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Creative Destruction and Unemployment in an Open Economy Model

by Ignat Stepanok

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Kiel Institute for the World Economy, Kiellinie 66, 24105 Kiel, Germany

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Keywords: Creative destruction, unemployment, trade liberalization.

JEL classification: O41, J63, F16.

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Creative Destruction and Unemployment in an Open Economy Model*

Ignat Stepanok†
Kiel Institute for the World Economy

November 1, 2014

Abstract

I develop a model of endogenous economic growth and search and matching frictions in the labor market. I study the effect of trade liberalization between two identical economies on unemployment. I solve for two versions of the growth model, the first one where trade liberalization has only a temporary effect on growth, a semi-endogenous growth model. In the second version trade liberalization has a permanent effect on growth, a fully endogenous growth model. I show that in both versions trade liberalization has a steady state effect on unemployment that is negative for countries with a relatively larger R&D sector and positive otherwise.

Keywords: Creative destruction, search, unemployment, trade liberalization.
JEL: O41, J63, F16.

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1 Introduction

This paper studies the effect of trade liberalization on long run unemployment in a model of endogenous growth, where growth is the result of a creative destruction process. Firm turnover, job creation and job destruction are therefore endogenous. Unemployment comes from search and matching frictions in the labor market and is affected by trade openness through the economy-wide distribution of resources dedicated to R&D and production of goods for consumption. I study two versions of the growth model: in the first one trade liberalization has only a temporary effect on growth, a semi-endogenous growth model. In the second version trade liberalization has a permanent effect on growth, a fully endogenous growth model. Both versions do not exhibit scale effects, in the sense that growth is not affected by the size of the population. In both versions I find that trade liberalization has a long run effect on unemployment: it leads to lower (higher) unemployment in countries with a relatively large (small) R&D sector.

One can easily think of channels other than growth connecting openness and unemployment levels: models with firm heterogeneity as in Felbermayr et al. (2011a), with asymmetric countries which have different factor endowments as in Davidson et al. (1999). A growth model is however particularly useful for analyzing the job creation and destruction process due to its inherent structure of endogenous firm turnover that depends on expected profits.

The empirical evidence on the long run connection between trade liberalization and aggregate unemployment is scarce. It is widely considered that trade openness has no effect on long run unemployment. Nevertheless some recent evidence shows the opposite. Dutt et al. (2009) provide evidence that a more open trade policy leads to lower unemployment. Kim (2011) finds that in the presence of rigid labor market institutions trade liberalization can lead to higher unemployment or reduce unemployment for economies with flexible labor markets. Felbermayr et al. (2011b) find that greater trade openness leads to lower levels of structural unemployment. Hasan et al. (2012) reach the conclusion that after lowering trade costs urban unemployment in Indian states with more flexible labor markets and larger share of workers in net exporting industries decreased.[1]

[1] A short run connection between trade and firm turnover clearly exists with periods of trade liberalization usually being followed by a higher exit rate of firms and productivity gains due to market redistribution to the more productive firms within industries. Evidence is provided by Gibson and Harris (1996), Pavcnik (2002), Gu, Sawchuk and Rennison (2003), Trefler (2004). Firm entry and exit leads to unemployment and retraining for the workers that have to switch jobs or occupations. Trefler (2004) documents that employment

Among the first models to address the question of growth and unemployment are the ones in Pissarides (2000)[2] and Aghion and Howitt (1994). Pissarides (2000) describes how growth changes the effective discount rate of a firm and makes it announce more vacancies, since within a growing economy hiring later becomes more costly. This capitalization effect leads to a negative relation between growth and unemployment. Aghion and Howitt (1994) point out to a creative destruction effect of growth on unemployment: more frequent innovations replacing old products result in more layoffs thus increasing unemployment. They find that within an exogenous growth model, growth increases unemployment, but the effect is non-linear, for very high values of growth unemployment decreases. After endogenizing growth, they show that unemployment is neutral to an increase in the frequency of innovation, which in itself increases steady state growth. Increasing the size of the innovation step on the other side, causes higher growth but is accompanied by higher unemployment.

Mortensen and Pissarides (1998) study a setting in which new technologies can be adopted either by upgrading of existing jobs at some cost or by laying off workers and hiring new ones. When the cost to adopt a new technology is low, productivity growth leads to lower unemployment. Mortensen (2005) builds a Schumpeterian growth model where unemployed workers are indifferent between being unemployed or doing R&D, effectively assuming away frictions in the R&D labor market. He studies the effects of employee bargaining power, payroll taxes and employment protection policies on growth and unemployment.

The above are closed economy models and both endogenous growth models in Aghion and Howitt (1994) and Mortensen (2005) exhibit scale properties, in the sense that increasing the labor force would increase economic growth. This is not a desirable property. As shown in Jones (1995a), there has been no increase in the productivity growth of France, Germany, Japan and the US since 1950, while there has been a steady increase in their populations. A number of growth models that take this fact into consideration have been subsequently developed starting with Jones (1995b).

On the connection between growth and unemployment, it is clear that both variables are endogenous and affect each other through a number of channels. In a regression of unemployment on growth of GDP for the OECD, Aghion and Howitt (1992) find an inverse

in Canadian industries opening up for trade decreased in the short run as a result of NAFTA. In this version of the model I do not look at transitional dynamics and therefore do not aim to contribute to the debate on the short run effect of trade on unemployment.

[2] The first edition of the book is from 1990.

U-shaped relationship: increasing growth would increase unemployment for lower growth rates and would decrease it for the highest growth rates. A positive correlation is documented in Caballero (1993). Bean and Pissarides (1993) look at unemployment, average labor productivity growth and total factor productivity growth. They do not find a clear and significant cross-country correlation for the OECD. Other studies find a negative relationship: Bruno and Sachs (1985), Ball and Moffitt (2001), Muscatelli and Tirelli (2001), Pissarides and Vallanti (2007), Miyamoto and Takahashi (2011).

The model with international trade, growth and unemployment closest to mine is the one developed in Sener (2001). Sener introduces population growth and removes the scale property mentioned above. He assumes an exogenous duration for how long it takes firms to find workers, which yields an exogenous arrival rate of workers to vacancies. Sener also solves for a semi-endogenous and a fully endogenous growth version of the model. In both versions unemployment depends on the rate at which workers are matched to vacancies, the birth rate of people and the innovation rate. In the semi-endogenous version, unemployment of the workers subject to search and matching frictions in the labor market remains unchanged by trade liberalization in the long run. In my model with an endogenous rate of workers being matched to jobs, I find that unemployment either increase or decreases depending on the size of the R&D sectors of the trading countries.

In the fully endogenous version of the model in Sener (2001) trade liberalization increases the innovation rate, which in turn increases unemployment of the workers subject to search and matching. In my model this channel is present. However due to the endogenous rate of workers finding a job, the effect on unemployment can be reversed again depending on the size of the R&D sector.

In the model developed in this paper economic growth is described as a process of creative destruction like in Grossman and Helpman (1991). Population grows and the size of the economy scale effect on growth is removed as in Segerstrom (1998) and in Dinopoulos and Thompson (1996). Trade liberalization is described as a reduction in an iceberg trade cost. Unemployment is generated by search and matching frictions in the labor market. A departure from the standard search and matching literature is that posting a vacancy is costless, similar to the approach of other Schumpeterian models of growth and unemployment.[3] The hiring process for the firm is not costless however. The time it takes to find workers is time it could have used to produce and sell its product. In order to keep the model tractable, one

[3] See Aghion and Howitt (1994), Sener (2001) and Mortensen (2005).

does have to avoid describing firms as waiting to first hire R&D workers and later workers for production. I assume that R&D is done with final consumption goods. In equilibrium unemployment depends on the innovation rate, the population growth rate and the rate at which workers find a job.

