ then follows from the fact that for given positive I^*, θ^*, q^*, and p^*, the LHS of (29) is strictly decreasing in u, and the RHS of (29) is strictly increasing in u. This can also be seen by solving (29) for $u^* = \frac{1}{1 + \frac{p^*\left(I^* + q^*\right)}{q^* I^* (1-\phi)}}$.

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Figures

a next-generation firm with
$(m + 1)^{th}$ technology emerges
captures ϕ of the market
innovation rate *I*

Type A industry (share n_A)	**Type B industry (share $1 - n_A$)**
Incumbent monopolist: **m^{th} technology** Entrepreneurs: **invest R&D to develop $(m + 1)^{th}$ technology**	Technology Follower: **m^{th} technology, market share $1 - \phi$** Technology Leader: **$(m + 1)^{th}$ technology, market share ϕ**

matching rate *q*
a technology leader with $(m + 1)^{th}$ technology
captures the entire market

Figure 1: industry configuration

Figure 2a **Figure 2b**

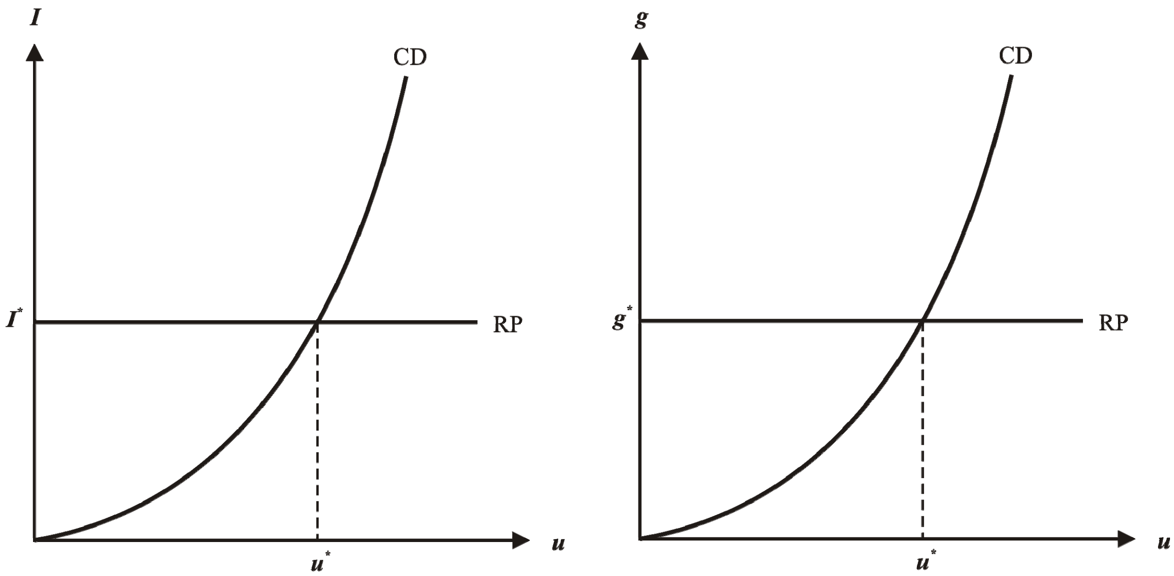

Figure 2: steady-state equilibrium

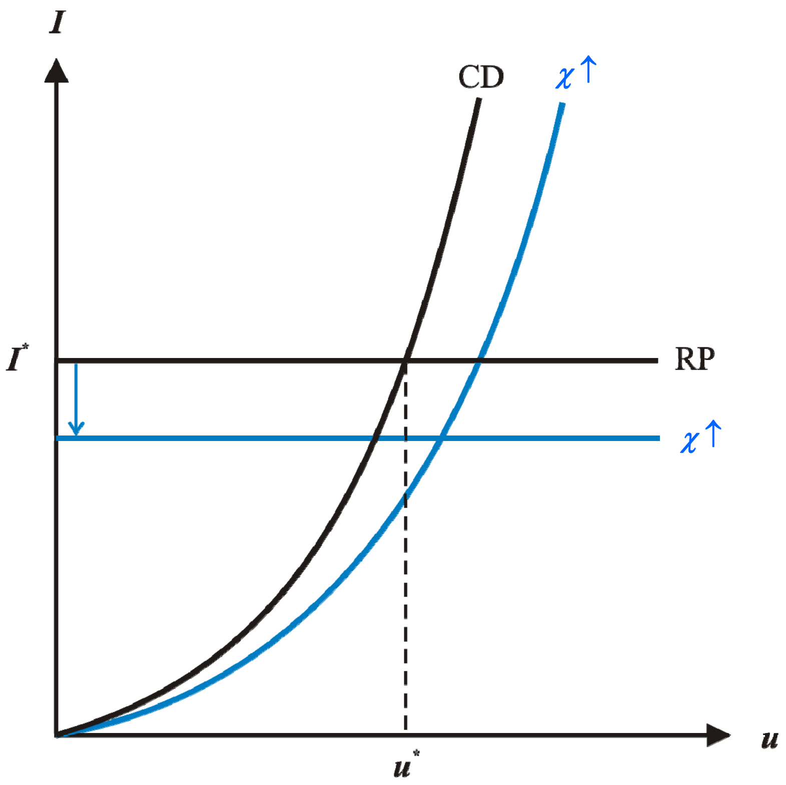

Figure 3: **steady-state effects of an increase in financial default risk**

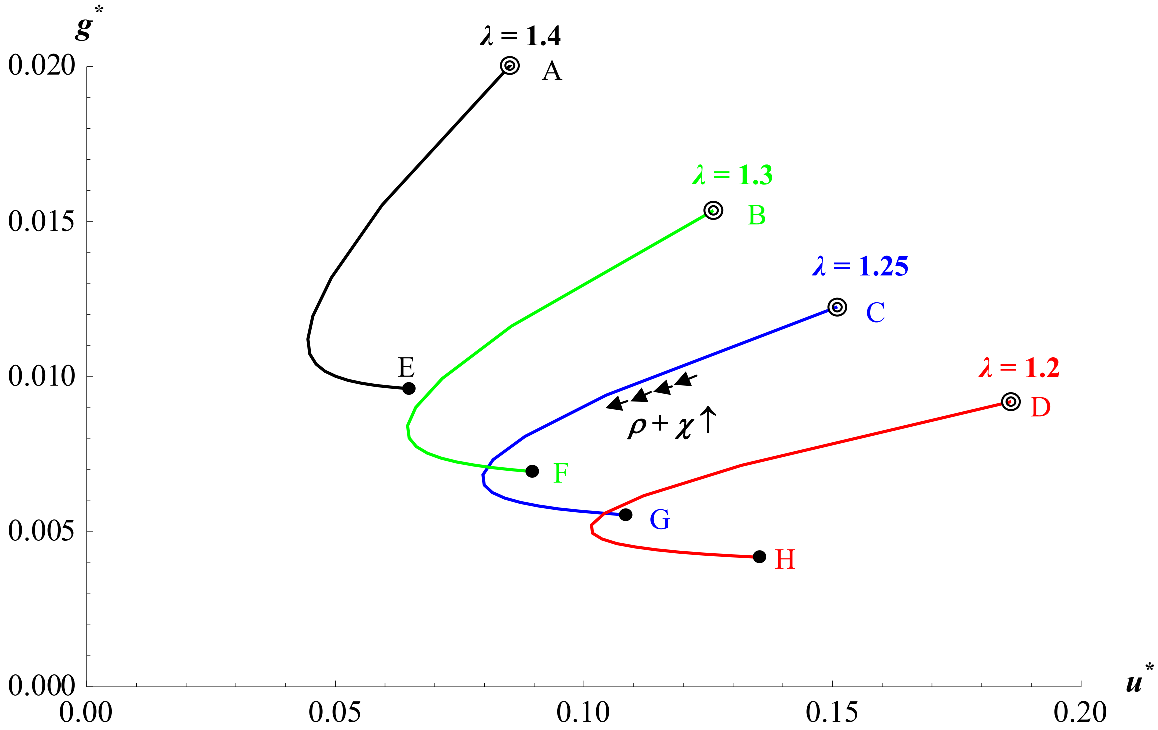

Figure 4: Growth and unemployment effects of continuously rising $\rho + \chi \in$ [0.035, 0.095] for alternative values of λ

