Global Quality Competition, Offshoring and Wage Inequality

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Abstract

In the 1970s and 1980s the US position as the global technological leader was increasingly challenged by Japan and Europe. In those years the US skill premium and residual wage inequality increased substantially. This paper presents a two-region quality ladders model of technical change where firms from the leading region innovate in all sectors of the economy, while the lagging region progressively catches up as its firms enter global innovation races in a larger number of sectors. As the innovation gap closes, the advanced country experiences fiercer foreign technological competition which forces its firms to innovate more. Faster technical change then increases the skill premium and residual inequality. Offshoring production and innovation plays a key role in shaping the link between international competition and inequality. The quantitative analysis exploits the variation in the geographical distribution of R&D investment in OECD STAN data to construct a measure of international technological competition between the US and the rest of the world. In a calibrated version of the model, the observed increase in foreign competition experienced by US firms accounts for up to $1/6^{th}$ of the surge in the US skill premium and up to one half of the increase in residual inequality between 1979 and 1995.

JEL Classification: F16, J31, O33

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1 Introduction

Wage inequality has increased rapidly in the United States in recent decades. The skill premium, measured as the college/high school wage ratio, increased by approximately 20 percent from the late 1970s to the early 1990s, while residual wage inequality - the wage dispersion across workers with similar observable characteristics - increased by about 15 percent over this period (Autor, Katz and Kerney, 2008 and 2010, and Heatcote et al., 2010). At the same time, American firms experienced fiercer international competition as Japanese and European firms were progressively closing the technological gap with the US frontier. Focusing on R&D investment as a proxy for innovation, there is evidence of a substantial change in the geographical distribution of innovation during this period: the US share of global R&D investment in manufacturing sectors declined from about 50 percent in 1979 to 39 percent in 1995, while Japan's share increased from 17 to 28 percent in the same period (OECD STAN). Although, the across-sector average for Europe is fairly constant, in some innovation-intensive industries Europe's share of global R&D grows substantially in this period. This suggests that US global technological leadership was increasingly challenged by foreign firms during the years of increasing wage inequality.

What is the role of foreign technological competition in shaping the dynamics of US wage inequality in the 1980s and 1990s? In this period US firms offshore a non negligible share of production and innovation activities.[1] How does offshoring affect the link between increasing foreign competition, technical change and wage inequality?

This paper tackles these questions in a version of the quality ladder growth model (Grossman and Helpman, 1991, Aghion and Howitt, 1992) in which a backward region progressively catches up with the leading region by increasing the number of industries in which it participates in innovation races for global leadership. The increase in international competition for innovation between the two regions affects the incentive to innovate and wage inequality in the leading economy. The two regions, domestic and foreign, share the same size and preferences, and the economy is populated with a continuum of monopolistic competitive sectors with firms investing in innovation to improve the quality of goods. The top-quality firm in each industry becomes the leader and supplier in a global economy without trade barriers. The trade direction of each product may reverse over time as the identity of the quality leader changes. The patterns

[1] The employment share of US affiliates of multinational corporations is on average 26%, and the R&D employment share of US affiliates is on average 12% in these years (BEA International Investment Statistics).

of trade are determined by the number of sectors in which each countries' firms have the technological leadership, which depends on firms past investment in innovation.

International technological competition is represented by the following feature of the economy: I assume that the domestic region is the world leader in that its firms invest in innovation in all sectors of the economy, while foreign firms innovate only in few sectors. The share of sectors in which firms from both regions compete in innovation is used as a measure of international competition. Each firm undertakes two activities: production of goods using unskilled workers, and innovation employing skilled workers. Workers have heterogeneous abilities drawn from a fixed distribution. They can decide to spend time in school in order to become skilled workers and acquire a level of efficiency proportional to their innate ability. The presence of a fixed cost of education determines the ability cutoff above which workers attain education. Hence, the relative supply of skills is endogenous and responds to changes in the skilled/unskilled wage ratio, the skill premium. Moreover, since skilled workers are paid proportionally to the efficiency gained during their schooling period, the dispersion of skilled wages is affected by the cutoff ability level for obtaining education.

As foreign firms enter the global innovation race in a sector, with a probability proportional to their innovation effort, they become the global quality leaders and production shifts abroad. As a consequence, the domestic demand for production workers declines, triggering a reduction in domestic unskilled wages. This *wage-stealing* effect increases the skill premium in the domestic country directly by reducing unskilled wages, and indirectly by reducing the cost of innovation, the skill-using activity. Finally, an increase in the returns to education induces workers with lower ability to acquire education, thereby reducing the ability cutoff of skilled workers and increasing the dispersion of their wages. Hence, stiffer international competition leads to higher residual inequality as well as higher skill premium.

In this benchmark economy labor markets are assumed to be completely local and firms cannot locate either production or innovation abroad. I then introduce the possibility of offshoring production and innovation at no additional cost. Offshoring allows firms to locate their activities where factor prices are lower, thus leading to factor-price equalization. Since labor markets are global in this economy, the wage-stealing channel cannot operate and changes in international competition affect inequality through a new mechanism: assuming that the innovation technology has decreasing returns at the regional level, foreign entry in innovation in a sector leads to a more efficient international allocation of innovation efforts, thereby increasing the global demand for skills and the skill premium.[2] This is the *global efficiency* effect. As before, an increase in the education premium increases the share of skilled workers and reduces their average ability, thus leading to higher residual inequality.

In the quantitative analysis I use OECD STAN data on R&D investment in two and three-digit manufacturing industries to construct an empirical measure of the type of international competition presented in the model. The US is the domestic region and Japan and Europe represent the foreign region. The sectors where US investment in research dominates global spending in innovation are labeled *gap* sectors, while the sectors where innovation efforts are more evenly distributed across countries are called *neck and neck*. The share of neck-and-neck sectors in the economy is the empirical measure of international competition I focus on. The data show that about 42 percent of sectors are neck-and-neck in 1979 rising to percent in 1995. Feeding the model the observed reduction in competition yields the following results: under local labor markets, there is an increase in inequality accounting for about $1/6^{th}$ of the increase in the skill premium, and approximately 45 percent of the growth in residual inequality observed between 1979 and 1995. In the economy with offshoring, the observed increase in competition accounts for seven percent of the increase in the skill premium and about $1/5^{th}$ of the growth in residual inequality.

The large literature on US wage inequality in recent decades focuses on two main sources, globalization and technological change (see Hornstein, Krusell, Violante, 2005, and Acemoglu and Autor, 2010, for a survey). One strand of the literature studies the effects of trade liberalization on wage inequality when technology is given (e.g. Yeaple, 2005, Burstein and Vogel, 2010), and another analyzes the interaction between trade liberalization, technical change and wage inequality (e.g. Dinopoulos and Segerstrom, 1999, Acemoglu, 2003, and Epifani and Gancia, 2008). The present paper follows this second line of research in that technology is endogenous, but analyzes a *source* of inequality different from trade liberalization: the increase in international technological competition triggered by foreign entry in global innovation races.

The paper is closely related to the research on international technology diffusion and innovation which studies how changes in the cost and speed of diffusion affect the incentives to innovate in trading economies. Keller (2004) provides a comprehensive survey of this large literature.

[2] There is strong empirical evidence on the decreasing returns to innovation at the country level (see e.g. Hall et al. 1986, Kortum, 1993, Blundell et al. 2002).

Some examples are Helpman (1993), Eaton and Kortum (1999) and (2006), Rodriguez-Claire (2007), and Hsieh and Ossa (2010). Helpman (1993) sets up a quality ladder growth model with an innovating region (North) and an imitating region (South) trading freely. Faster technology diffusion, represented by a reduction in the imitation cost, spurs innovation by reducing wages - the cost of innovation. Eaton and Kortum (1999) build a multicountry quality ladder model in which all countries innovate and contribute to the world technology frontier, and diffusion depends on each country's capacity to adopt foreign technologies. Following Eaton and Kortum, in this paper both regions innovate but there is a reduced-form representation of technology diffusion: the exogenously-given level of international technological competition can be thought of as the equilibrium outcome of different adoption rates (or barriers to diffusion). This simple way of modeling diffusion allows me to directly exploit the variation in the geographic distribution of R&D investment obtainable from the OECD STAN data. Similarly Krugman (1979), presents a diffusion model in which the leading country is assumed to be able to produce virtually all the goods in the economy, whereas the follower country can produce only the "old" goods. As in the present article, both countries have the same preferences and technologies, and the difference in production possibilities is exogenous. Krugman suggests that the source of the productive advantage of the leading economy might be related to a more skilled labor force, external economies, or to a difference in "social atmosphere." In the case of technological competition between the US, Europe and Japan that I analyze, one important exogenous source innovation advantage could be past and present innovation policy. US technology policy mainly targeting military innovations was key in shaping US technological leadership in the post-WWII period (Nelson, 1993), while the aggressive industrial policy of the Japanese Ministry of International Trade and Industry (MITI) and some European success story like Airbus, can be at the root of these country's entry into global R&D races in the 1980s (see e.g. Tyson, 1992, and Nelson, 1993).[3]

Impullitti (2010) uses a similar model of diffusion to explain the effects of foreign competition on innovation and welfare, but assumes away any effect on the labor market.[4] The main

[3]The main argument made by the innovation policy literature is that goverments can stimulate firms entry in innovation by either providing, through procurement, a sufficiently large market size that makes it worth for firms to pay the high fixed costs and bear the high risk on investing in innovation; or facilitate commercial innovation through tax susidies and technology transfer (see e.g. Hart, 2001, and Hausman and Rodrik, 2003)). For an in depth discussion of innovation and industrial policy theories and evidence see Fagerberg, Mowery, and Nelson (2004), and Harrison and Rodriguez-Claire (2010).

[4]Rodriguez-Claire (2007) and Hsieh and Ossa (2010) focus on quantifying the welfare effects of technology

contribution of this paper is first, to provide a theory of how faster international technology diffusion affects wage inequality - a channel that is not explored in the existing literature - and secondly, to quantify the contribution of this specific channel to the path of inequality observed in US data.

There is a growing body of work analyzing the effects of offshoring on wage inequality. Feenstra and Hanson (1999), Grossman and Rossi-Hansberg (2008), and Burnstein and Vogel (2008) among others have highlighted channels through which trade in intermediates and offshoring opportunities affect the skill premium. In this line of research the source of inequality is represented by changes in the opportunity (cost) of offshoring, for a given level and structure of technology. Acemoglu, Gancia, and Zilibotti (2010) contribute to the literature by introducing innovation and studying how exogenous changes in the possibility of offshoring affects technology, which in turn determines wage inequality. I follow a similar approach in analyzing the interaction between exogenous offshoring and endogenous technology, but I assume that all goods can be offshored and focus on how changes in international competition affect innovation and inequality in the presence of offshoring.

Finally, the literature on globalization and inequality discussed above has mainly focused on one measure of inequality - the skill premium - while little attention has been given to the rise in residual inequality. The record increase of US wage dispersion across workers with similar observable characteristics in recent decades[5] has been mostly linked to changes in the speed and structure of technological change (e.g. Acemoglu, 1999, Caselli, 1999, Galor and Moav, 2000, and Violante, 2002). I contribute to this literature by analyzing how globalization, in the form of increasing technological competition, affects innovation and the returns to observed and unobserved ability, thus shaping the dynamics of residual inequality. The model's prediction that growth in residual inequality is driven by increases in the share of educated workers in the population is in line with the empirical results of Lemieux (2006). Using May CPS data, Lemieux shows that a large fraction of the increase in residual inequality is attributable to an increasing dispersion of unobserved workers' abilities in the 1980s, a period in which the workforce grows older and more educated.

diffusion as well, using different data and frameworks.

[5] Juhn, Murphy, and Pierce (1993), and Lemieux (2006) provide comprehensive empirical analysis of the evolution of residual wage dispersion in the US.

2 Stylized facts

In this section I introduce and discuss the data providing motivation for the paper as well as empirical support for the quantitative analysis. First I discuss the dynamics of the skill premium and residual inequality in the US. Secondly, I explore the evolution of countries' shares of R&D investment at the industry level. As my interest is in international competition among technological leaders, I restrict the attention to the US, Japan, and 10 European countries: Germany, France, the U.K., Italy, Sweden, Denmark, Finland, Ireland, Spain, and the Netherlands.[6] I then build an index of countries neck-and-neckness in R&D; that is, I construct a measure of the share of industries where domestic and foreign countries effectively compete for innovation. This allows me to obtain an empirical measure for the international technological competition defined in the model, which I will use to perform quantitative analysis.