The main result of the model is that trade liberalization leads to a lower steady state unemployment level in countries with a relatively larger R&D sector and to higher steady state unemployment in countries with a relatively smaller R&D sector. Following liberalization fewer goods need to be produced in order for one to be sold on the foreign market. This decreases the number of vacancies, thus pushing unemployment up. It also increases expected profits of firms however, thus leading to a higher investment in R&D and more vacancies for R&D positions. The relative strength of the two channels is determined by the size of the R&D sector and in turn determines how trade liberalization affects unemployment.

The contribution of the current paper is twofold: first, it endogenizes the rate at which workers arrive to vacancies in a model without a growth scale effect. This yields results that differ from the ones in Sener (2001), showing that trade liberalization has an effect on steady state unemployment in a semi-endogenous growth model and that it can decrease unemployment in a fully endogenous growth model. Sener (2001) relies on an exogenous labor market tightness parameter.

The second contribution lies in integrating labor market frictions in the R&D sector. Sener (2001) assumes no labor market frictions in the R&D sector and in Mortensen (2005) R&D is done by people who are indifferent between remaining unemployed or doing R&D. In my model final goods are the input to the R&D process. They are in turn produced by workers that are subject to search frictions when looking for a job.

In the data, country R&D sectors are small in terms of the resources they employ as a share of all resources used in the economy. Incorporating this sector to be affected by labor market frictions is not going to be crucially important to unemployment through the slightly more or less people employed in it. As I will show however a small change in the size of the R&D sector has important consequences for the rate of innovation and for the sign and magnitude of the effect of trade liberalization on steady state unemployment. The R&D sector is important for unemployment because it affects the expected costs and benefits of innovating firms, which in turn are the ones that announce new vacancies within the larger production sector.

The next section lays out the model and shows the steady state equilibrium, section three

discusses its properties, section four concludes. Some of the more involving calculations are presented in the appendix.

2 The Model

There are two symmetric countries Home and Foreign. Consumer preferences are represented by a Cobb-Douglas utility function. Consumers either work and receive wages or are unemployed. Labor is the only input to production and grows at a constant rate n. There is a continuum of products of mass one, each denoted by ω. Half of the products originate from Home, the other half from Foreign. Each product has quality levels denoted by $j \in \mathbb{N}$. If j^* is the state-of-the art quality, then all lower qualities are open for production by any firm in both countries. The state-of-the-art quality however is protected by a patent and can be produced only by the firm that discovered it.

A basket of all goods sold on the market serves as the input to R&D. Firms invest in discovering higher qualities of existing products. When a state-of-the-art quality of a product is discovered the firm holding the patent announces the vacancies it needs to cover demand in both Home and Foreign. Announcing vacancies is costless and no other firm can announce a vacancy for the same quality of that specific product. It takes a certain amount of time to find the workers, which time is a function of the aggregate number of vacancies announced and the number of unemployed workers available for hiring in the economy. I assume that workers that have a job do not search for one. After a firm has the workers to start producing it immediately enters both its home and the foreign market, where it sells until it gets replaced by another firm that holds a blueprint for a higher quality level of the same product and has found the workers to produce. There are iceberg trade costs $\tau \geq 1$ for shipping goods between countries, meaning that τ units have to be produced in order for one to arrive and be sold on the foreign market.

2.1 Consumers

There is a fixed number of households in the economy and each household grows at a rate n. The number of consumers in the economy at time t therefore equals $L_t = L_0 e^{nt}$, where L_0 is the number of consumers at the initial period. Each consumer is infinitely lived and is either unemployed, during which period she does not receive any wages, or employed and earning

wages w. Households consist of many members, which share their income; any uncertainty related to individual unemployment is therefore taken away. The representative household maximizes present discounted utility

$$U \equiv \int_0^\infty e^{-(\rho-n)t} \left(\log[\upsilon_t] + u_t k\right) dt,$$

where ρ is the consumer's subjective discount rate, u_t is the share of unemployed people within the household and k is the utility from home production or leisure. The individual's static utility defined over all available products and product qualities at time t is

$$\log \upsilon_t \equiv \int_0^1 \log \left(\sum_j \lambda^j d(j, \omega, t) \right) d\omega, \tag{1}$$

where $d(j, \omega, t)$ is the amount consumed of product ω, quality j at time t and $\lambda > 1$ is the step-size of each innovation.

There are three steps of optimizing consumer utility. If $p(j, \omega, t)$ is the price of quality j of product ω at time t, then the consumer buys that quality level, which offers the lowest quality adjusted price $p(j, \omega, t)/\lambda^j$. If the quality adjusted price for two versions of the same product is the same, I assume that consumers buy the higher quality version. Let $p(\omega, t)$ be price of that quality level that offers the lowest quality adjusted price. Demand for all other quality levels is zero. The second optimization step yields demand for product ω, given per capita expenditure c_t at time t:

$$d(\omega, t) = \frac{c_t}{p(\omega, t)},$$

where $d(\omega, t)$ is demand for that quality j of product ω, which has the lowest quality adjusted price.

The third optimization step determines the consumer expenditure path $\dot{c}_t/c_t = r_t - \rho$, which is the familiar Euler equation. I follow Mortensen (2005) in choosing consumer expenditure to be the numeraire, thus $c_t = 1$ for all t, from which follows that $r_t = \rho$ for all t.

2.2 R&D Races

Firms do innovative R&D to improve on the state-of-the-art qualities of products. Leaders do not find it optimal to improve on their own products because they have strictly less to gain than a follower firm. Home firms do not improve on Foreign originating products and

vice versa. While this assumption would not be innocuous in a model with asymmetric countries, in a symmetric world allowing or not for a shifting comparative advantage in products between countries would not affect the endogenous growth rate or the level of unemployment.

Let $I_i(\omega,t)$ be the Poisson arrival rate of improved products from follower i's investment in R&D trying to improve on product ω at time t. A basket of goods is used as an input to the R&D process. I depart from the usual assumption that labor is the only input to R&D in order to simplify the labor market interactions. The R&D sector will still be influenced by search and matching frictions between firms and workers due to the fact that the goods needed to do R&D are produced by workers that are subject to those frictions. Let $l_i(\omega^*,\omega,t)$ denote the number of units of product ω^* used for the R&D process of firm i trying to improve on the quality of product ω at time t. The R&D technology has the same structure as the Cobb-Douglas utility function in (1) and depends on both the amount of goods used as input and their quality levels. Higher quality products contribute more strongly to the rate of innovation, which is the output of the R&D function. For every product ω, it is the quality j offering the lowest quality adjusted price that is used as an input by innovating firms. In equilibrium this happens to be the highest quality available.

$$I_i(\omega,t) = a_F \frac{\int_0^1 \lambda^{j(w^*)} l_i(\omega^*,\omega,t)d\omega^*}{X(\omega,t)\int_0^1 \lambda^{j(\omega^*)}d\omega^*}. \tag{2}$$

The parameter $a_F > 0$ is exogenous. The variable $X(\omega,t)$ changes with time and has a specific value for every product ω. If it increases, R&D becomes more costly, which means that more resources have to be invested in order to keep the arrival rate of new qualities constant. It is key in removing the growth scale effect present in Aghion and Howitt (1994) and Mortensen (2005). I will solve the model for two versions of the evolution of R&D difficulty $X(\omega,t)$: one in which it depends on the innovation rate $I_i(\omega,t)$ and another, where it depends on population size L_t.

The expression $\int_0^1 \lambda^{j(\omega^*)}$ denotes that as the average quality of products in the economy grows, R&D becomes more difficult. Due to the unit-elastic nature of the R&D technology through which individual products enter, innovating firms spend an equal amount of resources on every good at a given period t. An alternative and equivalent in its implications approach would be to introduce a final good as in Mortensen (2005), which would be produced by intermediate inputs. Those intermediate goods would be the set of all product

varieties available and individual product qualities would matter for the productivity of the final good technology.

