A Trapped Factors Model of Innovation

Nicholas Bloom*, Paul Romer†, and John Van Reenen‡

October 18, 2010

Abstract

When will reducing trade barriers against low wage country cause innovation to increase in high wage regions like the US or EU?.We develop a model where factors of production (such as skilled labor) are used to either produce or innovate. Because of sunk investments (like learning bydoing) they become "trapped" in producing old goods. In this model, trade liberalization with a low wage country reduces the profitability of the old good and so the opportunity cost of innovating falls. Interestingly, the "China shock" is more likely to induce innovation than liberalization with high wage countries, as richer countries will compete in both old and new goods. These implications are consistent with a range of recent empirical evidence on the impact of China and offers a new mechanism for positive welfare effects of trade liberalization over and above the standard welfare benefits from specialization and market expansion. Our model also suggests empirical identification strategies for trade effects need to combine labor market and product market information.

Keywords: Trade, Innovation, China

JEL Reference: O33, F16, O38, J33

Acknowledgements: We would like to thank Ken Arrow, Robert Hall, Chad Jones, Pete Klenow, Edward Lazear, John Roberts, John Sutton and participants at LSE, the Stanford GSB research lunch and Stanford Macro seminar for helpful comments. Van Reenen would like to thank the ESRC for financial support through the Centre for Economic Performance. The usual disclaimer applies.

*Stanford University, Centre for Economic Performance and NBER

†Stanford University

‡London School of Economics, Centre for Economic Performance, CEPR and NBER

1 Introduction

We consider new paths whereby trade can increase the rate of innovation and growth. Previous models show that trade can increase the size of the market for a new good, which increases the return to innovation. Here we show, paradoxically, that increased trade with a low-wage trading partner, which drives down prices and forces firms to shut down some lines of production, can also increase the rate of innovation. Instead of increasing the return to innovation, this kind of trade effect reduces the opportunity cost of the resources used to innovate.

We consider this channel because of micro-evidence about the effects of trade uncovered by a range of empirical work on the effects of China[1]. They find that trade shocks that impinge on specific firms and industries lead to more innovative activity at those firms much more than on others in the economy. This kind of effect cannot arise through a channel in which a trade shock acts simply on equilibrium prices.

To capture these firm specific effects, we assume that workers acquire human capital that is specific to a firm and the goods that it produces. This makes the human capital used by each firm a "trapped factor". If a factor of production is trapped in a firm, a trade shock that reduces the value of this factor in specific lines of production can encourage the firm to reallocate this

[1] For econometric evience see Bloom, Draca and Van Reenen (2010). For examples of case study evidence see Bartel, Ichinowski and Shaw (2007) on American valve-makers, Freeman and Kleiner (2005) on footwear or Bugamelli, Schivardi and Zizza (2008) on Italian manufacturers suggest this is an important phenomenon.

factor to other activities including innovation. Because the human capital is firm-specific, the shock reduces the opportunity cost of the human capital that it uses without having any effect on the cost of human capital to other firms. We show not only that trapped factors determine which firms innovate but also that they lead to a temporarily higher level of innovation in response to a trade shock. Because the rate of innovation is suboptimal, the induced increase in innovation raises welfare.

The model that we use exhibits endogenous growth. In such a model, changes in key parameters or policies can induce a permanent increase in the rate of growth (e.g. Romer, 1990.) The specific model we select is particularly easy to work with because it has no transition dynamics. This means that it generates growth at a constant rate from any initial condition. This gives us a simple way to describe the effects that a trade shock or any other policy change has the entire future path of output and consumption. At any date, the future of any variable can be described by two numbers, its current level and its rate of growth. Increased trade with then have a level effect and a growth effect.

The notion that there are such trapped factors seems both intuitively plausible and consistent with the evidence that there are persistent productivity differences between firms (e.g. Syverson, 2010). This idea underlines Melitz (2003) and much of modern trade theory and empirics. It is also consistent with the evidence on the importance of partial irreversibilities in adjustment costs.

The nature of the market failure is that skilled workers should specialize in innovation but they do not because the private incentive to innovate is below the social incentive. Their product specific skills cause them to be "trapped factors" from planner's point of view. An analogy would be engineers who could innovate, but end up Wall Street performing more basic (but highly lucrative) tasks.

The structure of this paper is as follows. In Section 2 we lay out a simple stationary model that captures the intuition behind the theory and in Section 3 we describe the predictions of this theory for innovation in a high wage country under two types of trade shock: a "China shock" (liberalization of goods with a low wage country) and an "OECD shock" (liberalization of trade with a high wage country). We show that the positive effect of liberalization holds only for the China shock. Section 4 contains a generalization of the model to a dynamic general equilibrium context first for the closed economy, then for the open economy. We show that the basic intuitions carry over in this more complex model. Section 5 describes some empirical implications of the trapped factor model and section 6 concludes.

2 Basic Intuition of the Model

2.1 Overview of Model

We assume that skilled workers can acquire human capital that is specific to the production of a particular good. Models with specific human capital can lead to ex post market power. In building a model, we cannot follow the simple strategy of assuming that workers are always paid their wage in a competitive spot market. We must instead specify a long-term contract that between worker and firm that both sides agree to under ex ante conditions of competition. As is well known, this long-term contract can take many different forms, all of which imply the same discounted present value of the relationship to the firm and the worker. We use simplest possible contract; workers and firms agree that workers will always be paid their marginal product at the firm. We verify that this is a contract that clears the ex ante competitive labor market[2].

In our model of innovation, firms incur costs to develop a non-rival design for a new product. They earn a return on this investment because a patent with a finite life lets them earn temporary ex post monopoly rents. After the patent expires, the market for the good is competitive. With this structure, we can examine the effect of a change such as the opening of trade with a low wage country in an equilibrium with monopolistic competition or in one with perfect competition.

We will make some artificial assumptions that simplify the analysis of the logical connections in the model. For example, we will specify a dynamic structure which implies that all patents in the economy expire on the same date. This means that prior to this date the model looks like a conventional model of monopolistic competition and that after this date it looks like a

[2] Workers are risk neutral so there is no incentive for the worker and firm to enter into an insurance agreement.

conventional model of perfect competition. We show the effects of a trade shock under these two extreme cases[3].

To focus attention on the effects of specific human capital, we also use artificial assumptions to rule out effects that have been studied elsewhere and are logically independent. For example, when trade opens between two economies, a monopolist may earn higher profits by selling in a larger market and this can change the rate of innovation. This effect is well studied (e.g. Krugman, 1979 or Acemoglu, 2008) and so we abstract away from it here. Thus, to simplify our analysis, we assume that differentiated goods developed in the home country can not be traded internationally. A trade shock in our model will influence incentives for innovation, but not through a market size effect.