Notes: In this graph, each line is drawn for a given λ and identifies the equilibrium combinations (u^*, g^*) that result when $\rho + \chi$ changes. Moving down on each line corresponds to higher levels of $\rho + \chi$. At points A, B, C and D, respectively, $\rho + \chi$ takes its lowest value 0.035. At points E, F, G and H, respectively, $\rho + \chi$ takes its highest values 0.095. For all cases of λ considered here, the critical $\rho + \chi$ that makes the impact on unemployment switch is in the 0.05-0.06 range. Notice that at reasonable rates of unemployment (5-15%) and of growth (0.4-2.0%), the curves largely retain their $\subset$ shaped nature. As λ increases, the critical growth rate level that makes the impact on unemployment switch shifts up slightly.

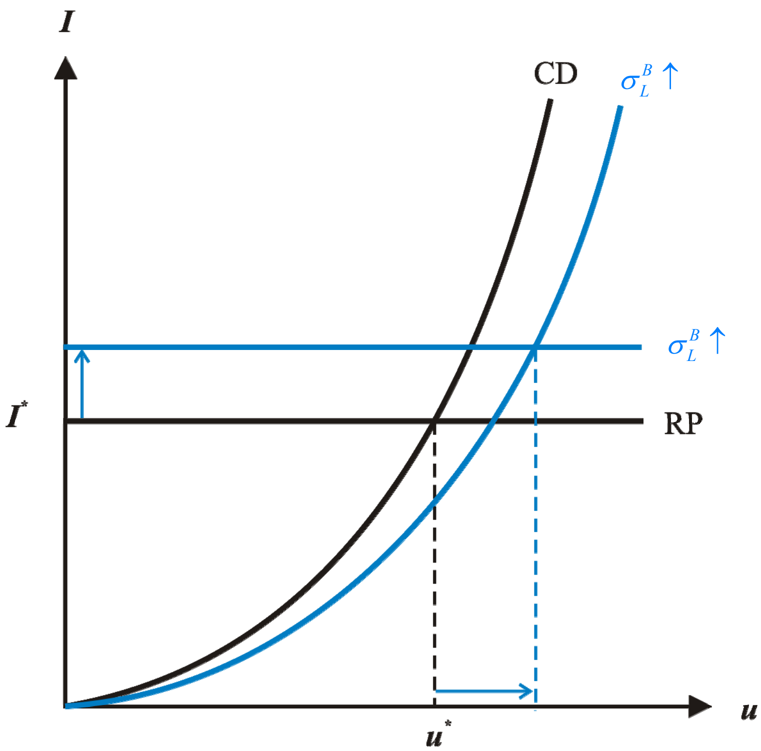

Figure 5: steady-state effects of an increase in σ_L^B

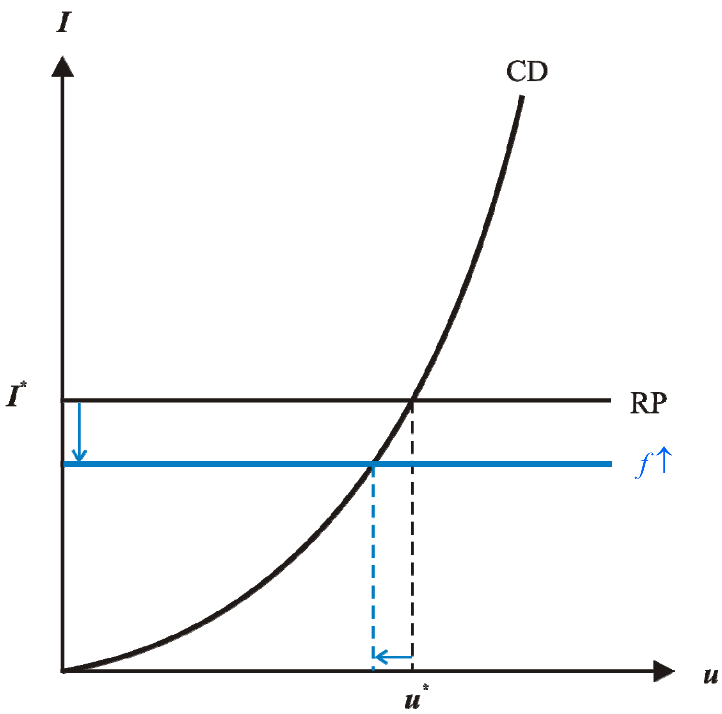

Figure 6: steady-state effects of an increase in f

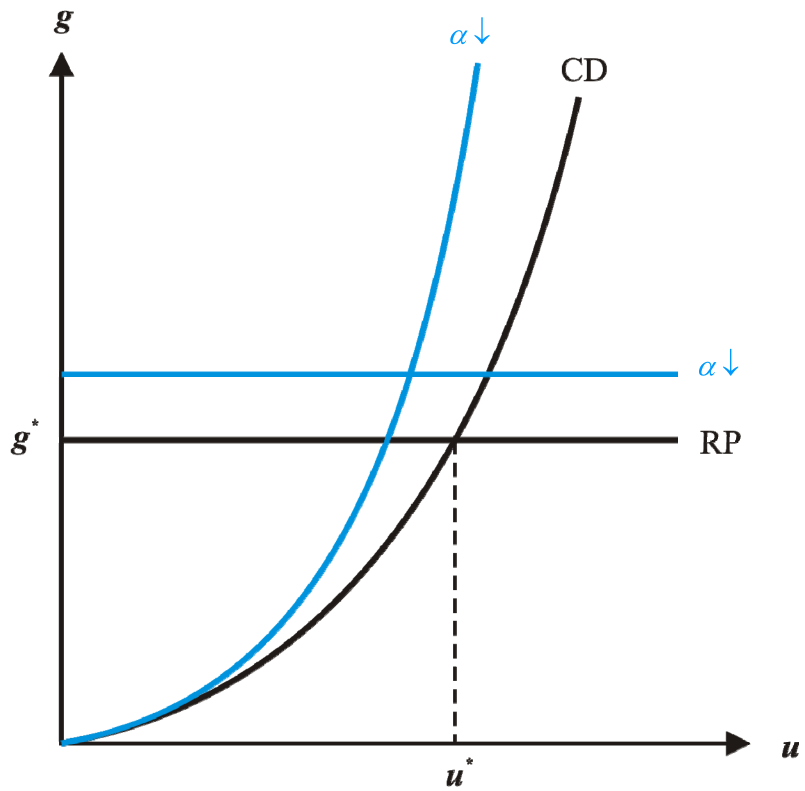

Figure 7: steady-state effects of a decrease in α

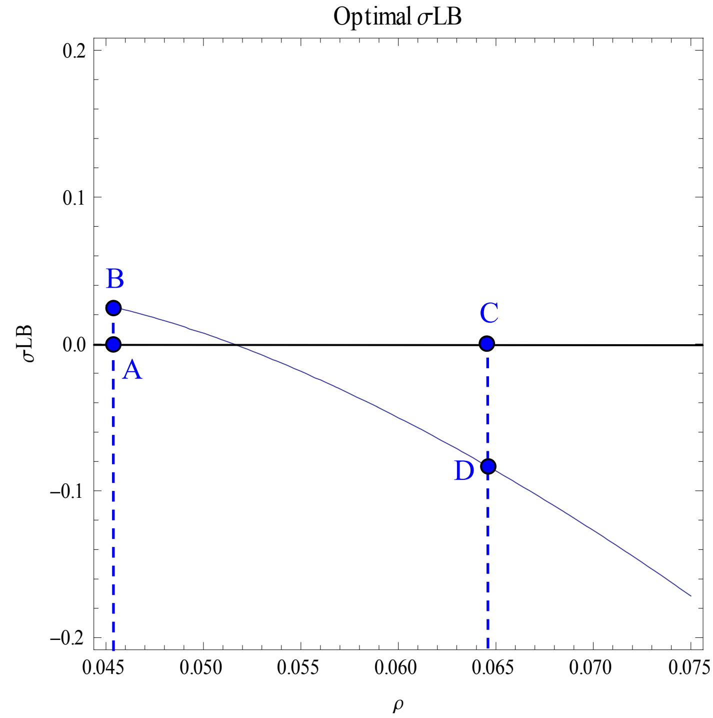

Figure 8a: welfare-maximizing level of σ_L^B ***as a function of*** $\rho + \chi \in$ **[0.045, 0.075]**