A number of follower firms invest in improving the existing state-of-the-art quality of a given product ω. When taking into consideration all their efforts, the aggregate investment in R&D within a particular product variety ω would be $I(\omega,t) \equiv \sum_i I_i(\omega,t)$, also $l(\omega,t) = \sum_i \int_0^1 l_i(\omega^*,\omega,t)d\omega^*$. I solve for an equilibrium where the arrival rates of new product qualities are independently distributed over time, across firms and products ω, that is $I(\omega,t) = I$.

The reason to depart from the usual assumption that the input to R&D is labor is to avoid modeling several hiring stages for a firm. If one models the search first for finding R&D workers and then production workers the setup becomes much more involving. Mortensen (2005) simplifies by making the unemployed indifferent between staying unemployed or doing R&D, thus making employment in research yield strictly lower return in comparison to production. Sener (2001) simplifies by dividing the labor force into skilled and unskilled workers. The former are the ones doing R&D and are hired in a frictionless market, thus not suffering from unemployment throughout their lifetime. He cites empirical evidence showing that skilled workers suffer from substantially lower unemployment rates relative to unskilled workers: Nickel and Bell (1995). The only workers subject to the search and matching frictions and therefore to unemployment are unskilled workers. Although leading to greater tractability of the model, by assuming no labor market frictions for the skilled workers, one may overstate the incentive of the economy to redirect resources towards the R&D process and lead either to a higher steady state or transitional growth rate, depending on the assumptions on the R&D function employed.

In my model, using goods as input to the R&D sector indirectly makes that sector dependent on labor market frictions. The goods used for R&D are produced by workers who are not hired immediately and face the risk of being unemployed.

2.3 Product Markets

The production technology has constant returns to scale, it takes one unit of labor to produce one unit of any quality level of any product. The marginal cost of producing one unit is therefore equal to the wage rate w. Firms set prices, where the optimal price both at home and abroad is the limit price $p = \lambda w_{CF}$, where w_{CF} is the wage a hypothetical competitive

fringe firm would pay its workers. Due to the fact that the competitive fringe firm would be selling at marginal cost, w_{CF} would also be the price at which it would sell if it were to operate. Note that $w \neq w_{CF}$. I assume that it is costless to post a vacancy and that how to produce the one step lower quality of the product is common knowledge. Given those two assumptions, the quality leader would not price above λw_{CF}. If the price were to be higher, infinitely many firms can announce the vacancies to produce the one step lower quality of the same product. Those vacancies would be filled almost immediately and by pricing at marginal cost w_{CF} the competitive fringe firm could sell at a lower quality adjusted price than the leader, thus stealing away the entire market. Since quality leaders will price so that they would keep the entire market, in equilibrium there will be no competitive fringe firms selling and every product will be sold in its state-of-the-art version by the same quality leader in both markets Home and Foreign.

Given the identical prices of all goods, and the fact that R&D firms spend an equal amount of resources on every good, it follows that they purchase identical amounts of every good ω available on the market. Using this, I can rewrite the numerator of the R&D technology in (2) as $l(\omega, t) \int_0^1 \lambda^{j(w^*)}$ and reduce equation (2) to the following:

$$I = \frac{a_F l(\omega, t)}{X(\omega, t)}, \tag{3}$$

where $l(\omega, t)$ denotes the units of that basket, consisting of an equal amount of every product (its highest quality) available on the market, that are invested in the R&D process for improving on the quality of good ω at time t.

Profits of a producer are determined by what it sells at home and abroad. In order to export a firm needs to ship $\tau > 1$ units of a good to sell one unit abroad. Demand for a product is determined by what is being sold and used for consumption, $d(\omega, t)L_t$ and what is being sold and used for R&D $l(\omega, t)$.[4] Profits from selling at home and abroad after substituting for total demand are

$$\pi(\omega, t) = (2\lambda w_{CF} - \tau w - w) \left(\frac{1}{\lambda w_{CF}} + \frac{I x_t}{a_F} \right) L_t, \tag{4}$$

where $x_t \equiv X_t / L_t$ denotes per capita R&D difficulty. Expression (4) takes into consideration not only demand for consumption of good ω, which equals $\frac{1}{\lambda w_{CF}}$ (keeping in mind that per

[4]Note that $\int_0^1 l(\omega^*, \omega, t) d\omega^* = \int_0^1 l(\omega^*, \omega, t) d\omega$. That is, the amount of all goods ω^* used for the improvement of good ω is the same as the amount of good ω^* used for the improvement of all goods ω.

capita expenditure is the numeraire $c = 1$) but also the amount of that good that goes into the R&D process of all innovating firms $l(\omega,t) = \frac{Ix_t}{a_F}$, which is derived from (3). Since prices both at home and abroad are the same, this combined demand is identical both at home and abroad. Summing the markups at home $\lambda w_{CF} - w$ and abroad $\lambda w_{CF} - \tau w$ yields $2\lambda w_{CF} - \tau w - w$ in the brackets above.

2.4 Value Functions and the R&D Equation

Follower firms make a decision on how much to invest in learning how to produce the next quality level of a product ω. The investment in learning how to produce the next quality level j, starts immediately after quality level $j-1$ has been discovered. The Bellman equation of a follower that does R&D is

$$rv_F(j) = \max_{l_i} - \lambda w_{CF} l_i + I_i v_L(j+1), \tag{5}$$

where v_L is the value of a firm that holds a blueprint for a state-of-the-art product, but has not hired workers to start producing yet. l_i is the optimal number of units of every product ω the follower firm i will invest in the R&D process, λw_{CF} is the price of those products and I_i the instantaneous probability with which it discovers the state-of-the-art quality. In the analysis below, firm values and profits are all function of j, which I will omit for brevity.

The new local technological leader has to find workers in order to be able to produce and start selling. Until this happens the old incumbent continues producing. The larger the demand for the product, the higher the number of workers needed to be hired. Firms know exactly how much labor they would need in order to cover demand. The value of the technological leader searching for workers to start production is

$$v_L = e^{-ry} \left(\int_0^\infty I e^{-I\eta} \int_0^\eta \pi(\omega,t) e^{-(r-n)s} ds d\eta \right). \tag{6}$$

For now it suffices to say that y signifies the duration required for a vacancy to be filled. With an instantaneous probability I, the firm loses its position of a technological leader and η is the duration of the incumbency of an innovation, where η is drawn from a distribution with a probability density function equal to $Ie^{-I\eta}$. The newest quality level of the product will not be sold for a period y, since the new leader will also have to search for workers first.

The value of a follower firm v_F equals zero. From (5) I obtain

$$v_L = \frac{X(\omega,t)\lambda w_{CF}}{a_F}.$$

This expression determines the value of the investment in R&D for a follower firm. It must equal the expected gain from holding a patent for a state-of-the-art quality expressed in (6). When I solve the integral in (6) and substitute for profits from (4), I obtain:

$$\frac{x\lambda w_{CF}}{a_F} = e^{-ry}\frac{2\lambda w_{CF} - \tau w - w}{r + I - n}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right). \tag{7}$$

Equation (7) is the R&D equation and is one of the key equations in the model. For it to hold in steady state it must be the case that $x_t = x$ for all t. The R&D equation describes the incentive of firms to do R&D. More research leads to a higher relative R&D difficulty x. A higher level of R&D investments (left-hand-side of the equation) would be justifiable only in the presence of higher demand, which consists of demand for both consumption and R&D (right-hand side of the equation).