2.2 Endowments

The economy is endowed with a fixed amount of low skilled labor, $\overline{L}$ and of High skilled labor (or Human capital), $\overline{H}$. We use j to index for differentiated good and t for a time period. The consumption of the "generic" good is z and the consumption of the differentiated good is c_j. The output of the generic good is x and the output of the differentiated good is v_j.

2.3 Assumptions on preferences

Utility takes the form

[3] The effects in an intermediate case with some patents that are still in force and others that have expired can be inferred as a mixture of these two extremes.

$$U = \sum_{t=0}^{\infty} \beta^t \left[z + \sum_{j=1}^{\infty} f(c_j) \right]$$

for some concave function $f(\cdot)$.

Remark 1 *With this expression, we have implicitly normalized the units for each of the different differentiated goods so that, in effect, one unit of shoes by designer X offers the same utility as one unit of televisions from consumer product company Y. This units choice is not restrictive. We will allow for the possibility that the cost of production can differ between the various differentiated products. We emphasize, however, that with our normalization, these kinds of cost differences between firms making different goods will reflect aspects of preferences as well as production technologies whereas cost differences between firms making the same good will reflect conventional productivity differences.*

2.4 Assumption on production possibilities

Remark 2 - *Output x of the generic good depends linearly on the quantity of low and high skilled labor devoted to its production:*

$$x = wL + \theta H$$

We have used the symbol w as a productivity parameter because in equilibrium it will turn out to be the competitively determined wage for unskilled labor.

For any index j, good j can be produced only if a quantity Γ of skilled labor has been devoted to the innovation process that produces the design for good j. In a harmless simplification, we will assume that production of good can begin place in the same period in which the good is designed.

For a good j with an existing design, output depends on the quantity of low skill labor L_j, and the quantity of both high skilled labor H_j' that is inexperienced and high skilled labor H_j that has experience working with this product:

$$v_j = \alpha_j \left(wL_j + \underline{\theta} H_j' + \overline{\theta}_j H_j \right)$$

High skilled workers acquire product specific human capital if in a previous period they have produced the product or worked on its design. For simplicity, we will assume that α_j can take on at most two values, $\alpha_1 \leq \alpha_2$ and that $\overline{\theta}_j$ can also take on at most two values $\overline{\theta}_1 \leq \overline{\theta}_2$. Because experience is beneficial, $\underline{\theta} < \overline{\theta}_1$.These two parameters α_j and $\overline{\theta}_j$ are i.i.d. random variables. The values are realized only after resources have been assigned to the design of good j.

2.5 Assumptions about Market Structure and Contracts

The market for the generic good is competitive. All profits and wages are denominated in terms of this good.

Once patents are introduced, the innovators who design and begin production of a new good in period t get a patent that lasts T periods and gives them the exclusive right to manufacture this good in periods $t, t+1, t+2..., T-1$.We will denote the simple monopoly profit captured in each period $\pi(\alpha, \overline{\theta})$. Let π without any arguments represent the ex ante expected profits before a design is produced so α and $\overline{\theta}$ are unknown. This profit also depends on the function $f(\cdot)$ and the productivity parameter w but as these are the same for all goods, we do not highlight this dependence in the the notation.

All firms commit to pay skilled workers a current wage equal to the worker's current value marginal productivity in the production of its good in any period where it chooses to hire them. The firm that produces good j is a partnership formed by the Γ skilled workers who must work together to produce its design. In addition to any income they receive as production workers, these Γ workers also receive a proportional share of the ex post monopoly rent that the partnership collects.

2.5.1 Assumptions about Timing

Any innovation that takes place in period $t < 0$ is not covered by a patent. As a result, before time 0 all workers produce the generic good. At $t = 0$, patents become available. Innovation and production of the differentiated goods begins in this period.

Remark 3 *This timing structure lets us examine productivity differences between firms with market power and with competition. It also lets us examine the effects of the two different types of trade shocks under these two different market structures.*

2.6 Assumptions about Trade Shocks:

At a date S, the home economy opens itself up to trade with a foreign country. Depending on the characteristics of the foreign country, we call this the "China shock" or the "OECD shock." Under the China shock, trade opens with a country that has a significantly lower wage for low skill labor. Under the OECD shock, the trading partner is a mirror image of the home country.

Under either type of trade shock, the foreign country (OECD or China) is allowed to export differentiated goods in the range $[1, J]$ to the home country.

Remark 4 *If the goods in this range are still under patent, firms in the home country can outsource production to the foreign country and import for local sale as a monopolist in the home market. If they are not under patent, the foreign firms can sell the goods directly in the home market.*

In trade that is balanced period by period, the home country is allowed by its laws to export in return only the generic good.

Remark 5 *This artificial assumption about the pattern of trade simplifies the analysis by switching off the "market size" effects that might otherwise change the incentives to innovate when a country opens to trade. For example, suppose that a firm that is contemplating the introduction of a new good after either type of trade shock. If it could sell the new good both at home and abroad, all else held constant, the trade shock would increase the ex post* *profit that a monopolist would capture and would thereby increase the incentive to innovate. This would be true for both an OECD shock or a China shock. The market size effect of trade on the incentive to innovate has been studied extensively before is not the focus here (for example, Krugman, 1979, Rivera-Batiz and Romer, 1991 or Acemoglu, 2008). To simplify the analysis, we simply restrict the pattern of trade and disallow sales in the foreign country of differentiated goods produced in the home country.*

2.7 Preliminary Results

Lemma 6 *If $f'(c)$ approaches 0 as c goes to ∞ and if $\overline{L}$ is large enough relative to $\overline{H}$, some unskilled labor will be used to produce the generic good and the wage for unskilled labor will be w.*

Proof. The marginal productivity w of an unskilled worker in the sector that produces the generic good sets a lower bound on their wages. Under conditions of monopoly or *ex post* competition, no firm producing a differentiated good will choose to hire additional unskilled labor if the marginal utility $f'(c)$ is below w. At any date, $\overline{H}$ limits the total number of differentiated products that can exist. This limits the total amount of L that will be employed in the production of differentiated products. ■

Lemma 7 *Suppose that the profit maximizing output for a monopolist facing a demand curve implied by f and production parameters α_j, w, and $\overline{\theta}_j$ exceeds the amount that can be produced by the designers of the product, $\overline{\theta}_j\Gamma$. Then* *the monopolist will employ some low skilled labor and its marginal cost of production will be $\alpha_j w$.*

2.7.1 The Decision to Innovate

Consider a group of Γ skilled workers who contemplate innovating and introducing a specific good j. Assume that other firms will innovate so that the relevant alternatives for these workers are to innovate or to work as inexperienced production workers at other differentiated product firms and to be compensated as experienced workers in all future periods. For this group of workers, the expected present discounted value of the profit associated with innovating, which we denote by Π is given by

$$\Pi = \sum_{t=0}^{T-1} \beta^t E\pi(\alpha, \overline{\theta})$$

If these workers design in this period, they forgo the opportunity to earn wages as inexperienced production workers at other firms. Whether they design this period or work as inexperienced workers this period, they will be experienced workers in all subsequent periods. So the opportunity cost of innovating is one period of lost wages at the rate of inexperienced workers. Because one inexperienced skilled worker produces the same output as $\underline{\theta}$ unskilled workers, the wages for the inexperienced skilled workers is $w\underline{\theta}$. If this opportunity cost is less than the profit from innovating, all inexperienced skilled workers will innovate when patents are introduced in period 0.