2.1 Wage inequality

The returns to college - measured as the ratio of wages of workers with a college or higher degree to wages of workers with at most a high school degree - show a drastic increase starting in the late 1970s, as shown figure 1. In 1978 the college premium is substantially equal to its value in 1963, with college graduates earning about 50 percent more than high school graduates and dropouts. From 1979 to 1995 the college premium increases by about 21 percent, with college graduates earning about 80 percent more than workers with lower levels of education. Since I interpret the returns to schooling as the true relative price of skills, the college premium will

[6] In the period 1973-1995, R&D expenditures in these countries represent between 95 and 98 percent of global R&D investment in manufacturing (OECD ANBERD Rev.2, 2005).

be the definition of the skill premium in the paper.[7]

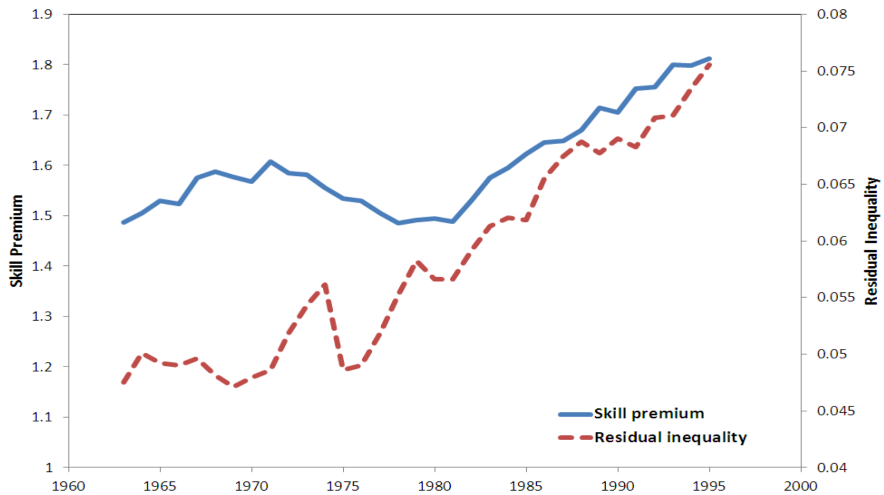

Figure 1. Wage inequality in the US

Figure 1 also shows the trend of residual inequality, measured as the variance of the residuals from a Mincerian regression of log wages on observable characteristics of workers, including education.[8] Residual inequality is therefore a measure of wage dispersion across workers with similarly observable characteristic. The figure shows a small increase before 1979 and, as in the case of the college premium, a steady increase afterwards, scoring a 30 percent growth between 1979 and 1995.

2.2 Global R&D investment and international competition

I use OECD STAN ANBERD data on R&D investment for two and three-digit manufacturing industries. Grouping together the 10 European countries, figure 2 reports sectorial average R&D investment shares for the US, Japan, and Europe. The figure shows that, while European countries as a whole kept a fairly constant share, the US share declined substantially, from 52 to 39 percent between 1973 and 1995, while Japan's share increased from 17 to 28 percent in the same period.[9] This suggests that the US position as the global leader in R&D investment

[7]Since returns to schooling may reflect returns to individual ability, the changes observed in figure 1 might be driven by composition effects (changes in the distribution of ability across education groups). As shown in Acemoglu (2002) and Acemoglu and Autor (2010) composition effects cannot account for the observed dynamics of the wage structure in the last thirty years. Hence the changes in the returns to schooling shown in the figure can be interpreted as changes in the true price of skills.

[8]Since in the model residual inequality will be defined as the dispersion of wages of educated workers, the series for residual inequality in figure 1 is obtained considering only wage dispersion among workers with a college degree or higher. The share of the total variance of residuals attributable to educated workers is obtained from Lemieux (2006) decomposition. The total variance of residuals is taken from Eckstein and Nagypal (2004).

[9]Similar results are obtained with the weighted average, where sectors' shares of total R&D are used as weights. The US weighted share, for instance, decreases from 57 percent in 1973 to 44 percent in 1995.

was increasingly challenged by Japanese firms, while Europe's share shows only a moderate increase. Figure 2 provides an clear picture of convergence in global R&D efforts.

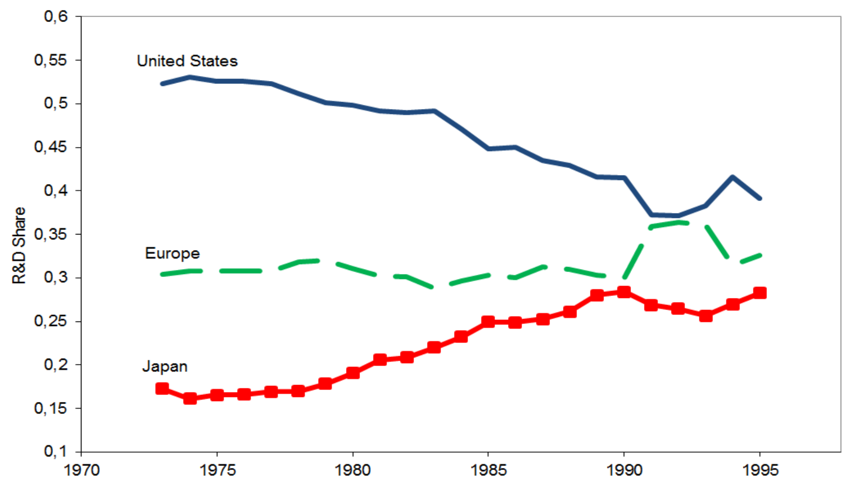

Figure 2. Global R&D Shares

Table 1 reports countries' shares in medium and high-tech sectors in 1973 and 1995.[10] The US share declines in all sectors except for Drugs and Medicines, Japan's share scores record increases in the most innovative industries: in Electrical Machineries the share rises from 16.6 percent to 43.2 percent (a 160 percent increase), in Office and Computing Machineries from about 6 to about 30 percent (a 368 percent increase), and in Radio, TV and Communication Equipment from 13 to 25 percent (a 95 percent increase). Europe provides a mixed picture with a substantial increase in Aircrafts (13 percent increase) - probably related to the entry of AIRBUS in the global market for airplanes - and in Motor Vehicles (16 percent increase), as well as decreases in Chemicals and Office and Computing Machineries. A similar picture can be obtained in medium and low-tech sectors which I do not show for brevity.

Table 1. Global R&D Shares (medium/high-tech secs)

	1973			1995			% change 1973-95		
industry	US	JAP	EU	US	JAP	EU	U.S.	JAP	EU
Aircrafts**	74.2	0.08	0.241	68.4	1.4	27.3	-7.76	81.6	13.3
Chem. no drugs*	39.7	18.5	39.8	35.9	26.1	36.3	-9.38	40.6	-8.68
Drugs and meds.**	41.3	14.5	42.2	45.5	16.8	34.6	10.1	15.7	-18
Electrical Machinery *	54.3	16.6	27.8	24.6	43.2	30.8	-54.5	160.3	10.6
Motor vehicles*	56.5	13.6	28.8	45.01	20.1	33.51	-20.4	47.7	16.3
Office & computing mach.**	76.5	6.4	16.1	53.7	30.2	13.98	-29.8	368.5	-13.2
Radio, TV & Comm. Equi.*	54.2	13.1	29.9	40.3	25.6	28.76	-25.5	95.08	-3.93

[10] The OECD classifies sectors in high-tech, medium high-tech, medium low-tech, and low-tech according to their R&D intensity (see Hatzichronoglou, 1997). High-tech and medium-high-tech industries represent 77 percent of total manufacturing R&D in the period considered.

This data can be used to build a measure of countries' neck-and-neckness in innovation. For each year, in the period 1973-95, I consider a sector neck and neck if the US share of total R&D investment is smaller than a certain threshold (NT henceforth). The measure of the neck-and-neck set of industries, that I call ϖ, is defined as the percentage of sectors with US R&D share below the threshold NT. I compute ϖ for different threshold values in the grid $NT \in (0.35, 0.68)$, and the final index is chosen taking the average index across thresholds.[11] This empirical index has been built to match the definition of technological competition studied in the model presented in the next section.

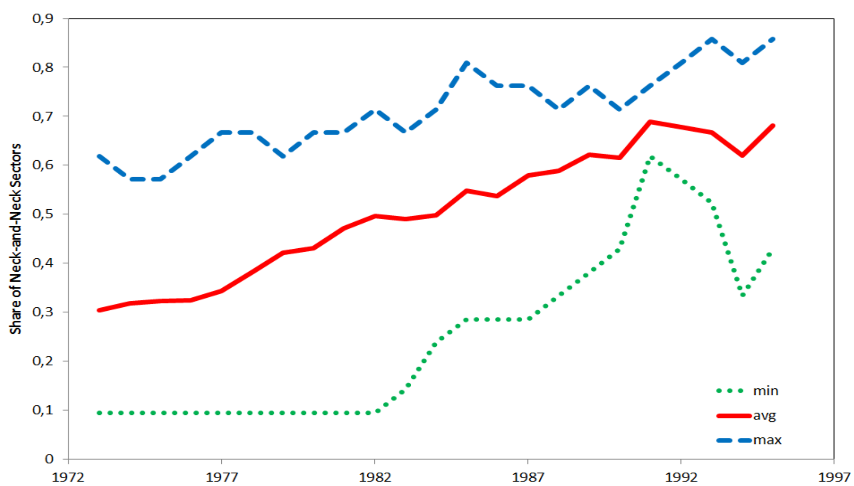

Figure 3. International technological competition

Figure 2 shows the values of ϖ obtained using the bottom threshold $NT = 0.35$ and the top threshold $NT = 0.68$; it also shows the average ϖ, which is computed taking the mean of all the ϖs obtained at each threshold levels in the set $CT \in (0.35, 0.68)$. All measures show an increasing trend, the average ϖ, which will be the index of international competition used in the quantitative analysis, increases from 0.3 (30 percent of the sectors are neck-and-neck) in 1973 to 0.68 in 1995.[12]

As figures 2 and 3 show, in the mid-1990s the convergence in R&D investment across countries seems to be completed. Interestingly, the increase in US wage inequality also slows

[11] The grid is chosen in order for the bottom threshold to yield a low and the top threshold to yield a high Herfindhal index of market concentration. More precisely, when the US share of global R&D is 0.35 and the rest of the market is equally spread between the Japan and Europe, the Herfindhal index for a sector (adjusted for the number of countries) is 0.01, which indicates a highly competitive market. While when the US R&D share is 0.68 the Herfindhal index is about 0.18, which is the level above which a market is considered highly concentrated.

[12] Using the average index allows me to address the problem of sensitivity to small changes that fixing one specific threshold might produce.

down in that period (see e.g. Acemoglu 2002, and Acemoglu and Autor, 2010). For this reason I focus the analysis on 1979-1995, the period of major increase in inequality and faster innovation convergence.

3 The model

In this section I set up the model and derive the steady state equilibrium system of equations.

3.1 Households

The economy is populated by two regions with the same population and preferences. In both regions there are heterogeneous households, differing in their ability to acquire working skills $\theta \in (0,1)$. Households have identical unit elastic preferences for a continuum of consumption goods $\omega \in (0,1)$, and each is endowed with a unit of labor/study time whose supply generates no disutility. Household of type θ is modelled as dynastic family that maximize intertemporal utility

$$U = \int_0^\infty N(0)e^{-(\rho-n)t} \log u_\theta(t)dt, \tag{1}$$

where population is specified according to $N(t) = N(0)e^{nt}$, with initial population $N(0)$ normalized to 1 and a constant population growth rate n. The rate of time preference is ρ, with $\rho > n$. The utility per person is given by

$$\log u_\theta(t) \equiv \int_0^1 \log \left[\sum_{j=0}^{j^{\max}(\omega,t)} \lambda^j q_\theta(j,\omega,t) \right] d\omega \tag{2}$$

where $q_\theta(j,\omega,t)$ is the per-member quantity of good $\omega \in [0,1]$ of quality $j \in \{0,1,2,...\}$ purchased by a household of ability θ at time $t \geq 0$. A new vintage of good ω yields a quality λ times that of the previous vintage, with $\lambda > 1$. Different versions of the same good ω are regarded by consumers as perfect substitutes after adjusting for their quality ratios, and $j^{\max}(\omega,t)$ denotes the maximum quality in which the good ω is available at time t.