2.5 The Labor Equation

Workers are either employed in production or unemployed. The workers employed in production service the demand for consumption goods and for goods used in the R&D process. Since both consumption and R&D make use of the full array of goods available in a given market, every good produced at Home will cover demand both at Home and abroad. Total labor used for production denoted by L_{Pt} equals

$$L_{Pt} = \frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix_t}{a_F}\right)L_t.$$

If u_t is the number of unemployed workers, then the following must hold $(1 - u_t)L_t = L_{Pt}$. This equation means that everyone who is employed must be working in the production sector. Substituting for L_{Pt} and dividing both sides by L_t yields

$$1 - u = \frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right). \tag{8}$$

This is the labor equation. I know that x is constant in steady state. For the labor equation to hold in steady state it must be the case that u is also constant, which is why I drop the time subscript. The intuition behind the labor equation is very straightforward. All employed resources (on the left-hand side) must be divided between production intended for consumption $\frac{1+\tau}{2}\frac{1}{\lambda w}$ and production intended for R&D $\frac{1+\tau}{2}\frac{Ix}{a_F}$. I divide the two expressions by 2, because only a half of the products originate from one country. Higher production can be justified if more of the economy's resources are utilized, unemployment would have to be lower.

2.6 Unemployment

What remains is to find the number of vacancies and unemployed people. I will use a standard constant returns to scale matching function $m_t(U_t, V_t) = \phi U_t^{\gamma} V_t^{1-\gamma}$ that depends on the number of unemployed people $U_t = uL_t$ and the number of announced vacancies $V_t = vL_t$. The parameter $\phi > 0$ determines the efficiency of matching. Once a worker finds a job he or she does not continue to search, there is no on-the-job search. I define $q \equiv m(U_t, V_t)/V_t$ to be the rate at which a vacancy is filled and $p \equiv m(U_t, V_t)/U_t$ the rate at which a worker finds a job. For simplicity I assume that the times it takes to fill a vacancy y is deterministic. Contrary to the usual search and matching framework, where there is no population growth, here $y \neq 1/q$. In this model the time it takes to fill a vacancy y will depend not only on q, but also on the population growth rate n.[5]

The flow of vacancies is determined by several factors. First it is the announcements of technological leaders that have just discovered a state-of-the-art product. They only have a blueprint for a product, but no workers to produce. The arrival rate of those announcements is equal to the arrival rate of innovations I. Those vacancies announced at time t will have to cover demand at home and abroad at time $t + y$. Due to growing population demand for a product grows constantly at a rate n. Firms are able to anticipate this increase and timely announce the vacancies in order to be able to cover the increase in demand a period y from the time of the announcement. Lastly, the pool of vacancies is reduced by the matches between vacancies and unemployed workers.

$$\begin{aligned} \dot{V}_t &= I\frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right) L_{t+y} \\ &\quad + n\frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right) L_{t+y} - m(U_t, V_t). \end{aligned} \tag{9}$$

The number of matches at time t can be written

$$m(U_t, V_t) = I\frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right) L_t + n\frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right) L_t,$$

[5] One can raise the question, why given the matching function and that vacancy posting is costless, a firm does not announce infinitely many vacancies. If the vacancies are infinitely many, only some will be matched with a worker, since the workers are a finite number. Still, however, those workers will be more than the firm needs. It is sufficient to assume that the firm pays some infinitesimal cost to go through the bargaining process with all the workers matched to its vacancies before it decides to hire only some of them. This cost can be the time spent on bargaining. This would stop the firm from announcing inifinitely many vacancies.

but also as $m(U_t, V_t) = qV_t$. Combining those two expressions for $m(U_t, V_t)$ with the one for the evolution of vacancies (9), yields

$$q = \frac{n}{e^{ny} - 1}.$$

From here I can express

$$y = \frac{\ln\left(1 + \frac{n}{q}\right)}{n}. \tag{10}$$

The duration it takes to fill a vacancy y is negatively related to the rate at which workers "arrive" to vacancies q. It is easy to show that when taking the limit of the population growth rate n going to zero, y equals the standard $1/q$.[6]

The dynamics of the number of unemployed people is characterized by the following equation

$$\dot{U}_t = \dot{L}_t - m(U_t, V_t) + I\frac{1+\tau}{2}\left(\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}\right)L_t.$$

Newborn enter the pool of the unemployed immediately. The number of matches announced at time $t - y$ reduces unemployment at time t. At the rate I local leaders go out of business, which means unemployment for all their workers. This last inflow into unemployment is due to innovations that happened a period y earlier.

I divide by L_t and use $m(U_t, V_t) = pU_t$. With the help of the labor equation (8) I substitute for $1 - u$ to obtain in the end an expression for unemployment:

$$u = \frac{n + I}{p + n + I}. \tag{11}$$

This is a key equation in the model that determines the rate of unemployment in the economy. Aghion and Howitt (1994) find that the frequency of innovation is neutral to unemployment and that the size of the innovation step is positively related to unemployment. On the contrary, I find that the frequency of innovation I is positively related to unemployment and the innovation step is neutral. This is similar to what is found in Sener (2001).

Using the definition of the matching function I can write $v = \phi^{\frac{1}{\gamma}} u q^{-\frac{1}{\gamma}}$. I derive an expression for v from the equation for the evolution of vacancies (9) and the labor equation (8). I substitute that in $v = \phi^{\frac{1}{\gamma}} u q^{-\frac{1}{\gamma}}$ and for u from (11) to find $p = \phi^{\frac{1}{\gamma}} q^{1-\frac{1}{\gamma}}$.

[6] Applying l'Hôpital's rule yields $\lim_{n \longrightarrow 0} \frac{\ln\left(1+\frac{n}{q}\right)}{n} = \lim_{n \longrightarrow 0} \frac{1}{1+\frac{n}{q}} \frac{1}{q} = \frac{1}{q}$.

2.7 The Wage Bargaining Problem

In order to find wages w, I have to start from the price and wage setting problem for a competitive fringe firm. Although in steady state equilibrium there will be no operational competitive fringe firms it is their potential entry and pricing behavior that influences the price that quality leaders charge. Everyone knows how to produce qualities of products lower than the state-of-the-art. Let us denote the price charged by a competitive fringe firm by w_{CF}. Therefore if a quality leader chooses to raise its price above λw_{CF} a home competitive fringe firm can enter and cover the home market, while another foreign one would enter and cover the foreign market by selling at a lower quality adjusted price than the market leader.[7] Both competitive fringe firms would price at marginal cost w_{CF}. Since any firm can become a competitive fringe firm and at any point in time, competitive fringe firms have zero value and would charge a price equal to marginal cost.

I assume that workers of a hypothetical competitive fringe firm continue searching while on the job. Unemployed people would therefore be indifferent between staying unemployed or working for a competitive fringe firm. The wage paid to workers of competitive fringe firms will therefore equal the value of leisure k and competitive fringe firms would price at $w_{CF} = k$.

With this information in mind I move on to the bargaining problem of a quality leader with its workers. Let the bargaining power of a firm be $0 < \beta < 1$ and that of a worker $1-\beta$. This is a noncooperative bargaining game of the Rubinstein type, where the parties do not search while negotiating (see Binmore et al. 1986 for details). That way the outside option of the worker is not unemployed search, but the value of leisure. I follow Mortensen (2005) in this approach, because it leads to a much simpler setting. Let the wage paid by a quality leader be denoted by w. The bargaining game is defined by the following maximization problem:

$$w = \arg\max \left(2\lambda k - (\tau + 1)w\right)^{\beta} \left(w - k\right)^{1-\beta}.$$

Both parties do not search while negotiating. The outside option of the worker is the value of leisure. Protracting the bargaining process has no value for the firm, it can only gain the

[7] Since it is costless to post a vacancy, infinitely many competitive fringe firms can announce the vacancies to cover demand on each market. One of them would be able to start production within an arbitrarily short period of time at Home and another in Foreign.

markup from selling at home $\lambda k - w$ plus the markup from selling abroad $\lambda k - \tau w$.