Assuming that the parameters are such that this strict inequality holds, all high skilled workers in period 0 will innovate. The total number of new goods introduced will be determined by the supply of skilled workers, $\overline{H}/\Gamma$.

Next, consider the decision about whether to innovate for experienced workers at a date $t > 0$. In period 1, some lucky workers developed goods with an experience parameter $\overline{\theta} = \overline{\theta}_2$. Other less fortunate ones have $\overline{\theta} = \overline{\theta}_1$. If the opportunity cost for the less fortunate of them $w\overline{\theta}_1$ exceeds the value Π from innovating, none of the experienced workers innovate.

To summarize, if the following strict inequality holds,

$$w\underline{\theta}\Gamma < \Pi < w\overline{\theta}_1\Gamma \tag{1}$$

then all inexperienced skilled workers will innovate. No experienced skilled workers with firm and product specific human capital will innovate.

We make one final remark. We can calculate the social value created by the introduction of a new differentiated product as follows. For the first T periods, the social value is $f(c_j^M)$ where c_j^M represents the monopoly output of this good. For periods all subsequent periods, the social value is $f(c_j^C)$ where c_j^C is the value produced under competition. The social cost of producing these quantities once a design exists is the amount of the generic good that must be foregone to produce them.

3 The Effect of Trade Shocks on Innovation

3.1 An OECD shock before or after date T

After date T, the market for any good that was introduced at time 0 is competitive. The price for the good is the marginal cost of producing an additional unit, w. If trade in good j opens with a country that has the same cost of low skilled labor as the home country, there is no change in the equilibrium allocation. The market price of the good is unchanged. Workers that have product specific human capital associated with the production of this good will continue to produce it. Low skilled workers in either country could also produce it. High skilled workers continue to produce rather than innovate.

Before date T, goods in the range $[1, J]$ are still under patent so the only way that they could be imported into the home country would be for the firm with the patent to outsource the production of its good to the OECD country. Because wages there are the same as at home, there is no incentive for this kind of outsourcing. This means that the opportunity cost of the time of the skilled workers who produce goods in the range $[1, J]$ is unaffected by the opening of trade with the OECD country.

3.2 A China shock after patents have expired (t $\geq$ T)

Suppose that the wage for workers in China is $w\prime < w$. Suppose that goods in the range $[1, J]$ can now be imported from China and in exchange, the home country exports the generic good. In this case, the competitive price for goods in this range will fall from to w to $w\prime$. All low skill labor in the home country will shift out of the production of goods in this range and shift into production of the generic good. Skilled experienced labor could continue to produce goods in this range, but the wage they will earn as a result will be per $\overline{\theta}w\prime$ worker. As a result, skilled workers who have product specific human capital in the production of goods in the range can earn if they continue to produce these goods. As long as the following inequality holds,

$$\overline{\theta}w\prime < \underline{\theta}w \tag{2}$$

these skilled workers would rather work as inexperienced workers in the production of goods that are not imported from China or in the production of the generic good rather than compete in the production of the goods that can be imported from China. This means that the opportunity cost of the time of skilled workers who face competition from the Chinese market falls to $\underline{\theta}w$ and the decision about whether to innovate is the same for these workers as it was at time 0. Inequality (2) implies that the returns from innovation are higher than the returns from production in the product lines that face competition.

Hence, the China shock after date T causes all the skilled labor that had been employed as experienced human capital in the production of goods in the range $[1, J]$ shifts into innovation at the time of the shock. A total quantity of human capital $J\Gamma$ is freed up at the time of the shock. It is used to innovate and introduce new goods.

Note that this new innovation arises even in the absence of any opportunity to sell a newly introduced good into the larger market made possible by trade with China. We rule out any such effect by assuming that the home country cannot export its differentiated products. In addition, if a firm that develops a new good could outsource its production to China, the incentives to innovate would be higher still because the marginal cost of production would be lower and the ex post monopoly rents would be larger. However, we have also ruled out this effect by assuming that the goods with index values greater than J cannot be imported from China even after the China shock. If we removed this restriction and allowed outsourced production of even newly introduced goods, this reduction in the marginal cost of production would create one additional reason why the China shock increases the incentives to innovate to a greater extent than an OECD shock.

3.3 A China Shock Before before patents have expired (t< T)

Suppose that the China shock arrives before the patents have expired. The only way that goods in the range $[1, J]$ can be imported into the home country is if the patent holders outsource production of the good to China. If they do so, they now face a marginal cost of a good in this range that is lower than before, $w\prime < w$. Firms with patents on goods in this range will outsource production and use low skill labor in China rather than low skill labor at home. This means that the opportunity cost of the experienced skilled workers who had been producing in the range falls, precisely as it did in the case where the China shock comes after date T. So just as in the case of a shock that comes after patents have expired, all skilled workers with product specific human capital in the range shift to innovation instead of production.

3.4 Summary

We have presented a stationary world where there is not dynamic ongoing growth in order to show the core intuition behind our model. In the model there are trapped factors through "learning by doing" which mean that pre-China we have an equilibrium without innovation and an equilibrium measure of goods being produced. After the China shock the opportunity cost of skilled workers producing the old good has fallen and there will be more innovation to produce new goods. This occurs whether or not the patent has expired on the current good produced. By contrast, a shock with an OECD country does not produce this effect.

4 Dynamic General Equilibrium

The model of the previous two sections was "stationary" in order to highlight the key intuition under the trapped factor approach. In this section we generalize the model to embed it in a full dynamic general equilibrium model of growth and show that the key intuitions continue to hold. We continue to use a model of horizontal product differentiation because this is the simplest framework that lets us consider the introduction of a new good that does not compete with existing goods. The specific model we use is based on an extension of the lab-equipment model from Rivera-Batiz and Romer (1991.) We modify this model in two ways. First, we assume that intermediate inputs are consumed after one period of use and that patent protection for a new design also lasts for just one period. These two changes remove the transition dynamics from the model. Second, we follow Romer (1986) and Jones (1995) and allow for diminishing returns in the technology for producing new designs. In our power function specification, an x increase in the inputs devoted to innovation leads to an x^ρ percent increase in new designs for some $\rho < 1$.

We start by presenting the growth model for a closed economy which we call North. Then we introduce a second economy, South, and introduce a parameter that measures the fraction of goods produced in the South that the North allows in as imports. We assume that workers in the South can produce goods but can't innovate. We also select parameters which ensure that wages for workers in the South are lower than wages for workers in the North.