At each point in time households choose the quantity purchased of each good $q_\theta(j,\omega,t)$ in order to maximize (2) subject to the per-period expenditure constraint. The utility function has unitary elasticity of substitution between every pair of product lines. Thus, households maximize static utility by spreading their expenditures $c_\theta(t)$ evenly across product lines and by purchasing in each line only the product with the lowest price per unit of quality[13]. Hence, the household's demand for each product is:

$$q_\theta(j,\omega,t) = \frac{c_\theta(t)}{p(j,\omega,t)} \quad \text{for } j = j^{\max}(\omega,t) \text{ and is zero otherwise.} \tag{3}$$

Given the optimal allocation of expenditures across different product lines at a given moment t in (3), the intertemporal optimization problem yields the Euler Equation

$$\frac{\dot{c}_\theta(t)}{c_\theta(t)} = r(t) - \rho. \tag{4}$$

Individuals are finitely-lived members of infinitely-lived households, being continuously born at rate β and dying at rate δ, with $\beta - \delta = n > 0$; $V > 0$ denotes the exogenous duration of their life[14]. They choose to acquire education and become skilled, if at all, at the beginning of their lives, and the duration of their schooling period, during which the individual cannot work, is set at $T_r < V$. In region $K = D$ (domestic), F (foreign) an individual with ability θ decides to acquire education if and only if:

$$\int_t^{t+V} e^{-\int_t^s r(\tau)} w_L^K(s)ds < \int_{t+T_r}^{t+V} e^{-\int_t^s r(\tau)} \max(\theta - \gamma, 0)\, w_H^K(s)ds, \tag{5}$$

with $0 < \gamma < 1$ defining a threshold ability requirement so that an agent with ability $\theta > \gamma$ is able to accumulate $\theta - \gamma$ units of skills after schooling, while a person with ability below γ gains no skills from education. Parameter γ could be interpreted as an ability-specific fixed cost of education.[15]

I focus on steady-state analysis, in which all variables grow at constant rate and w_L, w_H, and c_θ are all constant. From the Euler equation (4) we obtain $r(t) = \rho$ at all dates, and solving (5) with equality that agents acquire education if and only if their ability is higher than the following cutoff

$$\theta_0^K = \left[\left(1 - e^{-\rho V}\right) / \left(e^{-\rho T_r} - e^{-\rho V}\right)\right] \frac{w_L^K}{w_H^K} + \gamma \equiv \sigma \frac{w_L^K}{w_H^K} + \gamma. \tag{6}$$

with $\sigma \equiv \left[\left(1 - e^{-\rho V}\right) / \left(e^{-\rho T_r} - e^{-\rho V}\right)\right]$. I assume that agents draw their innate ability from a cumulative distribution function $\Gamma(\theta)$. This implies that $\Gamma(\theta_0^K)$ is the share of region K

[13] I assume that if there are two goods with the same quality-adjusted price, consumers will buy only the good with higher quality.

[14] It is easy to show that the above parameters cannot be chosen independently, but that they must satisfy $\delta = n/(e^{nV} - 1)$ and $\beta = ne^{nV} / \left(e^{nV} - 1\right)$ in order for the number of births at time t to match the number of deaths at $t + V$.

[15] This way of modeling the accumulation of skills has been first introduced by Findlay and Kierzkowski (1983), and extended to heterogeneous agents by Dinopoulos and Segerstrom (1999).

population deciding to not acquire education, and

$$L^K(t) \equiv \Gamma(\theta_0^K)N(t) \tag{7}$$

is the supply of unskilled labor at time t. A fraction $\left(1-\Gamma(\theta_0^K)\right)$ of the population decides to attain education and the skilled workforce is represented by the subset of these agents that have completed their schooling period, that is individuals born between $t-V$ and $t-Tr$. The supply of skilled labor in efficiency units at time t is then

$$H^K(t) = \widetilde{\theta}^K(\theta_0^K)\left(1-\Gamma(\theta_0^K)\right)\phi N(t), \tag{8}$$

with $0 < \phi \equiv \left(e^{n(V-T_r)}-1\right)/\left(e^{nV}-1\right) < 1$ and

$$\widetilde{\theta}^K(\theta_0^K) = \left[\int_{\theta_0^K}^1 (\theta^K-\gamma)\frac{d\Gamma(\theta)}{1-\Gamma(\theta_0^K)}\right] \tag{9}$$

is the average ability of educated workers. In steady state the growth rate of $L^K(t)$ and $H^K(t)$ is equal to n for $K = D, F$.

3.2 Production

In each region, firms can hire unskilled workers to produce any consumption good $\omega \in [0,1]$ under a constant return to scale technology with one worker producing one unit of product. The unskilled wage rate is w_L^K and I set $w_L^F = 1$, so that the unskilled foreign wage is the numeraire of this economy. As we saw in the previous section, only the top quality of each good is demanded by consumers, therefore in each industry only the product with the highest quality is produced. Quality leaders in each sector are challenged by followers that employ skilled workers to discover the next top-quality product. In this model, as in the baseline quality ladder growth model, leaders and followers have the same production and innovation technology, thus the Arrow effect implies that in equilibrium only followers innovate.[16] Successful innovation yields global market leadership which is protected by a perfectly enforceable patent law.

I assume that the technologies to produce goods one quality ladder below the top are obsolete and diffuse freely. This assumption allows foreign successful innovators to become

[16] An incumbent considering investing in innovation needs to subtract its present monopoly profits from the payoff of successful innovation, whereas followers have zero profits before innovating. It follows that the value of innovation for the followers is higher than for the leader. See Aghion and Howitt (1992) for a discussion of the Arrow effect, and Cozzi (2007) for a recent interpretation.

global market leaders.[17] The unit elastic demand structure encourages the monopolist to set the highest possible price to maximize profits, while the existence of a competitive fringe sets a ceiling equal to the world's lowest unit cost of the immediately inferior good on the quality ladder. Thus, the profit maximizing price of the quality leader is a limit price on the cost of the follower (competitive fringe).

In order to determine the optimal pricing I anticipate a fundamental feature of the model that will be discussed more in depth in the next two sections. I assume that domestic firms invest in innovation and compete for market leadership in all sectors of the economy, while foreign firms invest only in a subset of sectors. The share of industries in which domestic and foreign firms invest in innovation is the measure of the international technological competition I focus on. I call these industries '*neck and neck*', while the remaining industries in the product space are the '*gap*' industries. Hence, a larger share of neck-and-neck industries implies a stronger international competition to achieve global market leadership. Since domestic firms can potentially be leaders in all sectors of the economy, they produce more and demand more unskilled labor, thus paying higher wages. To obtain an non trivial market structure I focus on the equilibrium in which the gap between the two countries' unskilled wage is constrained by the following condition, $w_L^D/\lambda \leq w_L^F \leq w_L^D$. This narrow gap case (Grossman and Helpman, 1991) allows for equilibrium product-cycle trade (Vernon, 1966) with global market leadership shifting from domestic to foreign firms as the latter innovate and viceversa. Although the foreign region has a cost advantage in production, focusing on the narrow gap case guarantees that the wage gap is not so large that a foreign follower can price a domestic leader out of the market without innovating.[18]

Since both domestic and foreign followers operate with the same technology, and foreign unskilled labor is cheaper, domestic followers do not represent an effective competitive threat in sectors where firms from both countries are active in innovation. Thus the price $p^K\left(j^{\max}(\omega,t),\omega,t\right)$ of a top quality good is

$$p^K\left(j^{\max}(\omega,t),\omega,t\right) = \lambda w_L^F(t) = \lambda \tag{10}$$

[17] Without this assumption if a leader experiences successive innovations, followers will be pushed out of the market permanently. The assumption of immediate diffusion of the old production technology is discussed in Glass (1997) and widely used both in North-North models of trade and growth (e.g. Dinopoulos and Segerstrom,1999), and in North-South models (Glass, 1997, Glass and Saggi, 1998).

[18] If foreign firms' cost is instead always lower than that of domestic firms, we would have a less general and less interesting equilibrium with only foreign firms producing in neck-and-neck sectors.

in neck-and-neck sectors for $K = D, F$. In gap sectors, the competitive fringe cost is the domestic wage and limit pricing leads to

$$p^D\left(j^{\max}(\omega,t),\omega,t\right) = \lambda w_L^D(t). \tag{11}$$

From the static consumer demand (3), we can conclude that the demand for each product ω is:

$$\frac{(c^D(t)+c^F(t))N(t)}{p^K\left(j^{\max}(\omega,t),\omega,t\right)} = q\left(\omega,t\right), \tag{12}$$

where $c^D(t) = \int_0^1 c_\theta^D(t)d\theta$ and $c^F(t) = \int_0^1 c_\theta^F(t)d\theta$ are average per-capita expenditures at time t. Letting $q\left(\omega,t\right)$ be the quantity produced of good ω, the above equation implies that supply and demand of goods are equal in equilibrium. It follows that the stream of monopoly profits accruing to domestic quality leaders in neck-and-neck industries is $\pi_n^D(\omega,t) = q\left(\omega,t\right)\left(\lambda w_L^F - w_L^D(t)\right) = (c^D(t)+c^F(t))N(t)\left(1 - w_L^D(t)/\lambda\right)$, where I have used (3) to substitute for $q\left(\omega,t\right)$. Profits of domestic leaders in gap industries are $\pi_g^D(\omega,t) = q\left(\omega,t\right)\left(\lambda w_L^D(t) - w_L^D(t)\right) = (c^D(t)+c^F(t))N(t)\left(1-1/\lambda\right)$, and profits of foreign leaders are $\pi^F(\omega,t) = (c^D(t)+c^F(t))N(t)\left(1-1/\lambda\right)$.

3.3 Innovation races and the value of a firm

In each industry, quality followers employ skilled workers to produce a probability intensity of inventing the next top-quality version of their products. The arrival rate of innovation in industry ω at time t is $I(\omega,t)$, which is the sum of the Poisson arrival rate of innovation produced by all firms targeting product ω. The innovation technology available to a firm i in region K for innovation in sector ω is

$$I_i^K(\omega,t) = \frac{Ah_i^K(\omega,t)\left(\frac{H^K(\omega,t)}{X(\omega,t)}\right)^{-\alpha}}{X(\omega,t)}, \tag{13}$$

where $X(\omega,t) > 0$ measures the degree of complexity innovation, $\alpha > 0$, $H^K(\omega,t) = \sum_i h_i^K(\omega,t)$ and $I^K(\omega,t) = \sum_i I_i^K(\omega,t)$ are total skilled labor and total innovation rate in sector ω and region K respectively. This technology implies that each firm's instantaneous probability of success is a decreasing function of the total domestic labor resources devoted to innovation in an industry. A possible interpretation of this property is that when firms increase innovation inputs in a sector, the probability of duplicative innovation effort also increases, thereby reducing the probability that any single firm will discover the next vintage of goods. Therefore, the sector-specific negative externality in innovation technology produces decreasing returns to innovation at the industry level. Moreover, (13) implies that this negative externality is also region-specific;[19] this feature can be motivated by the presence of fixed costs, such as lab equipment, by institutional differences, and by the presence of a workforce with heterogeneous ability in research.[20]

The complexity index $X(\omega, t)$ is introduced to avoid the counterfactual prediction of the first generation innovation-driven growth models that the size of a region affects its steady-state growth (Jones, 1995). Following Dinopoulos and Segerstrom (1999) I eliminate scale effects assuming $X(\omega, t) = 2\kappa N(t)$, with $\kappa > 0$, thereby formalizing the idea that it is harder to innovate in a more crowded global market.[21]

Each innovating firm chooses l_i^K in order to maximize its expected discounted profits. Free entry into innovation races drives profits to zero yielding

$$v^K(\omega, t) A \left(\frac{L^K(\omega, t)}{X(\omega, t)} \right)^{-\alpha} / X(\omega, t) = w_H^K(t). \tag{14}$$

where $v^K(\omega, t)$ is the value of a firm in sector ω and region K. This condition states that the cost of one unit of skilled labor employed in innovation w_H^K must be equal to its benefits, represented by the marginal product $A \left(L^K(\omega, t)/X(\omega, t) \right)^{-\alpha} / X(\omega, t)$ times the prize for a successful innovation $v^K(\omega, t)$.

Efficient financial markets channel savings into innovative firms that issue a security paying the monopoly profits if they win the race and zero otherwise. Since there is a continuum of industries, and simultaneous and independent innovation races, consumers can perfectly diversify away risk: the expected rate of return of a stock issued by a firm is equal to the riskless rate of return $r(t)$. It is easy to show that this leads to the following value of a firm

$$v^K(\omega, t) = \frac{\pi^K(\omega, t)}{r(t) + I(\omega, t) - \dot{v}^K(\omega, t)/v^K(\omega, t)}, \tag{15}$$

[19] There is strong empirical evidence on the nonlinearity of the relation between innovation activity of a country (measured using patent data) and its R&D investment. Working with a large sample of US firm-level data, Hall et al. (1986) find an elasticity of patents to R&D of 0.5. The evidence surveyed in Kortum (1993) suggests point estimates for the patent/R&D elasticity in the range 0.1 - 0.6. More recently, Blundell et al. (2002) find a long-run elasticity of 0.5.

[20] Eaton and Kortum (1999) adopt a similar technology in their multi-country version of the quality ladder growth model. They suggest a microfundation for decreasing returns in innovation at the country level based on heterogeneous ability workers. As investment in innovation increases in a country, workers of lower ability will be used and productivity will decline. This microfundation applies to this model as well.

[21] This specification of the difficulty index is a reduced form version of the solution to the scale effects problem based on the assumption that aggregate R&D becomes more difficult over time as it is spread over more varieties (see e.g. Howitt, 1999). In my simplified version of this approach, population growth mimics the expansion in the variety of goods.

where $I(\omega, t)$ denotes the worldwide Poisson arrival rate of an innovation that will destroy the monopolist's profits in industry ω. This is the Schumpeterian rate of *creative destruction*, the expected value of a patent is inversely proportional to total innovation in the industry. Substituting for the value of the firm from (15) into (14) and using (13) to express the amount of skilled workers in terms of the innovation rate we obtain the following conditions

$$\frac{\pi^K(\omega,t)}{r(t)+I(\omega,t)-\dot{v}^K(\omega,t)/v^K(\omega,t)}\left(\frac{I^K(\omega,t)}{A}\right)^{\frac{-\alpha}{1-\alpha}}\frac{A}{X(\omega,t)}=w_H^K(t),\ \text{for } \omega\in(0,1) \text{ and } K=D,F \tag{16}$$

This condition, together with the Euler equation summarizes the utility maximizing household choice of consumption, savings, and education, and the profit maximizing choice of production and innovation. Innovation arrival rates determine the evolution of the average quality of goods in the economy $O(t)=\ln\lambda\int_0^1\left[\int_0^t I(\omega,\tau)d\tau\right]d\omega$, obtained from the preferences in (2).