Maximizing over the quantity that is to be produced is skipped, because with the given utility function, demand is such that producers would like to sell the lowest possible quantity at the highest possible price. The availability of competitive fringe firms as an entry threat determines the price at $\lambda w_{CF} = \lambda k$. There is therefore no over-hiring externality, where firms would increase size in order to reduce the workers' bargaining position. Solving yields the wage:

$$w = (1-\beta)\frac{2\lambda k}{\tau+1} + \beta k. \tag{12}$$

This equation pins down the wage as a function of exogenous variables only. It is clear that trade liberalization $\tau \downarrow$ increases the wage $w \uparrow$, which occurs due to the increasing profits that can be shared after shipping goods to the other country becomes cheaper.

3 The Steady State Equilibrium and Its Properties

Before defining the equilibrium I need to elaborate on the equation which determines the evolution of R&D difficulty $X(\omega, t)$. Following Sener (2001), I will explore two versions of the evolution of R&D difficulty $X(\omega, t)$. There are of course other approaches to tackle the scale effect property of the early growth models (see Dynopoulos and Syropoulos (2007) for instance), but the versions studied here are probably the most widely used ones. In the first approach, $X(\omega, t)$ depends on the innovation rate I and leads to a so called TEG model, where tariffs have a temporary effect on growth, as introduced in Segerstrom (1998). In the second version, R&D difficulty depends on population size and gives rise to a model where tariffs have a permanent effect on growth (PEG). It was introduced in Dinopoulos and Thompson (1996). Both of those versions of the R&D technology take care of the population scale effect and allow for a balanced growth path in an economy with a growing population. This happens due to the steadily increasing R&D difficulty $X(\omega, t)$, which means that more resources have to be dedicated to R&D in order to preserve the same product quality innovation rate I in steady state.

To calculate the economy's steady state growth rate I use the expression for the individual's static utility (1) and substitute for demand. Differentiating with respect to time and solving the integral yields the economic growth rate:

$$g \equiv \frac{\dot{\upsilon}_t}{\upsilon_t} = I \ln \lambda.$$

It increases in the rate of innovation I and the step-size of each innovation λ.

3.1 The TEG Version of the Model

In the TEG version of the model, the R&D difficulty parameter evolves according to the following process $\frac{\dot{X}(\omega,t)}{X(\omega,t)} = \mu I(\omega, t)$. The parameter $\mu > 0$ is exogenous and as previously mentioned, in equilibrium $I(\omega, t)$ is the same for every ω. This technology has the property that R&D becomes increasingly more difficult as more R&D is done on a product. From the fact that relative R&D difficulty x is constant in steady state, it follows that $\frac{\dot{X}(\omega,t)}{X(\omega,t)} = \frac{\dot{L}_t}{L_t} = n$. This also means that the innovation rate is pinned down by the population growth rate and the R&D difficulty parameter $I = \frac{n}{\mu}$.

The steady state equilibrium in this model is defined by the set (x, w, u, q, y), which can be solved for, using the R&D equation (7), the labor equation (8), the expression for unemployment (11), expression (10), which pins down the duration to fill a vacancy y and the equation that determines the wage (12).

I substitute for the wage from (12) in the R&D equation (7) and then for $\frac{1}{\lambda k} + \frac{Ix}{a_F}$ from the labor equation (8) to obtain an expression for x. I then substitute this expression for x back into the labor equation to obtain an equation in one unknown q. For brevity I will not be substituting for $y = \frac{\ln\left(1+\frac{n}{q}\right)}{n}$. I am able to show that if

$$\Omega \equiv 2\frac{Ie^{-ry}\beta}{r + I - n} > 1 \tag{13}$$

holds, then trade liberalization $\tau \downarrow$ leads to a lower rate at which workers arrive to vacancies q, which in turn means a higher steady state value of p. If (13) does not hold then the effect on p is reversed. Inequality (13) is clearly not a simple expression in exogenous variables only: the arrival rate of workers to vacancies q, contained in y, can be solved for numerically. The expression nevertheless has a clear economic meaning.

Using the labor equation, the share of all productive resources in the economy dedicated to R&D can be written as:

$$\Psi \equiv \frac{\frac{Ix}{a_F}}{\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}}.$$

The expression is valid for both the TEG and PEG versions of the model. I substitute for the denominator using the R&D equation (7) and then for the wage from (12) to obtain

$$\Psi = \Omega\left(1 - \frac{\tau + 1}{2\lambda}\right).$$

The details are spelled out in the appendix. Given $\lambda > \tau$, Ψ increases in Ω. This would hold for every combination of τ and q. Inequality (13) holds for an economy with a higher share of (non-idle) resources dedicated to R&D and does not hold for an economy where relatively fewer resources are dedicated to the R&D sector.

Turning to the unemployment equation (11), it is clear that the unemployment rate u is inversely related to p and any changes to u would come from changes in p, given an innovation rate I that is constant in steady state and an exogenous population growth rate n. The steady state growth rate g remains unaffected by trade liberalization as is standard for this type of an endogenous growth model. I summarize the results in the following proposition:

Proposition 1 *In the TEG model trade liberalization represented by a bilateral reduction in the iceberg trade cost $\tau \downarrow$:*

a) increases the rate at which workers find a job $p \uparrow$ if (13) holds and decreases it otherwise.

b) reduces (increases) unemployment u if a relatively larger (smaller) share of the country's resources are dedicated to R&D, i.e. if (13) holds (does not hold).

c) has no effect on the rate of innovation I or on the long run economic growth rate g.

The total production within the economy is allocated for three purposes: goods used for consumption, goods used for R&D and goods used to cover the iceberg trade cost when exporting. Consumption expenditure is the numeraire and given a constant price index (not to be confused with a quality-adjusted price index) the amount of goods used for consumption does not adjust. Trade liberalization increases firms' profits, which is mitigated by the fact that wages increase. That in turn increases the incentive for firms to innovate, which increases demand for every product because more of it is needed for the R&D sector. The R&D sector is the first channel through which aggregate production is positively affected by trade liberalization.

At the same time lower variable costs to trade mean that fewer goods are produced in order for the same amount to arrive abroad. Less is "lost" on the way, since transportation has become more efficient. This second channel reduces the amount produced by firms. Which of the two above-mentioned channels is more prominent will determine how trade liberalization affects aggregate production and in turn unemployment.

The equation through which the importance of the first channel can be described is the R&D equation (7). It is fairly intuitive, its left-hand side (LHS) describes the cost of doing R&D and the right-hand side (RHS) the benefit. It becomes clear that a higher relative R&D difficulty (the LHS of the equation), can be supported either by a higher "discounted markup" or by higher demand for products (the RHS of the equation). A higher discounted markup means that it is more profitable to be a producer, which leads to more R&D in the economy and hence also to a higher relative share of R&D spending. The opposite is also true, for a higher share of R&D spending in the economy, the discounted markup must be higher.[8]

Suppose we keep y fixed for a moment in the R&D equation. There is a set of the exogenous parameters and a value of y, which comprise the expected discounted markup, for which an increase in R&D difficulty x would lead to a higher cost of doing R&D on the LHS to be exactly offset by a higher benefit coming from higher demand on the RHS. In this specific case y would not need to adjust in order to balance the R&D equation. For a high expected discounted markup however a higher x would mean higher cost to do R&D on the LHS and a disproportionately higher benefit from increasing demand on the RHS. In order for the R&D equation to hold, e^{-ry} would have to decrease, which is the same as saying that q would have to decrease or p to increase. And vice versa, for a relatively smaller expected discounted markup, an increase in x on the LHS would be counterbalanced only by an increase e^{-ry} on the RHS.

In what direction and how much labor market tightness adjusts depends on how profitable it is to produce relative to the cost of innovating. When demand increases producing is per unit more profitable in an R&D intensive economy. Innovating follower firms would announce more vacancies relative to those announced in an economy with a smaller R&D sector that experiences the same expansion in demand.