We start by showing that when the trade restriction is relaxed so that more goods enter from the South and compete with goods that were formerly produced in the North, the growth rate increases, by an amount we will call Δ. Next we show that if the human capital that is used by firms in the North is firm specific, the same trade shock increases the aggregate growth rate to a value that is higher than Δ for one period and which settles back to Δ in subsequent periods. During this single period of enhanced growth, we can decompose the growth rate as a weighted average of the growth rate of the firms that experience the trade shock $\Delta_1 > \Delta$ and growth at firms that do not experience the trade shock $\Delta_2 < \Delta$. In the presence of the shock, the extra growth from the firms that experience the shock is partially, but not fully, offset by the firms that do not experience the shock.

4.1 Closed economy growth model

There are two types of inputs in production, human capital and differentiated intermediate inputs. Physical units of a differentiated input such as a personal computer are produced at time t, and completely consumed when they are used in production at time $t+1$. Let A_t denote the number of intermediate inputs that could be produced at time $t-1$ and are hence available for use in production at time t. For a specific good $j \leq A_t$ let x_{jt} denote the number of units produced at time $t-1$ and available for use in production at time t.

To avoid integer constraints, we follow the usual strategy of letting the set of differentiated inputs be a continuum. Nevertheless, to explain the structure of the model, it helps, as an expositional device, to refer to a discrete version of the model and to give names to specific intermediate inputs. For example, let good 1 be desks, let good 2 be computers, and let good 3 be mobile phones.

Suppose that at time 1, $A_1 = 2$ so both desks and computers were produced last period and are available for use in production at time $t = 1$. At time 1, the available stock of desks and computers can be used, together with human capital in three different productive activities: producing utility via household production, producing intermediate inputs, or innovating. Let

x_1^k denote the number of desks used in productive activity k, where k can take on the values u for utility from household production, d for production of new desks, c for the production of computers, m for the production of mobile phones, and i for innovation, with a similar notation x_2^k for the allocation of computers to the various types of production. (For simplicity, we are suppressing the time subscripts on these x's.)

With H^i units of human capital, x_1^i desks, and x_2^i computers, the production function for new designs such as the design for a mobile phone takes the form

$$\text{New designs } = \left(H^i\right)^\alpha \left[\left(x_1^i\right)^{1-\alpha} + \left(x_2^i\right)^{1-\alpha}\right].$$

Note that this is like a Cobb-Douglas production function but with two types of non-human inputs instead of just one. Note also that the lab-equipment model gets its name from the assumption reflected here that differentiated goods like desks and computers can be inputs that are used in laboratories to design new goods like mobile phones.

The production function for desks will take exactly the same functional form. If we define one units of desks to be the number of desks that can be produced with the same inputs that can produce one new design, we can then write the output of desks as

$$\text{Desks for use next period} = \left(H^d\right)^\alpha \left[\left(x_1^d\right)^{1-\alpha} + \left(x_2^d\right)^{1-\alpha}\right].$$

With the same units convention, the production function for computers will take the same form, as will the production of utility at home. Finally, if one new design is produced in this period, period 1, then A_1 which was equal to 2 increases to A_2 equal to 3. This means that mobile phones can also be produced according to this same expression. Next period, these mobile phone can be used in all of the various productive activities: producing desks, computers, phones, utility, new designs and the new goods that correspond to these designs.

With a common production function and these assumptions on units, we can simplify the description of activity at time 1 as follows. We can define total output Y_1 as

$$Y_1 = H^\alpha \sum_{j=1}^{A_1} x_{j1}^{1-\alpha}$$

and impose the restriction that total output must be equal to the sum of output from all of the different activities:

$$Y_1 = (A_2 - A_1) + u_1 + \sum_{j=1}^{A_2} x_{j2}.$$

With this kind of structure, it is a common short hand to speak of output Y as if it is flow of general purpose intermediate input that is then turned into new designs, utility or intermediate inputs in the same period. We will rely on this standard abuse of the language in multi-sector models. Although this is not a natural model of production, there is no harm in assuming that there is an actual flow of intermediate output that corresponds to Y. With this background, we will speak of Y as the numeraire good, but what this means in the terms of the micro foundations suggested here is that the bundle of goods that produces one unit of Y in each period is the numeraire.

With these preliminaries in place, we can now introduce diminishing returns into the production of new designs. We will assume that given an aggregate economy wide stock of designs A_t, and an aggregate amount of forgone output Z in the production of new designs, the number of new designs that are produced takes the form suggested by Jones,

$$A_{t+1} - A_t = Z^{\rho} A_t^{1-\rho}.$$

A useful way to recast this expression is as a cost function instead of as a production function:

$$Z = \Gamma(A_{t+1} - A_t, A_t) = (A_{t+1} - A_t)^{\gamma} A_t^{1-\gamma}$$

where $\gamma = \frac{1}{\rho}$.

If we switch to the continuous version of differentiated products model by replacing sums with integrals, we can now summarize the technological constraints with these two equations:

$$Y_t = H^{\alpha} \int_0^{A_t} (x_{jt})^{1-\alpha} dj$$
$$Y_t = u_t + \int_0^{A_{t+1}} x_{j,t+1} dj + \Gamma(A_{t+1} - A_t, A_t)$$

Our last assumption concerns decentralized decision making in innovation. We can think of a firm as being associated with a set of input types that it has designed. Let N be the total number of firms. In a symmetric equilibrium, at time t each of the N firms will have designed a fraction $1/N$ of all the existing designs in the range $[0, A_t]$ of existing designs. We will assume for simplicity that the goods associated with each firm are a random selection from $[0, A_t]$.

As in Romer (1990) or Jones (1995), we assume that at time t, all potential innovators have free access to the existing stock of ideas, A_t so that it is non-excludable in the production of new ideas. As in Jones (1995), we also assume that the congestion effects in discovery are not priced. These arise from the duplication of effort that arises when different firms inadvertently conduct work on designs for the same type of good in "patent races" that yield a valid patent for only one of the participants. All firms get new designs in proportion to the resources that they that they devote to innovation so each firm pays the average cost of producing new designs rather than the marginal cost.

Because output Y is the numeraire, the aggregate inverse demand for input j can be inferred as the derivative of the aggregate production function yielding

$$p = (1 - \alpha) H^{\alpha} x^{-\alpha} \tag{3}$$

Let r be the interest rate on one-period loans of the numeraire. If good j is competitive because its patent has expired, the cost of producing one unit of this good was one unit last period. Today, producers will pay a competitive price $p_C = 1 + r$ to use this input.