3.4 International technological competition

The international competition is defined in the model by the share of industries where firms from both regions compete in innovation. I assume that there exists an exogenously given subset of industries $\overline{\omega}\in(0,1)$ where domestic and foreign researchers compete to discover the next vintage of products, while in the complementary $1-\overline{\omega}$ industries only domestic firms compete for innovation. This leads to the following composition of worldwide investment in innovation,

$$\begin{aligned} I(\omega,t) &= I_n^D(\omega,t)+I^F(\omega,t) && \text{for } \omega\leq\overline{\omega} \\ I(\omega,t) &= I_g^D(\omega,t) && \text{for } \omega>\overline{\omega} \end{aligned} \tag{17}$$

where $I_g^D(\omega,t)$ is innovation in sectors where only domestic firms compete to improve product's quality, and $I_n^D(\omega,t)$ is domestic innovation in industries in which foreign firms compete in innovation as well; $I^F(\omega,t)$ is foreign innovation.

The set of sectors $\overline{\omega}$ could be obtained as an equilibrium result by, for instance, introducing heterogeneous innovation technologies across industries and countries, as shown in Impullitti (2010).[22] For tractability I consider $\overline{\omega}$ exogenous but, in order to keep in mind this heterogeneous-industries interpretation, I call goods in the set $\omega\leq\overline{\omega}$ *neck-and-neck* industries

[22] The goods in $\overline{\omega}$ would be those for which the technology gap between the most advanced country (home) and the laggards (foreign) is sufficiently small to allow the laggards to effectvely compete in innovation with the leaders.

and those in the set $1-\varpi$ *gap* industries. Besides tractability, there is another reason to consider ϖ exogenous: the paper is motivated by the evidence discussed in section 2 showing that US leadership in R&D investment is increasingly challenged by Japan and Europe in the period considered. The goal of the paper is to build the simplest model that allows to exploit that evidence. Introducing heterogeneous technologies would require data on innovation technology at the region and sector level which are not available.[23]

Since goods $\omega \in (0,1)$ are symmetric (same technologies, both in production and innovation, and enter symmetrically in the utility function), the only source of structural asymmetry between the two countries is produced by the partition of sectors in neck and neck and gap. Therefore we can write, $I_g^D(\omega,t) = I_g^D(t)$ for all $\omega > \varpi$, $I_n^D(\omega,t) = I_n^D(t)$ and $I^F(\omega,t) = I^F(t)$ for all $\omega \leq \varpi$.

3.5 Labor markets

To close the model we need to introduce the labor market clearing conditions and trade balance. I analyze two different benchmark economies. In one offshoring is not possible and, consequently, labor markets for both types of workers are local. In the second scenario instead, firms can offshore both innovation and production at no additional costs, leading to perfectly global labor markets for skilled and unskilled workers, and to equalization of factor prices across regions.

3.5.1 Local labor markets

The production technology specified above implies that the demand for unskilled workers is equal to total production of goods in each national economy. For the domestic region the unskilled labor market clearing condition is

$$\Gamma(\theta_0^D) = \left[\frac{\left(c^D(t) + c^F(t)\right)}{\lambda}\right]\left[\varpi\beta(t) + \frac{(1-\varpi)}{w_L^D(t)}\right], \tag{18}$$

where the left-hand side is the population adjusted domestic supply of unskilled workers from (7), and the right-hand side is the domestic demand for unskilled workers. The variable $\beta(t)$ indicates the fraction of neck-and-neck industries with a domestic leader. The structure of global innovation activity specified in (17) implies that $\beta(t)$ evolves according to the law of

[23] See Impullitti (2010) for a detailed discussion of this issue.

motion

$$\dot{\beta}(t) = (1 - \beta(t))\, I_n^D(t) - \beta(t) I^F(t), \tag{19}$$

where the first term on the right-hand side is the flow into $\beta-$type industries and the second is the flow out. Hence, the relative strength of domestic innovation determines domestic leadership in neck-and-neck industries. Equation (18) shows that a higher ϖ leads to a higher aggregate market size of domestic firms, and consequently to a higher domestic demand for unskilled workers. Similarly for the foreign region we have

$$\Gamma(\theta_0^F) = \left(\frac{c^D(t) + c^F(t)}{\lambda}\right) \varpi\,(1 - \beta(t))\,. \tag{20}$$

The market clearing condition for skilled workers in the domestic region is

$$\widetilde{\theta}^D(\theta_0^D)\left(1 - \Gamma(\theta_0^D)\right)\phi = 2\kappa\left[\varpi\left(\frac{I_n^D(t)}{A}\right)^{1/(1-\alpha)} + (1 - \varpi)\left(\frac{I_g^D(t)}{A}\right)^{1/(1-\alpha)}\right], \tag{21}$$

where the left-hand side is the domestic supply of skilled labor (per capita) from (8), and the right-hand side is the domestic demand for skilled workers obtained from (13) and $X(\omega, t) = 2\kappa N(t)$. Similarly, the skilled labor market clearing condition for the foreign region is

$$\widetilde{\theta}^F(\theta_0^F)\left(1 - \Gamma(\theta_0^F)\right)\phi = 2\kappa\varpi\left(\frac{I^F(t)}{A}\right)^{1/(1-\alpha)}. \tag{22}$$

To close the model we need to introduce the conditions for balanced trade: in each region total expenditures plus savings (investment in innovation) must equal national income, wages plus profits (or interest income on assets). The trade balance condition is

$$w_H^D(t)\widetilde{\theta}^D(\theta_0^D)\left(1 - \Gamma(\theta_0^D)\right)\phi + c^D(t) = w_L^D(t)\Gamma(\theta_0^D) + \frac{c^D(t) + c^F(t)}{\lambda}\left[(1 - \varpi)(\lambda - 1) + \varpi\left(\lambda - w_L^D(t)\right)\beta(t)\right], \tag{23}$$

for the domestic region and

$$w_H^F(t)\widetilde{\theta}^F(\theta_0^F)\left(1 - \Gamma(\theta_0^F)\right)\phi + c^F(t) = \Gamma(\theta_0^F) + \frac{c^D(t) + c^F(t)}{\lambda}\varpi\,(\lambda - 1)\,(1 - \beta(t))\,, \tag{24}$$

for the foreign region. Notice that investment in innovation is simply the wage bill of skilled workers and that each region appropriates the monopoly rent associated to quality leadership in the subset of industries where that region is the world leader.

3.5.2 Offshoring and global labor markets

Next, I consider an economy in which both production and innovation activities can be offshored. In order to keep the model tractable I focus on the simple case in which production and innovation can be offshored at no additional cost. The first implication of full offshoring is that both labor markets will be perfectly global, thus leading to factor price equalization (FPE henceforth), implying $w_L^D(t) = w_L^F(t) = 1$, $w_H^D(t) = w_H^F(t) \equiv w_H(t)$, and consequently $\theta_0^D = \theta_0^F \equiv \theta_0$. FPE and the first order conditions for innovation (27) imply that innovation in neck-and-neck sectors is equalized, that is $I_n^D(t) = I^F(t) \equiv I_n(t)$. The possibility of locating production and innovation abroad changes the labor market clearing conditions described above as follows: there is only one market clearing condition determining the equilibrium of the global market for unskilled workers,

$$2\Gamma(\theta_0) = \left(\frac{c^D(t) + c^F(t)}{\lambda}\right) \tag{25}$$

and one equilibrium condition for the global market for skilled labor,

$$2\widetilde{\theta}(\theta_0)\left(1 - \Gamma(\theta_0)\right)\phi = 2\kappa\left\{2\overline{\omega}\left(\frac{I_n(t)}{A}\right)^{1/(1-\alpha)} + (1-\overline{\omega})\left(\frac{I_g^D(t)}{A}\right)^{1/(1-\alpha)}\right\}. \tag{26}$$

4 Steady-state equilibrium

A balanced growth path for this economy is an equilibrium in which per-capita variables are constant, the share of industries with a domestic leader is constant, the share of population acquiring skills is constant, and the average quality of goods grows at a constant rate. Since wages are constant in steady state, the free entry condition (14) and $X(\omega, t) = 2\kappa N(t)$ imply that $\dot{v}^K(\omega, t)/v^K(\omega, t) = \dot{X}(\omega, t)/X(\omega, t) = n$, for $K = D$, F and for all $\omega \in (0, 1)$. Per-capita expenditure is constant in steady state, then the Euler equation (4) yields $r(t) = \rho$. The global distribution of innovation and the equations for profits specified above imply that conditions

(16) become

$$
\begin{aligned}
v^D(\omega) &= \frac{(c^D+c^F)\left(1-w_L^D/\lambda\right)}{\rho+I_n^D+I^F-n}\frac{A}{2\kappa}\left(\frac{I_n^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} = w_H^D, \text{ for } \omega\leq\overline{\omega} \\
v^F(\omega) &= \frac{(c^D+c^F)(1-1/\lambda)}{\rho+I_n^D+I^F-n}\frac{A}{2\kappa}\left(\frac{I^F}{A}\right)^{\frac{-\alpha}{1-\alpha}} = w_H^F, \text{ for } \omega\leq\overline{\omega} \\
v^D(\omega) &= \frac{(c^D+c^F)(1-1/\lambda)}{\rho+I_g^D-n}\frac{A}{2\kappa}\left(\frac{I_g^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} = w_H^D, \text{ for } \omega>\overline{\omega}\ .
\end{aligned} \tag{27}
$$

where I have used $X(\omega,t)=2\kappa N(t)$, $r(t)=\rho$, and $\dot{v}^K(\omega,t)/v^K(\omega,t)=n$

The steady-state version of the labor market clearing conditions (18), (20), (21), and (22) can be obtained by simply dropping the time index and considering that in steady state (19) implies $\beta = I_n^D/\left(I_n^D+I^F\right)$. Similarly the trade balanced conditions (23), (24) can be obtained by simply dropping the time index and using the steady-state values for β and θ_0^K. Using (6) to express θ_0^K as a function of wages, the equilibrium system is composed of nine equations, (27), the steady-state versions of (18)-(22), (23) and (24), and eight unknowns $\left(c^D,\ c^F,\ I_g^D,\ I_n^D,\ I^F,\ w_H^D,\ w_L^D,\ w_H^F\right)$. This is a general equilibrium model, thus for Walras Law we can solve for eight equations and eight unknowns.

Factor price equalization in the economy with offshoring leads to a simpler equilibrium system. With global wages, domestic and foreign firms value in neck-and-neck sectors are equalized, $v^D(\omega)=v^F(\omega)$ for $\omega\leq\overline{\omega}$, leading to equal innovation, $I^F=I_n^D\equiv I_n$. Equations (27) then become

$$
\begin{aligned}
\frac{(c^D+c^F)(1-1/\lambda)}{\rho+2I_n-n}\frac{A}{2\kappa}\left(\frac{I_n}{A}\right)^{\frac{-\alpha}{1-\alpha}} &= w_H, \text{ for } \omega\leq\overline{\omega} \\
\frac{(c^D+c^F)(1-1/\lambda)}{\rho+I_g^D-n}\frac{A}{2\kappa}\left(\frac{I_g^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} &= w_H, \text{ for } \omega>\overline{\omega}\ .
\end{aligned} \tag{28}
$$

The other equilibrium conditions are the steady-state versions of global market clearing conditions (25)-(26) and trade balance (23)-(24). Using (6) to express θ_0^K as a function of wages, the equilibrium system is composed of six equations, (28), the steady-state versions of (25)-(26) and (23)-(24), and five unknowns $\left(c^D,\ c^F,\ I_g,\ I_n,\ w_H\right)$. Walras law allows us to solve for five equations and five unknowns.

I complete the description of the model by deriving the two measures of inequality I focus on, the skill premium and residual inequality. The skill premium, defined as the average wage of skilled workers over the unskilled wage is

$$s^K = \frac{w_H^K\, \widetilde{\theta}^K(\theta_0^K)}{w_L^K} \tag{29}$$

where $\widetilde{\theta}^K(\theta_0^K)$ is the average efficiency units of a skilled worker defined in (9). Wage dispersion in the economy is pinned down by the dispersion of skilled wages. Since the wage of a skilled worker with ability θ is $w_H^D(\theta) = \left(\theta^D - \gamma\right) w_H^D$, residual inequality is the variance of $w_H^D(\theta)$,

$$res^K = var(\theta) = \left[\int_{\theta_0^K}^1 (\theta^K - \gamma)^2 \frac{d\Gamma(\theta)}{1 - \Gamma(\theta_0^K)}\right] - \left[\widetilde{\theta}^K(\theta_0^K)\right]^2. \tag{30}$$

5 Foreign competition, innovation and wages: analytical results

In this section I derive a few analytical results providing some key intuitions for the effects of an increase in international competition on innovation and wages in the home country. In the following section we calibrate the model and explore its properties numerically.