[8] Since consumption expenditure is the numeraire, revenue in the economy depends on the relative size of the R&D sector: higher revenue for firms can come only from a larger R&D sector. The expected discounted markup

$$M \equiv e^{-ry}\frac{\beta 2\lambda k - \beta k(\tau + 1)}{r + I - n}$$

is proportionate to the share of the R&D sector Ψ. The ratio Ψ/M simplifies to

$$\Psi/M \equiv I/(\lambda k).$$

The first channel described above is more prominent than the second in an economy with a sufficiently large share of its productive resources dedicated to R&D: trade liberalization decreases unemployment.

It is interesting to contrast the result of how trade liberalization affects unemployment with the one in Sener (2001). Sener separates labor into two categories, skilled and unskilled. A simplifying assumption is that there are no search frictions for the skilled workers and they are the ones that do R&D. Due to the exogenous labor market tightness parameter, p and q are constants. The unemployment rate of the unskilled workers that are subject to search and matching frictions in their labor market is therefore independent of τ in a TEG world.

In Sener (2001) aggregate unemployment, which consists of the number of unskilled unemployed workers divided by all workers, skilled and unskilled, decreases as a result of trade liberalization. This happens because more workers choose to become skilled and in steady state they are not subject to search and matching frictions. In a model with labor market frictions in both the production and R&D sector and with an exogenous labor market tightness parameter, unemployment would not respond to changes in τ however. Endogenizing labor market tightness gives the long run effect of trade liberalization on unemployment.

To illustrate the results in the above proposition I solve the model numerically as well. The benchmark parameters I use are the following: $\rho = 0.04$, $n = 0.018$, $\lambda = 1.4$, $\gamma = 0.5$, $\beta = 0.75$, $a_F = 1$, $\mu = 0.3029$, $k = 1.1$, $\phi = 1.4$ and τ changing from 1.3 to 1. The discount rate ρ is set to match the 4% real interest rate as in McGrattan and Prescott (2005). According to Kremer (1993) the world population growth rate during the 1980 was 1.8%. The markup of price over marginal cost from selling at home λ, is 40%. The markup for selling abroad λ/τ is between 7% and 40%, which are numbers within the range reported in Morrison (1990). The choice of a_F is not important for the TEG version of the model; it is a scale parameter, which affects only the magnitude of relative R&D difficulty x and nothing else. Regardless of the choice of k, a consumer would always strictly prefer to work than to enjoy home production because the endogenous wage is always higher than the value of leisure $w > k$, which can be seen in the equation for the wage (12) since $\frac{2\lambda k}{\tau+1} > 1$. The choice of k has to also be such that the labor equation (8) holds. Roughly speaking, the left-hand side can not exceed one, since $0 < u < 1$. Given a world in which $\tau = 1$ aggregate demand for a product can not exceed one, i.e. $\frac{1}{\lambda k} + \frac{Ix}{a_F} < 1$, which means that $k > \frac{1}{\lambda}$. To be consistent with the evidence presented in Jones (2005) where the average US GDP per capita growth rate for the period 1950 to 1994 is reported to be 2%, I set the technology

parameter $\mu = 0.3029$. The parameter determining the efficiency of the matching process ϕ is set in such a way that labor market tightness v/u generated by the model ranges between 0.1877 and 0.6396. This is in line with JOLTS and unemployment data provided by the U.S. Bureau of Labor Statistics, where the monthly rate of labor market tightness varies between 0.19 and 0.63 for the period 2003-2012[9]. The estimate of year 2000 tariff-equivalent costs to trade between the US and Canada was 25% and between the US and Mexico 33% according to Novy (2011). I therefore solve the model for a change in variable trade costs from $\tau = 1.3$ to $\tau = 1$. Given the choice of the bargaining parameter β, Ω varies between 1.074 for $\tau = 1.3$ and 1.070 for $\tau = 1$. Given the chosen parameters inequality (13) holds, and we would expect for trade liberalization to lead to an equilibrium where workers find jobs faster (higher p) and unemployment is lower.

$\beta = 0.75$	x	I	w	p	u	v	g
$\tau = 1.3$	2.59	0.0594	1.159	0.940	0.076	0.034	0.02
$\tau = 1.2$	3.26	0.0594	1.175	0.991	0.072	0.036	0.02
$\tau = 1.1$	3.99	0.0594	1.191	1.050	0.068	0.038	0.02
$\tau = 1.0$	4.81	0.0594	1.210	1.119	0.064	0.041	0.02

Table 1.

This is indeed what happens, unemployment decreases from 7.6% for $\tau = 1.3$ to 6.4% for the free trade case $\tau = 1$. The innovation rate I and the growth rate g remain constant in steady state, however the economy shifts resources to R&D on the transitional path because in steady state relative R&D difficulty x is higher. This means that in equilibrium more of the economy's resources are dedicated to the R&D sector.

To show the case of increasing unemployment as a result of trade liberalization, I change the bargaining parameter β from 0.75 to 0.65. Ω varies between 0.935 for $\tau = 1.3$ and 0.937

[9] To obtain those numbers using JOLTS I have divided total monthly, nonfarm, U.S. job openings by the monthly number of all unemployed individuals above the age of 16 in the U.S. for the period 2003-2012. Both measures are not seasonally adjusted.

for $\tau = 1$, which given (13) would predict higher unemployment in a more open economy.

$\beta = 0.65$	x	I	w	p	u	v	g
$\tau = 1.3$	2.19	0.0594	1.183	0.671	0.103	0.0238	0.02
$\tau = 1.2$	2.74	0.0594	1.205	0.650	0.106	0.0229	0.02
$\tau = 1.1$	3.34	0.0594	1.228	0.628	0.109	0.0221	0.02
$\tau = 1.0$	3.99	0.0594	1.254	0.606	0.113	0.0212	0.02

Table 2.

Unemployment does increase from 10.3% for $\tau = 1.3$ to 11.3% for the free trade case $\tau = 1$. In addition to the increasing unemployment brought about by the lower rate at which unemployed workers are matched with jobs p, trade liberalization increases relative R&D difficulty x as in the previous parameterization. Wages unambiguously increase as previously found.

3.2 The PEG Version of the Model:

The PEG version of the model is based on the following function for the evolution of R&D difficulty: $X(\omega, t) = mL_t$. The parameter $m > 0$ determines how much more costly it becomes to do R&D with a growing population. It is now the size of the population as opposed to the innovation rate as in the TEG version of the model that determines R&D difficulty. This changes the implications of the model significantly. Relative R&D difficulty $x \equiv X_t/L_t = m$ is immediately pinned down in steady state equilibrium. The equilibrium is defined by the set (I, w, u, q, y). Given that the economic growth rate g depends on I, it would be affected by changes in the exogenous policy variables as well. Trade has a permanent effect on steady state growth. I solve using the same equations: the R&D equation (7), the labor equation (8), the unemployment equation (11), the expression for the duration to fill a vacancy (10) and the equation that determines the wage (12).

I substitute for unemployment from the unemployment equation (11) into the labor equation (8) and solve for p. I then substitute for $x = m$ in the R&D equation (7) and solve for I. The expression for I depends on q which I can substitute for using $p = \phi^{\frac{1}{\gamma}} q^{1-\frac{1}{\gamma}}$ and the previously found expression for p, which is a function of one other endogenous variable, the innovation rate I. That way I arrive at one equation in one unknown I. I am able to show that $\frac{\partial I}{\partial \tau} < 0$, which means that trade liberalization $\tau \downarrow$ leads to a higher innovation rate $I \uparrow$. The details are spelled out in the appendix.