For a monopolist, the profit as of the time of use of a good developed last period can be written as

$$\pi = p_M x_M - (1+r)x_M$$

where the demand curve once again comes from marginal productivity. If the patent is still in force, the usual markup rule for a constant elasticity demand curve implies that the monopoly price p_M will be marked up by a factor $1/(1-\alpha)$ above its marginal cost, which was one unit of output yesterday or $1+r$ units of output today, so the monopoly price can be written as.

$$p_M = \frac{1+r}{1-\alpha} \tag{4}$$

and profit can be written as

$$\begin{aligned} \pi &= \frac{1+r}{1-\alpha} x_M - (1+r)x_M \\ &= \frac{\alpha}{1-\alpha}(1+r)\, x_M \end{aligned}$$

Using the inverse demand curve $p = (1-\alpha)H^{\alpha}x^{-\alpha}$ and the demand curve $x = H\left(\frac{1-\alpha}{p}\right)^{\frac{1}{\alpha}}$ from equation (3), the markup price implies monopoly output of

$$x_M = H\left(\frac{(1-\alpha)^2}{1+r}\right)^{1/\alpha} \tag{5}$$

After substituting in monopoly output (5), the expression for the profit per period from the sale of the good becomes

$$\begin{aligned} \pi &= \frac{\alpha}{1-\alpha}(1+r)\, H\left(\frac{(1-\alpha)^2}{1+r}\right)^{1/\alpha} \\ &= H\,(1+r)^{\frac{\alpha-1}{\alpha}}\,\Omega, \end{aligned}$$

where $\Omega = \alpha(1-\alpha)^{\frac{2-\alpha}{\alpha}}$.

The zero profit condition for the activity of designing new goods implies that this expression for π must be equal to the cost of producing the innovation. If we define the growth rate of designs g_t as

$$g_t = \frac{A_{t+1} - A_t}{A_t}$$

For each firm, the cost of per new design can be written as

$$\begin{aligned} \frac{1}{(A_{t+1} - A_t)} \Gamma(A_{t+1} - A_t, A_t) &= \left(\frac{A_{t+1} - A_t}{A_t} \right)^{\gamma - 1} \\ &= g_t^{\gamma - 1} \end{aligned}$$

In equilibrium, the rate of growth of output and designs is equal to the rate of growth of designs and will take on a constant value g. This means that the zero profit condition for innovation can be written as:

$$\begin{aligned} g^{\gamma-1} &= \frac{1}{1+r}\pi && (6) \\ &= H\,(1+r)^{-\frac{1}{\alpha}}\,\Omega && (7) \end{aligned}$$

To close the model, we need an expression for the interest rate. The standard assumption is that discounted utility takes the constant elasticity form

$$U = \sum_{t=0}^{\infty} \beta^t \frac{(u_t)^{1-\sigma}}{1-\sigma}$$

so the interest rate is determined by

$$1 + r = \frac{1}{\beta}(1+g)^{\sigma}.$$

Substituting this expression into the zero profit condition yields the basic equation for the growth rate as a function of the other parameters:

$$g^{\gamma-1} = H\beta^{-\frac{1}{\alpha}}(1+g)^{-\frac{\sigma}{\alpha}}\Omega.$$

For many of the arguments that follow, it helps to have a benchmark set of parameters that allow an explicit solution for g. The simplest way to do this is to assume that $\sigma = 0$ so that the interest rate r does not depend on the rate of growth. In this case, the equation for g simplifies to

$$g = \left(H\beta^{-\frac{1}{\alpha}}\Omega\right)^{\frac{1}{\gamma-1}}.$$

The key result, illustrated by this expression, is that an increase in scale, as measured by the stock of H, leads to an increase in the rate of growth. For example, if two nations with the same total level of H move from autarky to full integration, the growth rate increases by $2^{\frac{1}{\gamma-1}}$. In the next section, we show how this result generalizes to intermediate degrees of trade and integration.

4.2 Open Economy with Trade in Competitive Goods

Consider an extension in which an economy we will call the North trades with a second economy, South. Only the North can innovate. From the perspective of the North, the range of existing goods $[0, A_t]$ that can be used in production in period t can be partitioned into three intervals:

$$[0, A_t] = I \cup R \cup M$$

The set M (for monopoly) represents goods that are protected by a patent. All innovation takes place in the North, so goods in the range M are produced only in the North. They are sold and used in both the North and the South. The set R (for trade restrictions) represents goods that are protected by import restrictions imposed by the North. These goods are produced by competitive firms in both the North and the South. The set I (for imports) represents goods that can be imported into the North. In equilibrium, wages will be lower in the South so these goods will be produced only there. They are used in production in both the North and the South.

Just as it is possible to refer to aggregate output Y in the North, we can define aggregate output Y^* in the South. In the equilibrium with trade restrictions, the key parameter will be the price q of a unit of output in the South relative in terms of output in the North. This price is the real exchange rate. We assume that there is no borrowing or lending in the model. (In equilibrium, growth rates and interest rates will be the same in the two countries so this restriction is not binding.) As a result, this exchange rate is determined by the requirement that trade be balanced in each period.

The interval I is determined by trade restrictions in the North. The parameter ϕ indexes the extend of the restrictions. At any date t, the North allows a fraction ϕ of all goods that are off patent (and can therefore be reverse engineered in the South) to be imported.

Because of the symmetry in the model, all goods in a particular interval have the same price and quantity in each nation. This means that we can write aggregate output in the North as

$$\begin{aligned} Y &= H^{\alpha} \int_{I \cup R \cup M} (x_j)^{1-\alpha} dj \\ &= H^{\alpha} \left(I x_I^{1-\alpha} + R x_R^{1-\alpha} + M x_M^{1-\alpha} \right), \end{aligned}$$

where I, R, and M now represent the lengths of the corresponding intervals. Output in the South can be written analogously as

$$Y^* = H^{*\alpha} \left(I x_I^{*1-\alpha} + R x_R^{*1-\alpha} + M x_M^{*1-\alpha} \right)$$

where the lengths of the intervals are the same but the quantities used in the two countries can differ.

The real exchange rate q is determined by the requirement that trade has to be balanced in each period, which implies that

$$I p_I x_I = M p_M^* x_M^*.$$

In the North, we know that demand curve takes the form $x = H \left(\frac{1-\alpha}{p} \right)^{\frac{1}{\alpha}}$ so that revenue as a function of the price p_I can be written as

$$H p_I^{\frac{\alpha-1}{\alpha}} (1-\alpha)^{\frac{1}{\alpha}}.$$

Because the exports from the South are produced under conditions of competition, the price for each intermediate is its cost of production, q, for one unit of forgone output in the South from the last period, converted into units of output today by the interest rate r, so $p_I = q(1+r)$, which yields revenue per intermediate sold by the South of

$$H\left((1+r)\,q\right)^{\frac{\alpha-1}{\alpha}}(1-\alpha)^{\frac{1}{\alpha}}$$