5.1 Local labor markets

I first derive the solution for a version of the model without innovation. Assuming constant technology implies that there is only one activity, production, and both types of workers are used in this activity. Since in this case workers operate the same constant returns technology, there is only one wage in each national economy, the production wage, and no incentive to obtain education. The equilibrium is characterized by the steady-state version of the unskilled labor market clearing conditions (18) and (20), and by trade balance (23)-(24), yielding the equilibrium values of c^D, c^F and w^D. The labor market clearing conditions, modified to take into account that workers do not acquire education and that technology is constant, are

$$L^D = \left(\frac{c^D + c^F}{\lambda}\right)\left[\overline{\omega}\beta + \frac{(1-\overline{\omega})}{w_L^D}\right] \text{ and } L^F = \left(\frac{c^D + c^F}{\lambda}\right)\overline{\omega}\,(1-\beta)$$

where the labor supply is simply proportional to population $L^K = N^K$, and for generality we assume that it is different between countries.[24] Since there is no innovation, we assume that with exogenous probability β domestic firms are the global leaders in neck-and-neck sectors $\overline{\omega}$,

[24] The assumption of different population is introduced for generality but it is not needed for the results obtained below. For simplicity we also assume that population is constant.

and with probability $1-\beta$ the leadership is obtained by foreign firms. Combining these two equations we obtain

$$w_L^D = \frac{(1-\overline{\omega})}{\overline{\omega}} \frac{1}{l(1-\beta)-\beta} \tag{31}$$

where $l = N^D/N^F$ is the relative population. It is easy to see that $dw_L^D/d\overline{\omega} < 0$.

Proposition 1 *In an economy with constant technology and no offshoring, a larger number of neck-and-neck sectors $\overline{\omega}$ leads to lower domestic wages.*

An increase in the fraction of sectors in which both domestic and foreign firms obtain a share of the global market reduces domestic wages. This is the *wage-stealing effect* of increasing foreign competition: as foreign firms enter new sectors in which previously only domestic firms were operating, with some positive probability β production shifts abroad and the domestic labor market clears at a lower wage. As we will see below, this is a key effect in the full model as well: with endogenous technology, the share of sectors with domestic leaders β is an equilibrium result of global innovation races, but an increase in $\overline{\omega}$ still shifts a fraction of production abroad and reduces the domestic demand for unskilled labor.

5.2 Offshoring

Factor price equalization attained in the economy with full offshoring simplifies the model substantially and allows us to derive analytically the effects of foreign competition on inequality. The results are summarized below.

Proposition 2 *In an economy with complete offshoring an increase in foreign competition, triggered by a larger number of neck-and-neck sectors, stimulates innovation, thereby raising the relative skilled wage (w_H) and decreases the ability cutoff θ_0 in both regions. If the ability distribution is logconcave, a reduction in θ_0 increases the variance of skilled wages, thus raising residual inequality.*

Proof. See appendix. ■

In a world with offshoring there is no wage difference between the two regions, therefore increases in foreign competition cannot affect the skill premium through wage-stealing. The transmission mechanism from competition to inequality here is due to the endogenous technology feature of the model. Innovation increases with $\overline{\omega}$ because global innovation in neck-and-neck sectors is higher than in gap sectors, $2I_n > I_g^D$, therefore the total labor resources devoted to innovation, the right-hand side of (26), increases with $\overline{\omega}$. This is what I call the *global efficiency effect* and is produced by the decreasing returns to innovation featured in technology (13): the region-level concavity of the innovation technology implies that in each industry, two skilled workers from two different regions are more productive than two skilled workers from the same region. Thus, a higher $\overline{\omega}$ leads to a larger number of sectors with higher arrival rate of innovation and, consequently, to higher demand for skills worldwide. Notice that the positive impact of a higher $\overline{\omega}$ on global innovation could be offset by a negative effect on sectorial innovation rates I_n and I_g^D. As I show in the appendix, although $\partial I_g^D/\partial\overline{\omega}$ and $\partial I_n/\partial\overline{\omega}$ are both negative, the composition effect dominates, thus leading to an overall positive effect of foreign competition on global innovation.[25]

Equation (6), shows that an increase in the relative wage of skilled workers w_H/w_L, raises the return to education and reduces the ability cutoff θ_0 to choose education, thus increasing the share of skilled workers in the workforce. As a consequence, workers with lower ability enter the skilled workforce. If the ability distribution is logconcave - a property of many common distributions - a reduction in the cutoff θ_0 increases the variance of skilled wages, our measure of residual inequality.[26] Logoconcavity is only a sufficient condition for the wage variance to be increasing in θ_0. In the quantitative analysis I choose a distribution among those that can be logconcave under parameter's restrictions and I let the calibration pin down the parameters' value.

Finally, since an increase in skilled wages triggers a reduction in the θ_0, thereby leading to a lower average ability of skilled workers, I cannot show analytically that higher $\overline{\omega}$ leads to higher average skill premium $(w_H\widetilde{\theta}(\theta_0))$. The quantitative analysis that follows shows that the skill premium, as defined in (29), is increasing in competition for a wide set of plausible parameters.

[25] The effect of changes in $\overline{\omega}$ on innovation per sector can be attributed to the higher obsolescence of innovation produced by foreign entry.

[26] An (1998) shows that the the left-truncated variance of logconcave distributions decreases in the truncation point. A probability distribution is logconcave if the log of its pdf is concave. Many common distributions are logconcave: the normal, uniform, logistic, extreme-value, Chi, Chi-square, and Laplace. Other common distributions such as the power, Weibul, Gamma, Chi, Chi-squared, and Beta are logconcave for values of their parameters larger than one (Bagnoli and Bergstrom 2005). Logconcavity is only a sufficient condition for the variance of a left-truncated distribution to be decreasing in the truncation point. The Pareto distribution, for instance, is not logconcave but its variance is decreasing in the left-truncation point.

6 Quantitative analysis

In this section I calibrate the parameters of the model to match some basic long-run empirical regularities of the US economy, compute the numerical solution using the calibrated parameters and explore the effects of increasing international competition on wage inequality. I first analyze the model for the economy with local labor markets and then study the economy with offshoring.

6.1 Calibration

I assume that abilities are drawn from the cumulative distribution function $\Gamma(\theta) = \theta^{\varepsilon}$. This is a fairly general distribution function in $(0, 1)$: when $\varepsilon = 1$, the ability is distributed uniformly in the population, when $\varepsilon < 1$ the ability distribution is skewed towards low-ability workers, and for $\varepsilon > 1$ the ability distribution is logconcave.[27] I need to calibrate ten parameters: six of them, ρ, λ, n, T_r, γ and V are calibrated using benchmarks that are standard in the literature, while the other four, A, k, α and ε are calibrated internally so that the model's steady state matches salient facts of the economy. In the quantitative analysis I explore the effects of the increase in the international competition index shown in figure 3 on inequality from 1979 to 1995. Hence when the statistics used in the calibration show substantial increases in this period I use pre-1979 (pre-shock) values as targets.

Parameters calibrated "externally". Some parameters of the model have close counterparts in real economies so that their calibration is straightforward. I set ρ, which in steady state is equal to the interest rate r, to 0.07 to match the average real return on the stock market for the past century of seven percent, estimated in Mehra and Prescott (2003).[28] I set λ to 1.4, to match an average markup over the marginal cost of 40 per cent. Since, estimates of average sectorial mark-up are in the interval $(0.1, 0.4)$ (Basu 1996), I take a value within this range.[29] I choose n to match a population growth rate of 1.14 percent (Bureau of labor Statistics,1999). I choose the total schooling time $T_r = 4$ to match the average years of college in the US, and total working life $V = 52$ to match a life expectancy at birth for cohorts turning 18 years old

[27] This distribution is often used in quantitative models with heterogeneous agents, to match wage, income and earning dispersion. See e.g. Chatterjie, Corbae, Nakajima, and Rios-Rull (2007), and Antunes, Cavalcanti, Villamil (2008).

[28] Jones and Williams (2000) suggest that the interest rate in R&D-driven growth models is also the equilibrium rate of return to R&D, and so it cannot be simply calibrated to the risk-free rate on treasury bills - which is around 1%. They in fact calibrate their R&D-driven growth model with interest rates ranging from 0.04 to 0.14.

[29] I take the upper value of the range because the numerical solution is more robust with high λs.

in 1979 of 70 years (National Vital Report Statistics, 2010).[30] Autor, Katz, and Kruger (1998) show that the relative supply of skills (college and above over non-college) rises from 0.138 in 1970 to 0.25 in 1990. I follow this evidence by choosing the threshold $\gamma = 0.75$ to bound the relative supply of skilled workers below 25 percent of the workforce.

Parameters calibrated "internally". I simultaneously choose A, κ, α, and ε so that the numerical steady state solution of the model matches relevant US statistics. The calibrated parameters' values for the economy with local labor markets differ from those for the economy with offshoring. In this section I match the data to the theoretical moments from the model with local labor markets, and in section 6.3 I consider the model with offshoring. A, α, and κ are technology parameters relevant for innovation, the demand for skills and the skill premium. The shape parameter of the ability distribution ε affects the skill premium and wage dispersion. Hence I choose to calibrate A, κ, α, and ε targeting the following statistics: the overall growth rate of the economy, the innovation investment share of income, the skill premium, and residual inequality.[31] The parameters are calibrated in order to minimize a loss function defined by the quadratic distance between the moments in the model and the targeted statistics.

Since the paper focuses on innovation, it seems natural to use data from Corrado, Hulten and Sichel (2006, CHS henceforth), where US national account data have been revised to introduce investment in intangible capital, a new more comprehensive measure of investment in innovation[32]. The model I set up does not have tangible (physical) capital, therefore national accounting statistics used in the calibration must be adapted to the model economy. Hence, the growth rate of productivity is obtained subtracting the share attributable to tangible capital from the overall growth rate, and the income share of intangible investment is obtained subtracting investment in tangible capital from national income. After these adjustments the CHS data report an average growth of labor productivity of 1.17 percent a year in the period

[30] I consider that agents choose whether to go to college at age 18, so that the 18 years old cohort in 1979 is represented by people born in 1961, and life expectancy at birth in 1961 in the US is 70 years. I also include retirment years into working life assuming that pensions are proportional (equal for simplicity) to wages during working life.

[31] In the present framework with quality-improving goods, growth is interpreted as the increase over time of the consumer's utility level, which is pinned down by the growth rate of quality. It is easy to show that th growth rate is

$$g = \frac{\dot{u}}{u} = \frac{\dot{O}(t)}{O(t)} = \left[\bar{\omega}(I_n^D + I^F) + \left(1 - \bar{\omega}\right) I_g^D\right] \ln \lambda.$$

[32] It includes R&D, computer software, and investment in a set of activities aimed at improving existing goods, such as, advertising, design, marketing etc.

1970-79, and an average income share of intangible investment of 0.09 in the same period. I target a skill premium of 0.4 (in logs), which is the 1979 value in Autor at al. (2008), and a residual inequality of 0.05, the 1979 data point of figure 1 obtained with data from Heatcote et al. (2010) and Lemieux (2006). Finally, I use the 1979 value for the international competition index obtained in figure 3 above, hence I set $\overline{\omega} = 0.425$. The resulting calibrated values are $A = 1.5$, $\kappa = 0.95$, $\alpha = 0.1$, and $\varepsilon = 0.9$. Table 2 shows how well the model fits the US data at the initial data, 1979.

Table 2. Model fit (1979)

	Data	source	Benchmark model
TARGETED			
skill premium (logs)	0.4	Autor et al. (2008)	0.5
growth rate	0.0117	CHS (2009)	0.011
Innovation/GDP	0.09	CHS (2009)	0.09
residual inequality	0.05	Heatcote et al. (2010)	0.017

The calibration model fits the targeted statistics fairly closely.

6.2 International competition and wage inequality: local labor markets

I now analyze the effects of increasing international competition from its benchmark calibrated value $\overline{\omega} = 0.425$ to full symmetry ($\overline{\omega} = 1$) on the skill premium and on residual inequality in the economy without offshoring. Figure 4 below reports the simulation results using the benchmark parameters, the robustness of the results to parameters' change is analyzed in the appendix.