It is clear from the unemployment equation (11) that the effect of trade liberalization on unemployment will depend on the changes in p and the innovation rate I. Since the innovation rate always increases with trade liberalization, unemployment will increase through that channel. The higher firm turnover rate leads to more layoffs and thus more frequent vacancy announcements, which need time to be filled. In order to know the final effect of trade liberalization on steady state unemployment however, one needs to know not only the sign but also the magnitudes of $\frac{\partial I}{\partial \tau}$ and $\frac{\partial p}{\partial \tau}$. The exercise of finding them and the sign of $\frac{\partial p}{\partial \tau}$ is not tractable, which is why in order to show how trade liberalization affects unemployment I solve the model numerically. For now I summarize the analytical results in the following proposition:

Proposition 2 *In the PEG model trade liberalization represented by a bilateral reduction in the iceberg trade cost $\tau \downarrow$ leads to:*

a) an unchanged relative R&D difficulty x.

b) a higher rate of innovation $I \uparrow$ and a higher long run economic growth rate $g \uparrow$.

The benchmark parameters I use are the same as the ones used in the numerical simulation of the TEG version of the model with a few exceptions: $m = 1.8$ instead of $\mu = 0.3029$, where m is the new variable of the PEG R&D difficulty process and has a similar meaning to μ. This time $\phi = 1.1$. The choice of m and ϕ has been motivated with the intention to match the growth rate of 2% reported in Jones (2005) and JOLTS data on the vacancy unemployment rate ratio v/u.[10] I set the bargaining parameter initially at $\beta = 0.55$ and again solve for a change in τ from 1.3 to 1. The growth rate $g = I \ln \lambda$ is between 1.99% for $\tau = 1.3$ and 4.24% for $\tau = 1$.

$\beta = 0.55$	I	w	q	p	u	v	g	Ψ
$\tau = 1.3$	0.0591	1.207	2.3646	0.5117	0.1309	0.0283	0.0199	0.1407
$\tau = 1.2$	0.0795	1.235	1.8244	0.6632	0.1282	0.0466	0.0268	0.1807
$\tau = 1.1$	0.1018	1.265	1.4546	0.8318	0.1259	0.0720	0.0342	0.2200
$\tau = 1.0$	0.1259	1.298	1.1895	1.0172	0.1240	0.1060	0.0424	0.2588

Table 3.

As expected trade liberalization leads to a higher arrival rate of innovations I. As a result of this the growth rate increases. The unemployment rate increases through that channel as

[10] In the below simulations v/u ranges from 0.127 to 0.855.

well. At the same time, the rate at which unemployed people find a job p increases strongly enough to overturn the effect of the higher innovation rate and leads to an overall lower rate of unemployment decreasing from 13.09% at $\tau = 1.3$ to 12.40% at $\tau = 1$.

Reducing the bargaining power of firms to $\beta = 0.50$ decreases the share of the R&D sector for every level of trade openness τ and as a result changes the relation between trade openness τ and unemployment u.

$\beta = 0.50$	I	w	q	p	u	v	g	Ψ
$\tau = 1.3$	0.0505	1.219	3.0864	0.3920	0.1487	0.0189	0.0170	0.1228
$\tau = 1.2$	0.0685	1.250	2.4694	0.4900	0.1501	0.0298	0.0231	0.1596
$\tau = 1.1$	0.0880	1.283	2.0425	0.5924	0.1518	0.0440	0.0296	0.1962
$\tau = 1.0$	0.1092	1.320	1.7317	0.6987	0.1540	0.0622	0.0368	0.2324

Table 4.

As previously, the innovation rate I and the wage w are higher in a more open economy. The rate at which unemployed people are matched to vacancies p also increases but this time not sufficiently to overturn the effect of the innovation rate. Unemployment as a result of this increases. It is clear from the expression for steady state growth $g = I \ln \lambda$ that a higher innovation rate results in higher growth.

Although I can not arrive at a condition similar to (13) that would determine how trade liberalization affects unemployment, it is possible to see from the above numerical example that in the economy with the relatively larger R&D sector (higher Ψ, given the same τ) trade liberalization decreases unemployment (Table 3) and increases it otherwise (Table 4).[11] In a setting where the steady state innovation and growth rates are affected by trade liberalization, like the PEG model here, the standard creative destruction effect plays a role for unemployment as well. More frequent innovation (higher growth) reduces the expected duration of a firm's monopoly and leads to a higher firm turnover rate, this means more frequent job-worker separation and higher unemployment.

In a model with an exogenous labor market tightness and therefore an exogenous arrival rate of workers to vacancies as in Sener (2001), the unemployment rate would respond to

[11] It is easy to see that there is a large overlap between the size of the R&D sector in the two states above: Ψ varies between 0.1407 and 0.2588 in the state where $\beta = 0.55$ and between 0.1228 and 0.2324 in the state where $\beta = 0.50$. Since Ψ changes with τ it is important to compare the values of Ψ in the two states for a given τ. The bargaining parameter β directly affects the size of the R&D sector. Comparing two states with a larger difference in β would result in a greater difference in Ψ between states.

trade liberalization only through the innovation rate, since it is only the innovation rate that responds to changes in τ, see equation (11). Given an increasing innovation rate unemployment would unambiguously increase as is the case in Sener (2001) for unskilled workers in whose labor market there are search and matching frictions.[12] I show however that endogenizing the rate at which workers find a job p can reverse the effect of trade liberalization on unemployment.

4 Conclusion

This paper builds a model of endogenous growth where newer qualities of products replace old ones and make them obsolete. The process of creative destruction introduces an endogenous entry and exit rate of firms that have to search for workers before they can start producing. R&D is performed using a basket of all consumption goods available within the economy, thus incorporating the labor market frictions into the R&D sector. I solve for two versions of the evolution of R&D difficulty. In the first one, R&D difficulty increases depending on the innovation rate and yields a semi-endogenous growth model without a scale effect. Trade liberalization has no permanent effect on growth. Unemployment however is affected in steady state by trade liberalization. Openness means that fewer goods need to be produced in order for one to be sold abroad, thus reducing vacancies. It also means that it is more profitable to be a product quality leader, which increases the R&D effort of follower firms. In order to cover the needs of those innovating followers, the economy switches resources towards the R&D sector and more vacancies are announced by producing incumbents. The strength of those two opposing effects is determined by the size of the R&D sector. Unemployment decreases for countries with a relatively large R&D sector and increases in countries with a relatively small R&D sector.

In a second version of the model R&D difficulty evolves depending on the level of population. This yields a so-called fully endogenous growth model, in which the growth rate is affected by trade openness in steady state. In addition to the other two already described

[12] In Sener (2001) due to the presence of skilled workers and the fact that they do not suffer unemployment, a more open economy which tends to shift resources towards the R&D sector, would mean that fewer people are subject to search and matching frictions and aggregate unemployment defined by the number of the unskilled unemployed divided by the sum of all skilled and unskilled workers might decrease depending on parameters of the model.

channels of how openness affects unemployment, there is a third one: the higher equilibrium growth rate means more frequent firm turnover and job destruction. Steady state unemployment can again increase or decrease depending on the relative size of the R&D sector.