To capture monopoly revenue for the North from sales in the South, the demand for intermediate goods in the South can be inferred from the value of the marginal product of the input in the aggregate production function, where output in the South is valued at the price q. Hence the inverse demand curve there is

$$p = q(1-\alpha)H^{*\alpha}x^{-\alpha}$$

so demand takes the form

$$x = \left(\frac{q(1-\alpha)}{p}\right)^{\frac{1}{\alpha}} H^{*}$$

and revenue as a function of the price takes the form

$$xp = H^{*}q^{\frac{1}{\alpha}}p^{\frac{\alpha-1}{\alpha}}(1-\alpha)^{\frac{1}{\alpha}}$$

Because the form of the demand there is the same as in the North, the same markup rule applies, $p_M = p_M^{*} = \frac{1+r}{1-\alpha}$. Substituting this expressing in yields revenue per monopolized good sold in the South of

$$H^{*}q^{\frac{1}{\alpha}}\left(\frac{1+r}{1-\alpha}\right)^{\frac{\alpha-1}{\alpha}}(1-\alpha)^{\frac{1}{\alpha}} = q^{\frac{1}{\alpha}}H^{*}\left(1+r\right)^{\frac{\alpha-1}{\alpha}}(1-\alpha)^{\frac{2-\alpha}{\alpha}}$$

To calculate the lengths of the two intervals, we observe that in period t, $M = A_t - A_{t-1}$.If A grows at a constant rate g,

$$g = \frac{A_t - A_{t-1}}{A_{t-1}}$$

$M = gA_{t-1}$. The trade restrictions mean that only a fraction ϕ of the goods that are off-patent can be sold by the South to the North, so $I = \phi A_{t-1}$.

Combining these results yields an implicit expression for q which does not involve A_{t-1} or r:

$$\phi H \left(q\right)^{\frac{\alpha-1}{\alpha}} \left(1-\alpha\right)^{\frac{1}{\alpha}} = gq^{\frac{1}{\alpha}} H^* \left(1-\alpha\right)^{\frac{2-\alpha}{\alpha}}$$

which simplifies to

$$q = \left(\frac{\phi H}{gH^*}\right)^{\frac{\alpha}{2-\alpha}} \Psi$$

where $\Psi = (1-\alpha)^{\frac{\alpha-1}{2-\alpha}}$. As ϕ approaches 0, q also goes to 0. As ϕ grows, q increases to its maximum of 1. At this point the trade restrictions no longer bind.

To solve for g and q, we need the zero profit condition. The profits for the monopolist from sales in the North will be the same as in the closed economy,

$$\pi_N = H\beta^{\frac{1-\alpha}{\alpha}}\Omega.$$

If q is less than one, profit in the South is reduced because demand is lower there:

$$\pi_S = q^{\frac{1}{\alpha}} H^* \beta^{\frac{1-\alpha}{\alpha}} \Omega$$

Adding these together, the zero profit condition becomes

$$g^{\gamma-1} = \left(H + q^{\frac{1}{\alpha}} H^*\right) \beta^{\frac{1-\alpha}{\alpha}} \Omega.$$

After substituting in the expression for q, this becomes

$$g^{\gamma-1} = \frac{1}{1+\frac{1}{\beta}} \left(H + \left(\frac{\phi H}{gH^*}\right)^{\frac{1}{2-\alpha}} \Psi^{\frac{1}{\alpha}} H^*\right) \beta^{\frac{1-\alpha}{\alpha}} \Omega. \tag{8}$$

Result

Equation (8) does not have allow a simple analytic solution, but its behavior can be inferred from the fact that plausible values of g will be well below 1. Because $\gamma = 2$, the term $g^{\gamma-1}$ will be small and with not vary much with changes in g. To a first approximation, the ratio $\left(\frac{\phi H}{gH^*}\right)$ will have to stay constant as ϕ changes, so g will change roughly in proportion with ϕ.

Thus, increasing trade openness as indexed by ϕ will raise the growth rate.

4.3 Trapped Factors

There are several notions of trapped factors. The first we will introduce is a firm specific productivity parameter that is common to all activities (designing new goods and producing of good on and off patent). The second notion is also activity specific in the sense that it applies to production (for workers who helped design the new good) but not to design.

4.4 Between firm frictions

Consider a set of firms $1, ..., n, ..., N$. The first model just has higher firm-specific productivity across all activities (on patent goods and off patent goods), θ. Denote the range of imported goods produced as:

$$I(n) = \phi e^{-gT} \lambda(B(n))$$

where $B(n)$ is the set of goods for firm n and $\lambda(B(n))$ is the measure of goods in that set by firm n. Analogously for off patent trade restricted goods

$$R(n) = (1-\phi)e^{-gT}\lambda(B(n))$$

and for monopoly goods

$$M(n) = (1-e^{-gT})\lambda(B(n))$$

Denote how total output is allocated for firm n as

$$Y(n) = R(n)x_R + M(n)x_M + D(n)$$

where D are the resources allocated into designing new goods. We can expand this as:

$$\begin{aligned} & R(n)x_R + M(n)x_M + D(n) \\ = \ & (\theta H_n)^\alpha \int_0^{A_t} (x_{i,t})^{1-\alpha} di \\ = \ & (\theta H_n)^\alpha I x_I^{1-\alpha} + R x_R^{1-\alpha} + M x_M^{1-\alpha} \end{aligned}$$

Results

1. The results from the previous section all go through. There are resources released from the goods formerly producing R. These workers are reallocated into new designs. This is our core result - there will be more equilibrium innovation and growth when trade barriers are reduced by a greater degree

2. The loss of firm specific θ implies that the innovation will take place in the same firms who are hit by the shock. This is a second key result - the expansion of innovation will take place in the firms who have been most affected by the shock (implying a strong within-firm effect that has been found in the empirical literature)

3. The firm specific nature of θ implies that if we have an asymmetric shock, the firms who have a larger shock will have a larger increase in their innovative activity than those with a lesser shock. But the total amount of R&D increases by the same amount as it would do from a symmetric shock

5 Some Empirical Implications of the theory

The trapped factor theory we have described here has many rich empirical implications which we discuss in this section.

5.1 Core empirical predictions

The core results from the previous section showed that (as in the simpler model), a policy in the North of reducing trade barriers with low wage countries like China will have the following effects in the high wage countries:

1. Increases the aggregate growth rate through more innovation

2. Innovation is increased by more after a trade liberalization with low wage countries than with high wage countries

3. Increases innovation in the firms more affected by an asymmetric shock (for a given degree of trapped factors). This suggests that the shock will be a "within firm" phenomenon and not just a reallocation effect.

4. Will have a greater effect on those firms with more trapped factors (for a given size of a shock)

Some support for these implications is found in Bloom, Draca and Van Reenen (2010).

5.2 Why negative shocks can generate innovation

Many business school cases suggest that a negative shock can cause a firm to become more productive. Sometimes this is described as an increase in X-efficiency through companies being "shocked out of their lethargy". We motivated our paper with a recent example from the trade literature suggesting that in response to a reduction in trade barriers against Chinese imports, high country producers competing in the same final goods markets increased their rate of innovation and productivity (Bloom, Draca and Van Reenen, 2009).