The *wage-stealing effect*, derived analytically for a simplified version of the model with constant technology in the previous section, is confirmed in the numerical simulation of the full model. Foreign entry in innovation in new sectors shifts market shares abroad and reduces production wages in the home region. This can be easily seen looking at the demand for domestic unskilled labor, the right-hand side of (18): an increase in $\overline{\omega}$ raises the share of industries for which global leadership is shared according to countries' relative innovation intensity $\beta = I_n^D / \left(I_n^D + I^F\right)$, therefore reducing the domestic demand for unskilled labor. Notice that this result is not simply produced by competition from a region with lower production wages. The Schumpeterian innovation structure built in the model implies that global leadership can be attained only producing a higher quality. In existing multi-country models of endogenous technical change, wage-stealing from foreign competition is obtained as the lagging country imitates the leading technology and replace the leading country's firm because of lower wages (e.g. Helpman, 1993). The novelty of the current model is to allow for technological leapfrogging: in order to become the world leader, the lagging country firm must innovate and produce a higher quality good.

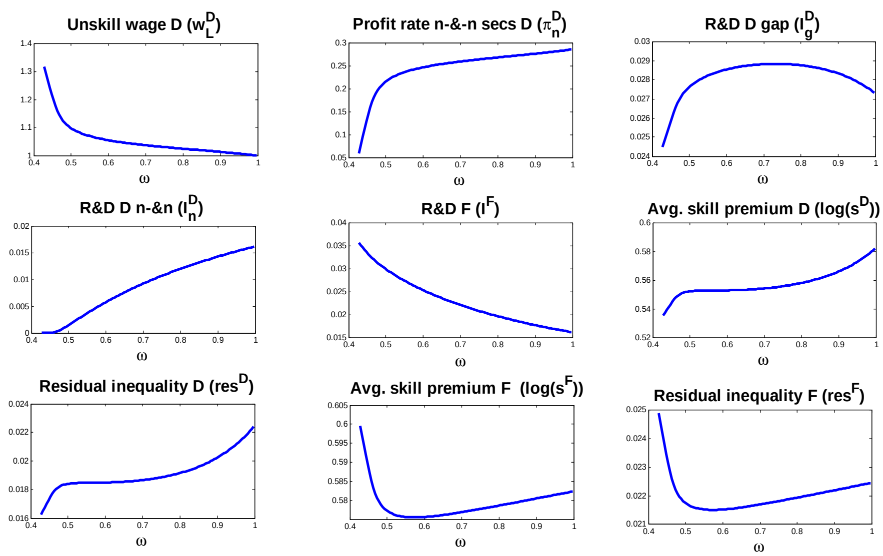

Figure 4. International competition and inequality: no offshoring

Endogenous technical change plays an additional role in shaping the effects of foreign competition on inequality. Foreign entry in innovation reduces domestic unskilled wages in neck-and-neck sectors. Lower unskilled wages imply lower production costs and therefore higher domestic profit rate in those industries ($\lambda - w_L^D$ is the markup), as we can see in the figure. Since innovation is profit-driven, innovation in neck-and-neck sectors I_n^D increases boosting the domestic demand for skills and the skill premium.[33] Hence international wage stealing increases the skill premium in the domestic region directly, because it reduces unskilled wages and indirectly, because it increases the incentive to innovate.

Besides its effect on firm-level innovation efforts, international competition can affect innovation and the relative demand of skills by changing the sectoral composition of innovation. It

[33]Notice that the domestic innovation per-firm in gap sectors I_g^D increases for low levels of ϖ and then it slightly decreases. The increase in I_g^D is a general equilibrium result produced by the optimal allocation of domestic innovation investment between neck-and-neck and gap sectors. This additional innovation effect of competition is, though, quantitatively of second order with respect to the increase in I_n^D: the former increases by about 10 percent as ϖ goes from 0.425 to 1, while the latter grows by more than 250 percent. Thus the relevant source of the increase in the relative demand of skills is innovation in neck-and-neck industries.

is easy to show that innovation is higher in neck-and-neck sectors, $I_n^D < I_g^D$: dividing up the first and the third condition in (27), we obtain

$$\frac{\left(\lambda - w_L^D\right)}{(\lambda - 1)} \frac{\rho + I_g^D - n}{\rho + I_n^D + I^F - n} = \left(\frac{I_n^D}{I_g^D}\right)^{\frac{\alpha}{1-\alpha}}.$$

Since domestic unskilled wage is higher than foreign, $\left(\lambda - w_L^D\right) / (\lambda - 1) < 1$, domestic innovation must be higher in gap sectors, $I_g^D > I_n^D$. Domestic demand for skilled workers in (21) is a weighted average of I_n^D and I_g^D with weights $\overline{\omega}$ and $1 - \overline{\omega}$ respectively, hence an increase in $\overline{\omega}$ reduces total domestic demand for skills and consequently the skill premium. This composition effect depends on the different obsolescence of innovation in the two types of sectors: in neck-and-neck sectors there is less domestic innovation because the equilibrium value of a patent needs to accommodate foreign innovation as well.

The mechanism through which increases in foreign competition affect residual inequality is the one described in section 5: a larger skill premium implies higher returns to education, leading to a lower ability cutoff θ_0^D and to a higher dispersion of skilled wages.[34] The empirical evidence in Lemieux (2006) shows that a similar channel has been driving the increase in US residual inequality in the 1980s. He shows that a large fraction of the growth in residual inequality in the 1980s is driven by an increasing dispersion of workers' abilities, which in turn can be attributed to a growing share of educated workforce.

Although the main scope of the paper is to study the response of inequality in the domestic region to increasing international competition, it is worth to briefly discuss the dynamics of foreign inequality. Figure 4 shows a U-shape relationship between $\overline{\omega}$ and both dimensions of foreign inequality, with the declining part dominating the increasing one. The economic intuition can be easily grasped because it follows from the same mechanisms at work for the domestic region. In this case the wage-stealing effect simply operates in the opposite direction: foreign entry in innovation races in a sector leads to a larger foreign production and higher demand for unskilled workers, and hence to a lower skill premium. The increasing part of the U-shaped inequality response to competition is generated by the increase in the number of sectors where foreign firms innovate, which raises foreign demand for skills.

I conclude this section showing the quantitative relevance of the channels described above

[34] Notice that, although the calibrated ability distribution is not logconcave ($\varepsilon = 0.9$), the simulation in figure 4 shows that the variance of skilled wages increases as the cutoff θ_0^D declines. As discussed above, a logconcave ability distribution is only a sufficient condition for the wage dispersion to be decreasing in the ability cutoff.

in accounting for the observed increase in the US wage inequality documented in section 2. Recall that the skill premium increases by 21.8 percent and residual inequality increases by 30 percent in the period between 1979 and 1995. In the same period the index of international competition shown in figure 3 raises from 0.425 to 0.69, suggesting that the foreign region, Japan and Europe in the data, was progressively catching up with the US in the race for global innovation leadership. Taking this index as a measure of ϖ, I now quantify the effects of the observed increase in ϖ on the two measures of inequality. Table 3 summarizes the results.

Table 3. International competition and inequality: no offshoring

		model	data	explained
Skill premium	% change (1979-95)	0.0331	0.218	0.158
Residual inequality	% change (1979-95)	0.136	0.3	0.453

The increase in international competition observed in the data accounts for about 16 percent of the 21.8 percent increase in the US skill premium, and about 45 of the observed increase in residual inequality. Notice that the particular form of the skill premium s^D adopted in (29) biases downward the effects of increasing international competition on the skill premium. Since, skilled wages are computed as w_H^D times the average ability level of the skilled workforce $\widetilde{\theta}^D(\theta_0^D)$, when w_H^D increases and θ_0^D decreases, agents with lower abilities enter the skilled workforce reducing its average skill level $\widetilde{\theta}^D(\theta_0^D)$ and, consequently, the average skill premium. Unskilled wages instead are not proportional to the average ability of the unskilled workforce, hence, the effects of changes in ϖ on the skill premium shown in table 3 should be interpreted as a fairly conservative quantitative evaluation.

Finally, figure 4 shows that as ϖ increases from 0.425 to 0.69, the skill premium and residual inequality in the foreign region decrease. Although the scope of the paper is not to explain the dynamics of inequality in the foreign region, it is worth highlighting that the model's predictions are not at odds with the evidence on foreign inequality. In fact, there is consensus that wage inequality in these countries is fairly stable and in some cases declining in the period of analysis. Fuchs-Schündeln, Krueger, and Sommer (2010) find a declining education premium and a stable residual wage variance in Germany between 1982 and 1995. Similar results can be found in Pijoan-Mas and Sanchez-Marcos (2010) for Spain, but the data are limited to the 1990s. Domenej and Floden (2010) report sharp declines of both measures of inequality for Sweden in the period 1975-95. Kambayashi et al. (2008) and Kawagughi and Mori (2008), show that inequality in Japan is stable or slightly declining in our period of analysis. Jappelli and Pistaferri (2010) find a stable education premium in Italy but an increasing residual wage variance.

Although the model's predictions shown in figure 4 suggest that inequality decreases in Japan and Europe as $\overline{\omega}$ increases from 0.425 to 0.69, in section 5.2 we have seen that the presence of offshoring introduces a new channel leading to an increase in inequality in both regions, as the share of neck-and-neck sectors increases. This can counterbalance the negative effect shown in figure 6 and potentially yield stable or even increasing inequality in the set of countries labelled the foreign region.

6.3 Offshoring

I now turn to the quantitative analysis of the economy with offshoring, featuring global labor markets for both types of workers. I calibrate this version of the model using the same externally calibrated parameters of the benchmark model without offshoring summarized in section 6.1, and recalibrate the four 'internal' parameters $(\alpha, A, \kappa, \varepsilon)$ targeting the same statistics of the benchmark model (growth rate, innovation/GDP, the skill premium, and residual inequality) but using the relevant moments computed for the model with offshoring. The new calibrated parameters are, $\alpha = 0.2$, $A = 1.12$, $\kappa = 0.1.49$, and $\varepsilon = 0.9$, table 4 shows the fit of the model.

Table 4. Offshoring: model fit (1979)

Moments	Data	source	Benchmark model
TARGETED			
skill premium	0.4	Autor et al. (2008)	0.52
growth rate	0.011	CHS (2009)	0.01
R&D/GDP	0.09	CHS (2009)	0.12
variance log wages	0.05	Heatcote et al. (2010)	0.17

In table 5 I repeat the exercise of computing the part of the observed increase in inequality that can be accounted for by an increase in $\overline{\omega}$ from 0.425 to 0.69.

Table 5. International competition and inequality: offshoring

		model	data	explained
Skill premium	% change (1979-95)	0.015	0.218	0.073
Residual inequality	% change (1979-95)	0.061	0.3	0.205

In this economy the observed increase in international competition can explain about seven percent of the increase in the skill premium, and about 20 percent of the growth in residual inequality. Thus this version of the model accounts for a smaller portion of the increase in inequality then the economy with local labor markets. Compared to the latter, here factor-price equalization implies that the increase in international competition does not trigger any wage-stealing effect. The only channel through which changes in international competition affect inequality in the leading region is by increasing the global efficiency of innovation, and the results in table 5 show the quantitative relevance of this channel only. In the economy without offshoring, instead, the efficiency effect does not operate but wage-stealing is active and seems to be quantitatively powerful.

A unified framework accounting for all these channels is the ideal next step needed to obtain a more complete quantitative evaluation of the effects of the international technological competition on US inequality. Available data show that the US economy is closer to the local labor market scenario than to the perfect offshoring model, but the share of offshored production and innovation is far from negligible. The BEA International Investment Statistics show that the employment share of US affiliates of multinational corporations is on average 26 percent in the period I focus on, and the R&D employment share of US affiliates is on average 12 percent. Using this data to calibrate an hybrid version of the model featuring partial offshoring is an interesting task for future research. Offshoring could be obtained as an equilibrium results driven by the balance between the costs (offshoring costs) of producing abroad and the benefits (saving trade costs). This would on one hand enrich the set up with an interesting feature of the real world but would also complicate it severely. There are several models in the literature with equilibrium offshoring, but they mostly feature exogenous technology. Recent attempts of modeling offshoring within an endogenous technical change framework are Nagavi and Ottaviano (2008), Acemoglu, Gancia, and Zilibotti (2010), Gustaffson and Segerstrom (2011). In these papers countries are symmetric, while the framework used in this paper presents the additional difficulty of studying asymmetric countries.

7 Extensions

Here I present two extension of the basic model. First I discuss the assumption that the share of competitive sectors is exogenously given, and propose a simple way to endogenize it. Second, I extend the model to allow for a more general factor proportion which skilled and unskilled workers are jointly employed in both production and innovation.

7.1 Endogenizing international competition

There are two reasons for treating $\overline{\omega}$ as an exogenous variable: first, this paper is motivated by the evidence discussed in section 2 showing that the US leadership in R&D investment is increasingly challenged by Japan and Europe in the period considered; the main purpose of the paper is to study the effects of the observed change in the geographical distribution of R&D investment on US wage inequality. For this purpose I set up a model allowing me to directly exploit that empirical evidence and perform a quantitative analysis with that data. The Second reason is that, as mentioned in the introduction, the innovation policy literature suggests that the US lead of the 1960s and 1970s and the Japanese and European catching up in the 1980s were at least in part produced by policy decisions, which can be regarded as fairly exogenous for the purpose of this paper. Key examples of policy-induced entry into highly innovative sectors are the MITI policy of building a world class semiconductor industry with substantial public subsidies, and the decision of a group of European countries to set up the Airbus consortium and create a European global player in the market for aircrafts.