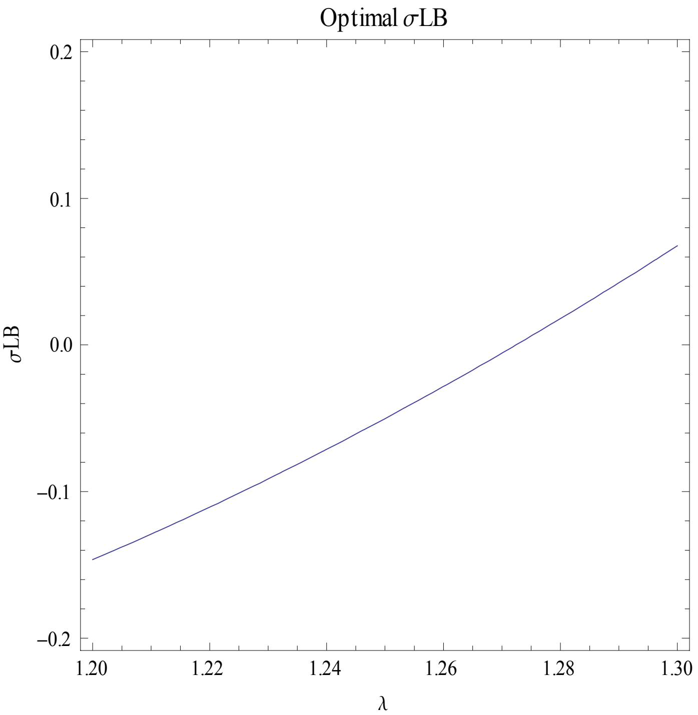

Figure 8b: welfare-maximizing level of σ_L^B ***as a function of*** $\lambda \in$ **[1.2, 1.3]**

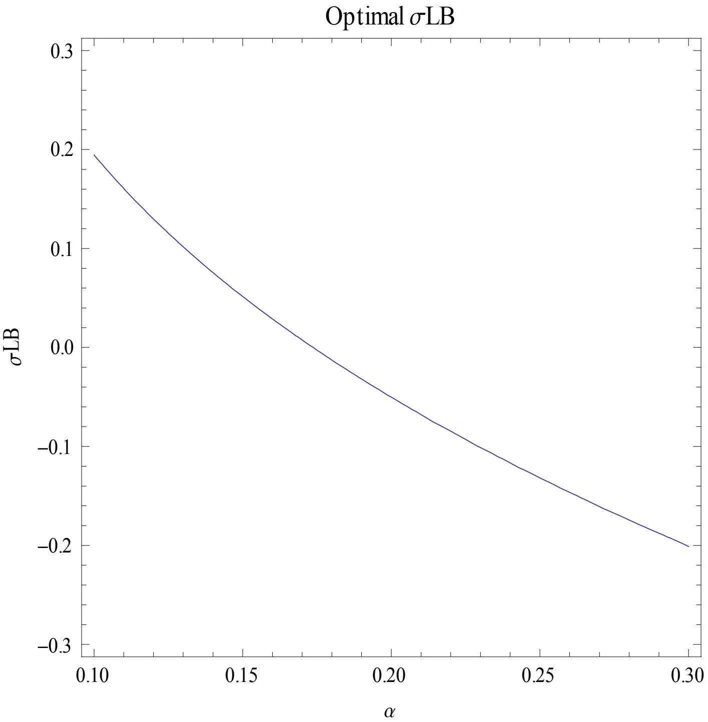

Figure 8c: welfare-maximizing level of σ_L^B ***as a function of*** $\alpha \in$ **[0.1, 0.3]**