Economists have been puzzled about the theoretical basis of such empirical findings. Why have firm's incentives changed to positively induce innovation? Our model offers a potential answer to this puzzle - the opportunity cost of innovation has declined because the "trapped" skilled workers have no incentive to continue working on their old products after the negative shock.

This has some similarities to the "pitstop" theory whereby recessions can stimulate innovation. This is based around a model where the resources to produce and to innovate are substitutes, so in a recession the relative value of using these resources to produce falls (as demand is low), therefore the incentive to reallocate these resources to innovation increases (examples include Aghion and Saint-Paul, 2002; Galli and Hammour, 1993; Lazear, 1976). Although our model has some similarities to these "virtue of bad times" theories, there are significant differences. First, these are all general equilibrium models - the relative price of innovation falls in equilibrium for all firms in the economy. By contrast, our model allows for partial equilibrium effects - innovation will be more likely in those industries facing the negative shocks (such as a trade shock). Second, our model allows for heterogeneity across firms in a way these representative firm models do not. Finally, the empirical basis of these models has been questioned by the empirical evidence by Barlevy (2008) that finds that R&D is pro-cyclical (or at best acyclical). Our model is much more general than being tied to business cycles.

5.3 Sources of Firm Heterogeneity

Firm productivity heterogeneity appears pervasive and many modern theories have been built upon this premise (see Syverson, 2010, for a survey). But identifying this heterogeneity is challenging. Our paper offers a framework for interpreting existing evidence and suggesting new empirical approached. Typically researchers will measure "revenue" total factor productivity (TFPR) which is a residual between a firm's deflated sales and it's weighted inputs) relative to an industry average. In our model, this will be a function of three elements:

1. "True" Productivity (sometimes called TFPQ) which we denote α_j.This is the firm-specific productivity "draw" that raises the productivity of all factors (e.g. Hopenhayn, 1992; Melitz, 2003). This is usually what researchers seek to identify.

2. A price cost margin. In our model this arises from the period when the product is under patent protection and competes in monopolistically competitive industries. This is not usually controlled for because researchers do not typically have measures of firm-specific prices. Because sales are deflated only by an industry price deflator, the firms with some market power will have higher TFPR but not necessarily higher TFPQ

3. Worker product-specific skills ("worker rents") which we denote $\overline{\theta}_j$.

Conventionally measured TFPR will incorporate all three elements. Many papers have emphasized the problem of separating elements (1) and (2) and made various proposals to deal with this[4]. Perhaps the most satisfactory is Foster et al (2008) who actually have data on plant specific output (and

[4]Examples of different approaches include Klette and Griliches (1997), de Loecker (2007), Hsieh and Klenow (2009).

input) prices for a small number of industries. For these sectors, they are therefore able to obtain credible measures of TFPQ.

A fundamental problem in differentiated product industries is comparing across firms who are producing different goods. Their prices will be different and we have to be careful we are not comparing "apples with oranges". Our approach, by contrast highlights worker product-specific skills as the key reason for generating heterogeneity in observed productivity differences between firms. Thus our perspective connects with a large literature in labor economics that has found considerable differences in observed wages for observationally identical workers. We discuss this next.

5.4 Worker "rents"

Differences in wages for observationally similar workers are a well-known fact of the labor market. A considerable part of these "rents" are linked to workers who are employed by the same high-paying (or low-paying) firms. For example in Abowd, Kramarz and Margolis (1999)'s work on French and US matched worker-firm data, about half of the unobserved heterogeneity was due to firm-specific effects (and the other half ascribed to worker's differential ability). In the older literature on inter-industry wage differentials (Krueger and Summers, 1988), significant unexplained industry-specific wage premia were observed, and a large proportion of this could not be explained by unobserved ability (Gibbons and Katz, 1993).

Our model provides micro-foundations for the existence and persistence of such "rents".

5.5 Identification of TFP differences

Innovation creates new products competing monopolistically competitively that command higher price cost margins than commodities competing under perfect competition. Worker rents in our model are generated when firms innovate and there is learning by doing on the product (Van Reenen, 1996, has evidence consistent with this). The difference is that after the patent expires, firm rents are driven to zero whereas worker rents persist (unless the product is completely destroyed by overseas competition as in the Chinese trade example discussed above) . Thus measured TFPR should fall post patent, whereas worker rents should not.

Conventionally measured TFP will be:

$$\ln \widetilde{Q_j} - \sum_f SHARE_{jf} \ln \widetilde{X_{jf}}$$

where $\widetilde{Q_j}$ is output of firm j (relative to a base firm in the industry as denoted by the tilda), $\widetilde{X_{jf}}$ is the relative factor input of factor f in firm j and $SHARE_{jf}$ is the relevant share of factor f for firm j. To simplify the notation consider labor as the only factor.

In our model we can write output (Q) divided by labor (N) as

$$
\begin{aligned}
\frac{Q}{N} &= \frac{Q_j}{L_j + H_j} = \frac{\alpha_j(L_j + \theta_j H_j)}{L_j + H_j} \\
&= \alpha_j(1 + (\theta_j - 1)S_j)
\end{aligned}
$$

where $S_j = \frac{H_j}{L_j+H_j}$, the share of all employees who are skilled workers.

Since we generally empirically measure firm output as revenues (R_j) deflated by an industry price index (P) instead of a firm-specific one (P_j).

$$
r_j - p = q_j + (p_j - p)
$$

$$
\ln\left(\frac{R_j}{P}\right) = \ln Q_j + \ln\left(\frac{P_j}{P}\right)
$$

$$
\begin{aligned}
\ln\left(\frac{R_j}{P}\right) - \ln N &= \ln\left(\frac{Q_j}{N_j}\right) + \ln\left(\frac{P_j}{P}\right) \\
&= \ln \alpha_j + \ln\left(\frac{P_j}{P}\right) + \ln(1 + (\theta_j - 1)S_j)
\end{aligned}
$$

The key question is how the labor index is calculated. The relative productivity of high skilled workers is θ_j so to identify TFPQ (α_j) we need to make an assumption about how to identify θ_j. Let us consider some simple examples to see the likely biases. Assume we measure firm-specific prices correctly and that wages reflect marginal products.