These explanations notwithstanding, there is no doubt that understanding the source of changes in foreign competition is an important issue. For this purpose, I now briefly discuss a simple way to endogenize international competition, and argue that the basic model represents a reduced form of this extended framework. Suppose that there is a region and sector-level heterogeneity in the innovation productivity parameter A taking the following form:

$$A^F(\omega) = \begin{cases} (1-\Delta(\omega))\, A^D(\omega) & \text{if } 0 \leq \Delta(\omega) < 1 \\ 0 & \text{otherwise,} \end{cases} \tag{32}$$

where $0 \leq \Delta(\omega) \leq \overline{\Delta}$ with $\overline{\Delta} \geq 1$, is a measure of the *distance* from the technological frontier (represented by domestic technology). This stylized representation of technological heterogeneity embodies the idea that firms in the foreign country must reach a threshold level of technology (distance to frontier) in order to efficiently enter global innovation races. Dividing up the first two equilibrium conditions in (27) and using (32) we obtain

$$I^F(\omega) = \begin{cases} (1-\Delta(\omega))^{\frac{1}{\alpha}} \left[\frac{w_H^D}{w_H^F} \left(\frac{1-\frac{1}{\lambda}}{1-\frac{w_L^D}{\lambda}} \right) \right]^{\frac{1-\alpha}{\alpha}} I_c^D(\omega) & \text{if } 0 \leq \Delta(\omega) < 1 \\ 0 & \text{otherwise} \end{cases} \tag{33}$$

Hence, foreign innovation takes place only in those industries in which the distance from the frontier is not too large.

The basic model is a reduced form of this one in that the competition measure $\overline{\omega}$, exogenous there, is now determined by a primitive of the economy (innovation technology) and is pinned down by the share of industries in which $\Delta(\omega) < 1$. Any time a sector experiences a reduction in the technological distance that brings $\Delta(\omega)$ below one, $I^F(\omega)$ becomes positive and $\overline{\omega}$ increases. Changes in the technology gap $\Delta(\omega)$ can be produced by changes in the cost of imitating or adopting the frontier research technology: education, technology and intellectual property rights policies are all possible sources of reduction in adoption costs.

In this extended framework, foreign competition affects innovation through the same mechanisms discussed in the baseline model. From (33) a decrease in $\Delta(\omega)$, provided that it goes below one, triggers foreign entry in innovation, thus producing a wage-stealing effect in the model with local labor markets and an efficiency effect in the economy with offshoring that increase domestic innovation and the relative demand for skills.[35]

Working with this augmented model requires the support of an empirical evidence different from that presented in section 2: the analysis must start from the observation that in the period considered industries show a progressive reduction in the innovation technology gap between the US and the lagging countries. In order to do that, one needs to find data on innovation productivity at the sectorial level for the set of countries considered, and document technological catch-up of Japanese and European firms. While TFP-based measures of distance from the technological frontier are available for some countries (see Aghion and Griffith 2005 for a survey), I am not aware of similar data for innovation productivity. Putting together such data set, and using it to perform quantitative analysis with the augmented model is an interesting area to be explored in future research.

Another way to endogenize international technological competition would be to allow firms from the lagging region to imitate the frontier technology of the leading region. This is the typical structure of North-South trade and growth model (see e.g. Grossman and Helpman, 1991, and Dinopoulos and Segerstrom, 2007), where once imitation takes place the Southern firm obtains the market leadership because of lower production costs (lower wages). The problem with using this framework to study the issues analyzed in my paper is that the leapfrogging

[35] Notice that this extension not only allows for the possibility of measuring changes in the share of competitive sectors, as in the basic model, but also accounts for changes in the intensity of competition within such sectors, which is pinned down by $\Delta(\omega)$. This implies that in the extended framework, a wage-stealing and an efficiency effect will be observed any time a competitive sector experiences a reduction in $\Delta(\omega)$, even when the share of competitive sectors $\overline{\omega}$ does not change.

produced by foreign competition would not be technological in nature: the foreign firm never introduces a new top-quality good and it drives the domestic firm out of the market only because of wage differences. While this would well describe a North-South type of competition, it does not capture the nature of competition between Japanese, European and American firms in the 1970s and 1980s. Moreover, in the offshoring scenario where wage differences disappear this would not be able to explain global competition for innovation and its implications for wage inequality.

7.2 Generalizing factor intensity

In the benchmark economy with local labor markets discussed above, an increase in international competition shifts production abroad and, since production employs only unskilled workers, unskilled wages decrease. This wage-stealing effect increases the skill premium directly, because of the decline of unskilled wages and indirectly, since a drop in production wages increases the returns to innovation, the skill-using activity. One might wonder whether this result crucially depends on the assumption that production employs only unskilled and innovation only skilled workers. In this section I analyze whether allowing for a more general factor intensity in production and innovation affects this basic result.[36]

I assume that both types of workers are used in the production of each good ω according to a constant return to scale technology with unit cost functions $A^D(w_L^D, w_H^D)$ and $A^F(w_L^F, w_H^F)$ for the domestic and foreign region respectively. Without loss of generality I now choose the domestic unit cost of production as the numeraire , $A^D(w_L^D, w_H^D) \equiv 1$. Again we focus on the narrow gap case, which in this economy is represented by the condition $A^D(w_L^D, w_H^D)/\lambda < A^F(w_L^F, w_H^F) < A^D(w_L^D, w_H^D)$. Similarly, skilled and unskilled workers are employed in innovation with a constant return to scale technology with unit cost[37] $B^D(w_L^D, w_H^D)X(\omega)$ and $B^F(w_L^F, w_H^F)X(\omega)$. The derivation of the equilibrium condition is similar to that in the basic model, below I report only the equations needed to analyze the main results. Limit pricing yields $p^K = \lambda A^F(w_L^F, w_H^F)$ in neck-and-neck industries and $p^K = \lambda A^D(w_L^D, w_H^D) = \lambda$ in gap

[36] Since wage-stealing does not happen in the economy with offshoring, the only interesting scenario to analyze is the case of local labor markets.

[37] It is easy to see how, for instance, a simple Cobb-Douglas specification with skilled and unskilled workers would be a generalization of technology (13). The aggregate innovation technology in a sector ω is $I^K(\omega) = A\left(H^K(\omega)/X(\omega)\right)^{1-\alpha}$ using (13), while using a Cobb-Douglas with two inputs we would have $I^K(\omega) = A\left(L^K(\omega)/X(\omega)\right)^{\alpha}\left(H^K(\omega)/X(\omega)\right)^{1-\alpha}$. Dinopoulos and Segrestom (1999) use a similar technology specification in their version of the quality ladder model with symmetric countries.

industries. The free entry condition in innovation becomes

$$P_I^K \equiv \frac{v^K(\omega)}{X(\omega)} = B^K(w_L^K, w_H^K) \text{ for } K = D, F \tag{34}$$

where the ratio $P_I^K \equiv v^K(\omega)/X(\omega)$ is the difficulty-adjusted return to innovation, and it can be thought as the relative price of innovation. Equation (34) shows that there is a link between the relative price of innovation and the relative price of skills. The value of a firm is

$$\begin{aligned} v^D(\omega) &= \frac{(c^D + c^F)\left(1 - \frac{A^D(w_L^D, w_H^D)}{\lambda A^F(w_L^F, w_H^F)}\right)}{\rho + I_n^D + I^F - n} \quad \text{for } \omega \leq \overline{\omega} \\ v^D(\omega) &= \frac{(c^D + c^F)\left(1 - \frac{1}{\lambda}\right)}{\rho + I_g^D - n} \quad \text{for } \omega > \overline{\omega} \\ v^F(\omega) &= \frac{(c^D + c^F)\left(1 - \frac{1}{\lambda}\right)}{\rho + I_n^D + I^F - n} \quad \text{for } \omega > \overline{\omega} \end{aligned} \tag{35}$$

for a domestic firm in neck-and-neck and in gap sectors, and for a foreign firm respectively.

Proposition 3 *Assuming no factor intensity reversal, an increase in the relative domestic price of innovation P_I^D raises the relative price of skills w_H^D/w_L^D and the cutoff θ_0^D to become skilled if innovation is the skilled-intensive activity.*

Proof. See appendix. ■

Figure 5 shows the result graphically. For a given relative price P_I^D the two curves $A^D(w_L^D, w_H^D) = 1$ and $P_I^D = B^D(w_L^D, w_H^D)$ are downward sloping in the space (w_L^D, w_H^D) and, in the absence of factor intensity reversal, $P_I^D = B^D(w_L^D, w_H^D)$ has a smaller slope. Thus, the two curves cross only once and uniquely determine the skilled and unskilled domestic wages. The figure shows how an increase in the relative price of innovation increases w_H^D and decreases the domestic unskilled wage. As in the basic model, equation (6) implies that a higher w_H^D/w_L^D leads to a reduction in the ability cutoff θ_0^D, thus increasing the share of skilled labor force. A logconcave ability distributions would again be a sufficient condition for the reduction of θ_0^D to increase residual wage inequality.

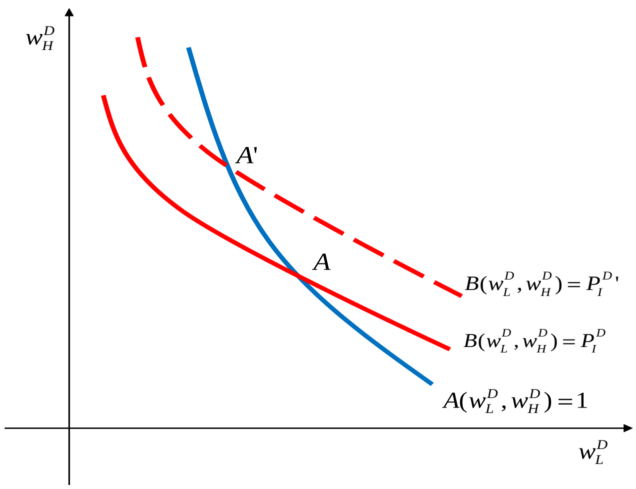

Figure 5. The Schumpeterian Stolper-Samuelson mechanism

This is a partial equilibrium result because the relative price of innovation P_I^D is an endogenous variable. Although solving the full model proves to be quite hard, equations (35) allows me to provide an intuition for the mechanism through which increasing international competition affects the value of a firm and P_I^D. As in the baseline model, an increase in $\overline{\omega}$ shifts production abroad, thereby reducing production costs and increasing the value of the domestic firm in neck-and-neck industries - first equation in (35). Thus the relative price of skills P_I^D in those industries increases. The only difference with the basic model is that now production costs $A^D(w_L^D, w_H^D)$ include both skilled and unskilled workers. In other words, here the *wage-stealing* effect of an increase in $\overline{\omega}$ affects both types of workers, but its qualitative effect on P_I^D is similar to that in the baseline model.[38] As long as innovation is more skill intensive than production, which is likely to be the empirically relevant case, production-shifting triggered by foreign entry increases the relative price of skills. Hence, the wage-stealing effect is robust to a specification of production and innovation technology with skilled and unskilled workers employed in both activities.

The relationship between the relative price of innovation and the relative price of skills is what Dinopoulos and Segerstrom (1999) call the "Schumpeterian Stolper-Samuelson" mechanism. In that paper the increase in the relative price of innovation is generated by a reduction in trade costs which raises the profits of exporters by increasing their market size. Here the rewards to innovation increase because of stiffer international technological competition, thus

[38] Since $A^D(w_L^D, w_H^D) = 1$ is the numeraire of this economy, the wage stealing effect affect the value of domestic firms in (35) via the relative production cost of domestic firms $A^D(w_L^D, w_H^D)/A^F(w_L^F, w_H^F)$.

the same mechanism is triggered by two different sources: trade liberalization in one case and international technological competition in the other.

8 Conclusion

In this paper I have built a quality ladder model of endogenous technical change in which a backward region progressively catches up with the leading region by increasing the number of industries in which its firms participate in innovation races for global leadership. Entry of firms from the lagging country in global innovation races increase innovation and wage inequality in the leading region through two channels: the *wage-stealing* and the *global efficiency* channel. The increase in international technological competition produced by foreign entry in innovation leads to global market-share losses for the leading region, and to lower production (unskilled) wages. This wage-stealing effect increases the skill premium directly by reducing unskilled wages, and indirectly by reducing the cost of innovation, the skill-using activity in the economy. Moreover, an increase in the skill premium induces workers with lower ability to acquire education and, since skilled wages are proportional to workers' ability, raises wage dispersion. Offshoring production and innovation leads to equalization of factor prices across regions, and neutralizes the wage-stealing effect. With global labor markets, fiercer international competition produces higher inequality by increasing the efficiency of global innovation: if innovation technology is characterized by decreasing returns at the regional level, as empirical evidence suggests, foreign entry in innovation leads to a more efficient international allocation of resources, thereby increasing the global demand for skills and the skill premium worldwide.