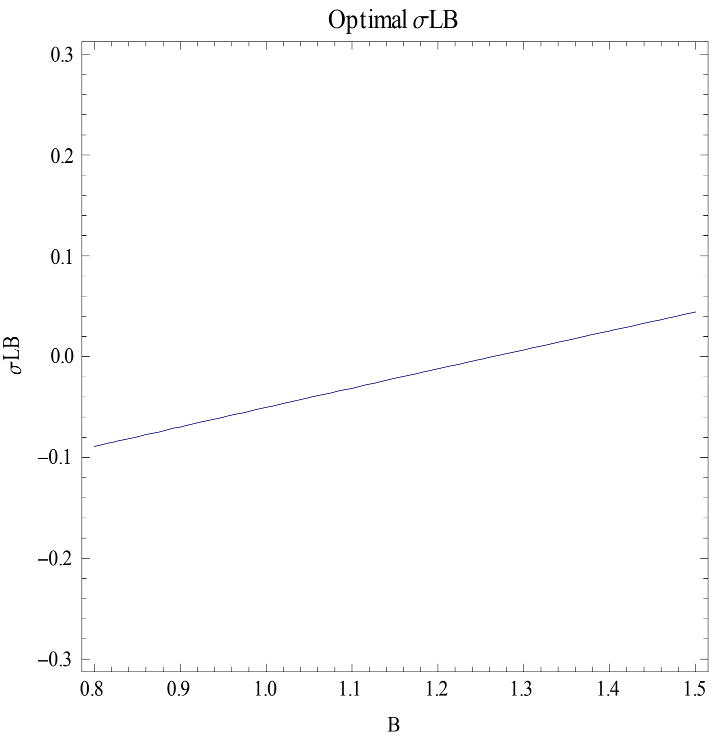

Figure 8d: welfare-maximizing level of σ_L^B ***as a function of B*** $\in$ **[0.8, 1.5]**

Table 1: Numerical steady-state equilibrium and comparative-static exercises

Benchmark parameters: $\sigma_L^B = 0, f = 0, \lambda = 1.25, \rho + \chi = 0.06, \alpha = 0.2, \phi = 0.01, N = 1, s = 0.01, A = 0.13, \eta = 0.6, \sigma_R = 0, B \equiv \beta\delta/\gamma = 1, \gamma = 1, w_L = 1$

Endogenous variables	**Benchmark solution**	$\sigma_L^B = 0.05$	$f = 0.05$	$\rho + \chi = 0.07$	$\alpha = 0.18$
Innovation rate I	0.04589	0.06735	0.04454	0.04027	0.05210
Type A industry share n_A	0.61194	0.54544	0.61902	0.66154	0.55559
Matching rate q	0.07237	0.08082	0.07237	0.07872	0.06513
Job finding rate p	0.31301	0.26522	0.31301	0.27590	0.36660
Vacancy rate v	0.35284	0.39575	0.34692	0.30583	0.40807
Unemployment rate u	0.08157	0.12059	0.08021	0.08726	0.07250
High-skilled wage rate w_H	2.42472	2.53428	2.45325	2.22091	2.23641
Per-capita consumption expenditure c	1.13655	1.08827	1.13825	1.12952	1.14779
RPA level X	0.01562	0.01718	0.01546	0.01453	0.01711
Firm value V^A	2.52567	2.17654	2.52944	2.30514	2.55064
Firm value V_L^B	0.03789	0.04353	0.03794	0.03227	0.03826
Firm value V_F^B	1.70012	1.53021	1.67801	1.50381	1.81622
Stock market value V^{TOT}	2.19886	1.87599	2.19881	2.02894	2.21636
Welfare H	0.16936	–0.01527	0.16216	–0.22383	0.38879
Utility growth rate $g = n_A I \log\lambda$	0.00627	0.00820	0.00615	0.00594	0.00646

Notes: Here we provide the main results of our Mathematica© Appendix, which is available upon request. In general, the benchmark parameters and outcomes are in line with the recent related theoretical growth literature that employ numerical simulations.

The stock market value V^{TOT} is defined as $V^{TOT} \equiv n_A V^A + (1 - n_A)\left[\phi V_L^B + (1-\phi) V_F^B\right]$.