1. If we use the firm's own skilled worker wages relative to unskilled worker wages as the proxy $(\frac{W_j}{W})$ of θ_j :

$$TFP1 = \frac{Q_j}{L_j + \frac{W_j}{W} H_j} = \alpha_j$$

2. If we use the conventional approach of using the "market" outside wage, $\underline{\theta}$, to weight up skilled workers we obtain:

$$TFP2 = \frac{Q_j}{L_j + \underline{\theta} H_j} = \alpha_j \left(\frac{L_j + \theta_j H_j}{L_j + \underline{\theta} H_j} \right) = \alpha_j \left(\frac{1 + (\theta_j - 1) S_j}{1 + (\underline{\theta} - 1) S_j} \right)$$

TFP2 will identify a mixture of TFPQ and the wage rent $\theta_j / \underline{\theta}$ associated with innovation

3. More generally, the industry average wage for skilled workers $\widetilde{\theta}$ will be a weighted average of $\underline{\theta}, \theta_1$ and θ_2

$$TFP3 = \frac{Q_j}{L_j + \underline{\theta} H_j} = \alpha_j \left(\frac{L_j + \theta_j H_j}{L_j + \widetilde{\theta} H_j} \right) = \alpha_j \left(\frac{1 + (\theta_j - 1) S_j}{1 + (\widetilde{\theta} - 1) S_j} \right)$$

Consequently, different measures of TFP will identify different theoretical objects of interest even in the case when we measure prices correctly. The "full" amount of productivity differences are contained in TFP2, but this will generally be disguised if we only consider TFP1: here we will miss out on the product-specific worker productivity. In principle, calculating TFP1 and TFP2 will enable us to decompose the TFPQ element from the worker rents.

6 Conclusions

In this paper we have considered a "trapped factor" model where some factors of production due to sunk costs are partially irrerversible and are therefore "trapped" in a firm (e.g. when there is firm-specific human capital from learning by doing). We show that in such a model that when a rich OECD country reduces trade barriers with a low wage country like China this can act to speed up the rate of innovation and therefore economic growth in the OECD country. This is because the trapped factor will be used (in part) to produce old goods and this sets the opportunity cost of innovation. A China shock reduces the profitability of producing these old low tech goods and therefore reduces the opportunity cost of innovation. Abstracting from market size effects, integration with a high wage OECD country does not have these pro-innovation effects. We show the intuition first in a simple stationary model and then generalize this to a dynamic general equilibrium context.

These results are important as they rationalize some "stylized facts" in the empirical literature on trade. First, opening up to trade with China appears to have generated faster technical change in firms in richer countries (like Europe and the US) not simply from reallocation but also through within firm innovation (e.g. Bloom, Draca and Van Reenen, 2010). Secondly, the effects of opening up to trade with countries like China appears to have stronger effects on innovation than trade integration with other rich countries.

This implies that there are some further benefits from trade in addition to the standard positive effects from specialization (as in Ricardo) and through innovation from market expansion (as in Krugman).

Our model is stylized but reflects some real features of modern economies. There are a number of possible extensions to this work. First, we can use this to explore welfare effects in the context of heterogeneous firm models of trade as in Melitz, 2003. Second, we can try to fit parameters of the stylized model using data on firms and workers to gauge whether the qualitative effects we identify are quantitatively large enough to make a material difference for long-run growth. Third, as we noted in the empirical section, our framework sheds new light on the issue of productivity heterogeneity and can be used to investigate how much of the observed TFP distribution is actually unobserved worker differences in firm-specific human capital. All of these avenues are being currently explored.

References

References

[1] Abowd, John, Kramarz, Kramarz and David Margolis (1999) "High-Wage Workers and High-Wage Firms" *Econometrica*, 67, 2, 251-333.

[2] Acemoglu, Daron (2008) "Equilibrium Bias of Technology" *Econometrica* 75(5) 1371-1409.

[3] Aghion, Philippe and Saint-Paul, Giles (1998) "The Virtue of Bad Times" *Macro-economic Dynamics* 2, 322-344

[4] Bartel, Ann, Casey Ichinowski and Kathryn Shaw (2007) "How does information technology really affect productivity? Plant-level comparisons of product innovation, process improvement and worker skills", *Quarterly Journal of Economics*, 122 (4), 1721-1758.

[5] Barlevy, Gadi (2007) "On the Cyclicality of Research and Development" *American Economic Review*, 97(4): 1131-1164

[6] Bloom, Nicholas, Draca, Mirko and Van Reenen, John (2010) "Trade induced Technical Change", LSE/Stanford mimeo

[7] Bugamelli, Matteo, Fabiano Schivardi and Roberto Zizza (2008) "The Euro and Firm restructuring", NBER Working Paper no. 14454

[8] De Loecker, Jan (2007) "Product Differentiation, Multi-product Firms and Estimating the Impact of Trade Liberalization on Productivity", NBER Working Paper, No 13155

[9] Foster, Lucia, Haltiwanger, John and Syverson, Chad (2009) "Reallocation, Firm Turnover and Efficiency: Selection on Productivity or Profitability?" *American Economic Review*, 98(1): 394-425.

[10] Freeman, Richard and Kleiner, Morris (2005), "The last American Shoe Manufacturers", *Industrial Relations*, 44, 307-342

[11] Gali, Jordi and Hammour, M (1993) "Long-run effects of Business Cycles", mimeo Columbia University

[12] Gibbons, Robert and Katz, Larry (1993) "Does unmeasured ability explain inter-industry wage differentials?" *Review of Economic studies,* 59: 515-535

[13] Hopenhayn, Hugo (1992), "Entry, Exit and Firm Dynamics in Long-Run Equilibrium", *Econometrica*, LX (5), 1127-50.

[14] Hsieh Chiang and Klenow, Peter (2007), "Misallocation and Manufacturing TFP in China and India" NBER Working Paper 13290.

[15] Jones, Charles (1995) "R&D-Based Models of Economic Growth" *Journal of Political Economy*, 103: 759-784.

[16] Klette, Tor Jakob and Griliches, Zvi (1996) "The Inconsistency of Common Scale Estimators When Output Prices Are Unobserved and Endogenous" *Journal of Applied Econometrics*, 11(4): 343-61

[17] Krueger, Alan and Summers, Larry (1988) "Efficiency Wages and the Inter-industry Wage Structure" *Econometrica*, 56(2), 259-93

[18] Krugman, Paul (1979) "A Model of Innovation, Technology Transfer, and the World Distribution of Income" *Journal of Political Economy*, 87(2): 253-66

[19] Lazear, Edward (1974) "Empirical Studies in Technical Change", PhD Dissertation, Harvard University

[20] Melitz, Marc (2003) "The impact of trade on intra-industry reallocations and aggregate productivity growth" *Econometrica*, 71, 1695-1725

[21] Romer, Paul (1986) "Increasing Returns and Long-run Growth" *Journal of Political Economy*, 94(5), 1002-37

[22] Romer, Paul (1990) "Endogenous Technological Change" *Journal of Political Economy*, 98(5), S71-102

[23] Rivera-Batiz, Luis and Paul Romer (1991) "Economic Integration and Endogenous Growth" *Quarterly Journal of Economics*, 531-555.

[24] Syverson, Chad (2010) "What determines productivity at the micro level", University of Chicago mimeo, forthcoming *Journal of Economic Literature*

[25] Van Reenen, John (1996) "The Creation and Capture of Economic Rents: Wages and Innovation in a Panel of UK Companies" *Quarterly Journal of Economics* (1996) CXI, 443, 195-226