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Appendix

The Wage Bargaining Problem

The quality leader firm's bargaining problem with workers is defined by:

$$w = \arg\max \left(2\lambda k - (\tau+1)w\right)^{\beta} (w-k)^{1-\beta}.$$

Solving yields

$$\begin{aligned}
(\tau+1)\beta \left(2\lambda k - (\tau+1)w\right)^{\beta-1} (w-k)^{1-\beta} &= (1-\beta)(w-k)^{-\beta} \left(2\lambda k - (\tau+1)w\right)^{\beta} \\
(\tau+1)\beta (w-k) &= (1-\beta)2\lambda k - (1-\beta)(\tau+1)w \\
w &= (1-\beta)\frac{2\lambda k}{\tau+1} + \beta k.
\end{aligned}$$

The TEG Version of the Model

I rewrite the labor equation (8) as

$$(1-u)\frac{2}{1+\tau} = \frac{1}{\lambda k} + \frac{Ix}{a_F}.$$

I substitute for the wage from (12) in the R&D equation (7):

$$\frac{x\lambda k}{a_F} = e^{-ry}\frac{\beta 2\lambda k - \beta k(\tau+1)}{r+I-n}\left(\frac{1}{\lambda k} + \frac{Ix}{a_F}\right)$$

and then for $\frac{1}{\lambda k} + \frac{Ix}{a_F}$ from the labor equation above to obtain:

$$x = a_F e^{-ry}\beta \frac{1}{\lambda}\frac{2\lambda - \tau - 1}{r+I-n} 2 \frac{1-u}{1+\tau}.$$

I use that expression for x in the labor equation (8) to obtain:

$$\left(1 - \frac{n+I}{\phi^{\frac{1}{\gamma}} q^{1-\frac{1}{\gamma}} + n + I}\right)\left(\frac{1}{1+\tau} - \frac{I}{\lambda}\frac{e^{-ry}\beta}{r+I-n}\frac{2\lambda - \tau - 1}{1+\tau}\right) = \frac{1}{2\lambda k}, \qquad (14)$$

where I have substituted for unemployment from (11) and then for $p = \phi^{\frac{1}{\gamma}} q^{1-\frac{1}{\gamma}}$ to express

$$1 - u = 1 - \frac{n+I}{\phi^{\frac{1}{\gamma}} q^{1-\frac{1}{\gamma}} + n + I}.$$

Clearly the left-hand side of (14) decreases as q increases. For brevity I am not substituting for $y = \frac{\ln\left(1+\frac{n}{q}\right)}{n}$. What is important, is to keep in mind that $\partial y / \partial q < 0$.

I am interested in how the left-hand side of (14) changes as a results of a lowering in τ. Since only the expression in the second brackets contains τ, let it be denoted by B and for brevity let also $A \equiv \frac{I}{\lambda}\frac{e^{-ry}\beta}{r+I-n}$. Then,

$$\begin{aligned}\frac{\partial B}{\partial \tau} &= -\frac{1}{(1+\tau)^2} - A\left(\frac{-(1+\tau)-2\lambda+\tau+1}{(1+\tau)^2}\right) \\ &= \frac{A2\lambda - 1}{(1+\tau)^2}.\end{aligned}$$

The denominator is positive. The numerator is positive if $A2\lambda > 1$ or after substituting for A:

$$\Omega \equiv 2\frac{Ie^{-ry}\beta}{r+I-n} > 1.$$

If the above inequality holds, then $\frac{\partial B}{\partial \tau} > 0$.

The right-hand side of (14) remains unchanged as a result of a lower τ, while the left-hand side decreases if $\frac{\partial B}{\partial \tau} > 0$. This can be offset only through a falling q which increases the left-hand side. From this follows that trade liberalization, given that $A2\lambda > 1$ holds, leads to a lower q. This in turn means that p increases.

If $A2\lambda < 1$, then $\frac{\partial B}{\partial \tau} < 0$, which would mean that the left-hand side of (14) increases when τ decreases. This can be offset by a rising q, which would decrease the left-hand side. This in turn would mean that p would decrease.

Next I show that a higher Ω corresponds to a higher share of resources dedicated to R&D in the economy. Let that share be denoted by Ψ. Using the labor equation, Ψ can be written as:

$$\Psi \equiv \frac{\frac{Ix}{a_F}}{\frac{1}{\lambda w_{CF}} + \frac{Ix}{a_F}}.$$

Using the R&D equation (7), the denominator can be written as

$$\frac{x\lambda k}{a_F}\frac{r+I-n}{2\lambda k - \tau w - w}\frac{1}{e^{-ry}}.$$

I substitute for in the expression for Ψ:

$$\Psi = \frac{I}{\lambda k}\frac{e^{-ry}}{r+I-n}(2\lambda k - \tau w - w).$$

I then substitute for the wage from (12) and obtain:

$$\begin{aligned}\Psi &= \frac{I}{\lambda k}\frac{e^{-ry}}{r+I-n}\left(2\lambda k-(\tau+1)k\left((1-\beta)\frac{2\lambda}{\tau+1}+\beta\right)\right)\\ &= \frac{I}{\lambda}\frac{e^{-ry}\beta}{r+I-n}\left(2\lambda-\tau-1\right)\\ &= \Omega\left(1-\frac{\tau+1}{2\lambda}\right).\end{aligned}$$

Given $\lambda > \tau$, Ψ increases in Ω. This would hold for every combination of τ and q (keeping in mind that y depends on q).

The PEG Version of the Model

In this section I show how I find the sign of $\frac{\partial I}{\partial \tau}$. In the labor equation (8) I substitute for unemployment and for $x = m$ and solve for p:

$$\begin{aligned}\frac{p}{p+n+I} &= \frac{1+\tau}{2}\left(\frac{1}{\lambda k}+\frac{Im}{a_F}\right)\\ p &= \frac{\frac{1+\tau}{2}\left(\frac{1}{\lambda k}+\frac{Im}{a_F}\right)}{1-\frac{1+\tau}{2}\left(\frac{1}{\lambda k}+\frac{Im}{a_F}\right)}(n+I)\\ p &= \frac{n+I}{\frac{2}{1+\tau}\left(\frac{1}{\lambda k}+\frac{Im}{a_F}\right)^{-1}-1}.\end{aligned}$$

Keeping in mind that $p = \phi^{\frac{1}{\gamma}}q^{1-\frac{1}{\gamma}}$. Using that and (10) I can write $e^{-ry} \equiv z(I,\tau)$, where I substitute for p from the expression above. e^{-ry} is a function of I and τ. Keeping I constant, a decreasing τ, decreases p. Lower p means a higher q, which in turn means higher e^{-ry}. I can therefore write that $\frac{\partial z}{\partial \tau} < 0$. Similarly, keeping τ constant, a decrease in I decreases p which in turn increases q, which in turn means that e^{-ry} goes up. I can therefore conclude that $\frac{\partial z}{\partial I} < 0$.

From the R&D equation (7) after substituting for $x = m$, I obtain

$$\begin{aligned}m &= z(I,\tau)\frac{\beta}{\lambda}\frac{2\lambda-\tau-1}{r+I-n}\left(\frac{a_F}{\lambda k}+Im\right)\\ I &= \frac{\frac{Z\beta}{\lambda m}\frac{a_F}{\lambda k}-(r-n)}{1-\frac{Z\beta}{\lambda}},\end{aligned} \qquad (15)$$

where $R \equiv 2\lambda-\tau-1$ and $Z \equiv z(I,\tau)R$. It is clear that $\frac{\partial R}{\partial \tau} < 0$. Since $\frac{\partial z}{\partial \tau} < 0$ and $\frac{\partial R}{\partial \tau} < 0$, it follows that $\frac{\partial Z}{\partial \tau} < 0$. Since R does not change with the innovation rate I and

$\frac{\partial z}{\partial I} < 0$, it follows that $\frac{\partial Z}{\partial I} < 0$. From $1 - \frac{Z\beta}{\lambda} > 0$ (which must hold for I to be positive) and $\frac{\partial Z}{\partial \tau} < 0$, follows that the left-hand side of the above expression decreases with a decreasing τ, or $\frac{\partial LHS}{\partial \tau} > 0$. Also from $1 - Z\beta k > 0$ and $\frac{\partial Z}{\partial I} < 0$, follows that the left-hand side of the above expression decreases with a decreasing I, or $\frac{\partial LHS}{\partial I} > 0$. From $\frac{\partial LHS}{\partial I} > 0$ and $\frac{\partial LHS}{\partial \tau} > 0$ follows that

$$\frac{\partial I}{\partial \tau} < 0.$$