The quantitative analysis uses OECD data on R&D investment in manufacturing sectors to build a model-specific measure of the degree of international technological competition between the global leader, the US, and its followers, Japan and Europe. This measure is then used to assess the relevance of the observed change in international competition for the dynamics of US wage inequality in the 1980s and 1990s. I find that the increase in foreign competition observed in the data accounts for up to $1/6^{th}$ of the surge in the US skill premium and up to about one half of the increase in residual inequality between 1979 and 1995.

As discussed in the introduction, there are several channels contributing to the evolution of US wage inequality, each accounting for a portion of the observed increase. For instance, Burstein and Vogel (2010) study the effects of trade on wages in a quantitative model of trade and multinational production firms showing that the increase in trade and multinational production observed between 1966 and 2006 account each for about $1/9^{th}$ of the increase in the US skill premium in that period. Dinopoulos and Segerstrom (1999) perform a similar quantitative analysis with a model of trade and endogenous technical change showing that trade liberalization accounts for about $1/5^{th}$ of the increase in the US skill premium between 1970 and 1990. These numbers, together with the results of this paper, suggest that there are several plausible and quantitatively relevant channels linking globalization and wage inequality, each explaining only a fraction of the overall increase shown in the data.

Further research could extend the model by removing the assumptions of costless trade and offshoring, thus allowing for a joint analysis of trade liberalization, lower costs of offshoring, and increasing technological competition. This would provide a unifying framework to asses the role of these key features of globalization in shaping the distribution of wages. Removing the assumption of costless trade by introducing variable trade costs is straightforward, while introducing costly offshoring would be an interesting challenge. Endogenous offshoring decisions would provide a more realistic benchmark economy by making the share of offshorable activities an equilibrium result (as e.g. in Grossman and Rossi-Hansberg, 2008, Gustaffson and Segerstrom, 2010, and Burstein and Vogel, 2010). This economy would be a combination of the two extreme economies studied in this paper, featuring both the wage-stealing and the efficiency effect of fiercer international competition.

A Proofs

Proof for proposition 2. Let $C = \left(c^D + c^F\right)/\lambda$ be global consumption, from (26) we know that $2\Gamma(\theta_0) = C$, thus $\theta_0 = \Gamma^{-1}(C/2)$. Using this expression for θ_0 into (6) we obtain $w_H = \sigma/\left[\Gamma^{-1}(C/2) - \gamma\right]$. Substituting this into (26) and (28) we obtain a system in three unknowns, C, I_g^D, I_n.

$$\frac{C(\lambda-1)}{\rho+2I_n-n}\frac{A}{2\kappa}\left(\frac{I_n}{A}\right)^{\frac{-\alpha}{1-\alpha}} = \frac{\sigma}{\Gamma^{-1}(C/2)-\gamma} \tag{I}$$

$$\frac{C(\lambda-1)}{\rho+I_g^D-n}\frac{A}{2\kappa}\left(\frac{I_g^D}{A}\right)^{\frac{-\alpha}{1-\alpha}} = \frac{\sigma}{\Gamma^{-1}(C/2)-\gamma}, \tag{II}$$

$$2\,\widetilde{\theta}(C)\left(1-\frac{C}{2}\right)\phi = 2\kappa\left\{2\overline{\omega}\left(\frac{I_n}{A}\right)^{1/(1-\alpha)} + (1-\overline{\omega})\left(\frac{I_g^D}{A}\right)^{1/(1-\alpha)}\right\} \tag{III}$$

Totally differentiating equations (I)-(III) with respect to (w.r.t.) C, I_g^D, I_n and $\overline{\omega}$ we obtain

$$\begin{bmatrix} \Phi_1 & \Phi_2 & \Phi_3 \\ \Phi_4 & \Phi_5 & \Phi_6 \\ \Phi_7 & \Phi_8 & \Phi_9 \end{bmatrix} \begin{bmatrix} \frac{dC}{d\overline{\omega}} \\ \frac{dI_g^D}{d\overline{\omega}} \\ \frac{dI_n}{d\overline{\omega}} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \Phi_{10} \end{bmatrix}.$$

where Φ_1, Φ_2, Φ_3 are the derivative of (I) w.r.t. C, I_g^D, and I_n respectively, Φ_4, Φ_5, Φ_6 are the derivative of (II) w.r.t. C, I_g^D, and I_n respectively, Φ_7, Φ_8, Φ_9, Φ_{10} are the derivative of (III) w.r.t. C, I_g^D, I_n, and $\overline{\omega}$ respectively. It is easy to show that the following results hold: $\Phi_1 > 0$, $\Phi_2 = 0$, $\Phi_3 < 0$, $\Phi_4 > 0$, $\Phi_5 < 0$, $\Phi_6 = 0$, $\Phi_8 < 0$, $\Phi_9 < 0$, and $\Phi_{10} > 0$. As I show below the sign of, Φ_7 is not relevant for the purpose of this proof. While $\Phi_{10} > 0$ if $2^{1-\alpha} I_n > I_g^D$, which can be proved as follows: combining (I) and (II) we obtain

$$\left(I_g^D\right)^{\frac{\alpha}{1-\alpha}} \left(\rho + I_g^D - n\right) = \left(I_n\right)^{\frac{\alpha}{1-\alpha}} \left(\rho + 2I_n^D - n\right),$$

which if $2^{1-\alpha} I_n = I_g^D$ yields $1 = 2^{1-\alpha}$ which holds only for a linear R&D technology, that is $\alpha = 0$. For any $0 < \alpha < 1$, (I) and (II) are satisfied only if $2^{1-\alpha} I_n > I_g^D$, which allows us to proof that Φ_{10} is positive. Once we signed all the Φs it is easy to show that $\det(\Phi) > 0$, and using Cramer's rule we obtain

$$\frac{dC}{d\overline{\omega}} = -\frac{\Phi_3 \Phi_5 \Phi_{10}}{\det(\Phi)} < 0, \quad \frac{dI_g^D}{d\overline{\omega}} = \frac{\Phi_3 \Phi_4 \Phi_{10}}{\det(\Phi)} < 0, \quad \frac{dI_g^D}{d\overline{\omega}} = \frac{\Phi_1 \Phi_5 \Phi_{10}}{\det(\Phi)} < 0$$

Since $2\Gamma(\theta_0) = C$ and $w_H = \sigma / (\theta_0 - \gamma)$, we can conclude that increases in $\overline{\omega}$ raises the share of skilled workers in the economy, increases the skill premium and residual inequality.

Proof of proposition 3. The envelope theorem implies that the unit factor requirement of skilled and unskilled workers in the two activities are $A_L = \partial A / \partial w_L$ and $A_H = \partial A / \partial w_H$ in production, and $B_L = \partial B / \partial w_L$, $B_H = \partial B / \partial w_H$ in innovation. Innovation is the skill-intensive activity if $B_H / B_L > A_H / A_L$. Totally differentiating $A^D(w_L^D, w_H^D) \equiv 1$ and (34) we obtain:

$$\frac{dw_L^D}{dP_I^D} = \frac{-A_H^D}{B_H^D A_L^D - B_L^D A_H^D} < 0$$

since $B_H / B_L > A_H / A_L$, and similarly

$$\frac{dw_L^D}{dP_I^D} = \frac{A_L}{B_H^D A_L^D - B_L^D A_H^D} > 0.$$

References

[1] Acemoglu D. (1999). "Changes in Unemployment and Wage Inequality: An Alternative Theory and Some Evidence," *American Economic Review*, 89, pp. 1259-1278.

[2] Acemoglu, D. (2002) "Technical Change, Inequality, and The Labor Market",*Journal of Economic Literature*, 40, pp. 7-72.

[3] Acemoglu, D. (2003). "Patterns of Skill Premia", *Review of Economic Studies*, volume 70, pp. 199-230.

[4] Acemoglu, D., and D. Autor (2010), "Skills, Tasks and Technologies:Implications for Employment and Earnings", forthcoming *Handbook of Labor Economics.*

[5] Acemoglu, D., G. Gancia, and F. Zilibotti (2011), "Offshoring, Innovation and Wages," mimeo.

[6] Aghion P., and P. Howitt (1992). "A Model of Growth through Creative Destruction", *Econometrica* 60(2): 323-351.

[7] An, M. (1998). "Logconcavity versus Logconvexity: A Complete Characterization", Journal of Economic Theory, 80, p. 350 369.

[8] Antunes, A., T. Cavalcanti, and A Villamil, (2008). "The Effect of Financial Repression & Enforcement on Entrepreneurship and Economic Development," *Journal of Monetary Economics*, 55 (2): 278-297.

[9] Autor, D., L. Katz, and M. Kearney (2008). "Trends in U.S. Wage Inequality: Revising the Revisionists", *The Review of Economics and Statistics*, 90(2), May, 300-323

[10] Bagnoli, M., and T. Bergstrom (2005). "Log-concave probability and its applications", *Economic Theory*, 26, p. 445–469

[11] Blundell, R., R. Griffith, and F. Windmeijer, (2002) "Individual effects and dynamics in count data models", *Journal of Econometrics* 180, 113-131.

[12] Burstein, A., and J. Vogel (2010), "Globalization, Technology, and the Skill Premium: A Quantitative Analysis", mimeo.

[13] Card, D., and J. Di Nardo, (2002) "Skill-Biased Technological Change and Rising Wage Inequality: Some Problems and Puzzles", *Journal of Labor Economics*, Vol. 20, No. 4 (Oct., 2002), pp. 733-783

[14] Caselli, F. (1999). "Technological Revolutions," American Economic Review, 89, 1, 78-102.

[15] Cozzi, G. (2007). "The Arrow Effect under Competitive R&D," *The B.E. Journal of Macroeconomics*, Berkeley Electronic Press, vol. 7(1)

[16] Chatterjee, S., D. Corbae, M. Nakajima, and V. Rios-Rull (2007). "A Quantitative Theory of Unsecured Consumer Credit with Risk of Default", *Econometrica*, Vol. 75, p. 1525-158.

[17] Dinopoulos E. and P. Segerstrom. (1999). "A Schumpeterian Model of Protection and Relative Wages," *American Economic Review* 89, 450-472.

[18] Dinopoulos, E., and P., Segerstrom, "North-South Trade and Economic Growth", mimeo Stockholm School of Economics, 2007.

[19] Domeij, D. and M. Floden. (2010) "Inequality Trends in Sweden 1978-2004," *Review of Economic Dynamics*, 2010, 13, 179-208.

[20] Eaton, J., and S. Kortum (1999), "International Technology Diffusion: Theory and Measurement", *International Economic Review* 40(3) (1999), 537-570.

[21] Eaton, J., and S. Kortum (2006), "Innovation, Diffusion, and Trade," *NBER Working Papers 12385*, National Bureau of Economic Research, 2006.

[22] Eckstein, Z., and E. Nagypal (2004), "The Evolution of US Earnings Inequality: 1961 - 2002," *Minneapolis FED Quarterly Review*, 28 (2), pp. 10-29.

[23] Epifani, P., and G. Gancia (2008) "The Skill Bias of World Trade", *The Economic Journal*, 118, 927-960.

[24] Fagerberg, J., D. Mowery, and R. Nelson (2004). *Oxford Handbook of Innovation*, Oxford University Press, New York.

[25] Feenstra, R. and G. Hanson (1999). "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the US, 1979-1990," *Quarterly Journal of Economics* 114, 907-40.

[26] Findlay, R., and H. Kierzkowski (1993). “International Trade and Human Capital: A Simple General Equilibrium Model”, J*ournal of Political Economy*, Vol. 91 (6), pp. 957-978.

[27] Galor, O., and O. Moav, "Ability Biased Technological Transition, Wage Inequality, and Economic Growth," *Quarterly Journal of Economics* , 115, May, 469-498.

[28] Glass, A.J., (1997). “Product Cycles and Market Penetration”, *International Economic Review* 38, 865-891.

[29] Grossman G. M. and E. Helpman. (1991). Innovation and Growth in the Global Economy. Cambridge: MIT Press.

[30] Grossman, G. M., and E. Rossi-Hansberg (2008). “Trading Tasks: A Simple Theory of Offshoring,” *American Economic Review* 98, 1978-1997.

[31] Gustaffson, P. and P. Segerstrom (2010). "North-South Trade with Multinational Firms and Increasing Product Variety" forthcoming, *International Economic Review.*

[32] Hall, B., Griliches, Z., and J, Hausman (1986), “Patents and R&D: is there a Lag?,” *International Economic Review*, 27 (1986), 265-83.

[33] Harrison, A., and A. Rodriguez-Claire (2010). "Trade, Foreign Investment, and Industrial Policy," *Handbook of Development Economics,* Volume 5, edited by Dani Rodrik and Mark Rosenzweig.

[34] Hart, David (1998). "U.S. Technology Policy: New Tools for New Times." NIRA Review, Summer, 3-6.

[35] Hausman, R., and D. Rodrik (2003). “Economic Development as Self-Discovery,” *Journal of Development Economics*, vol. 72, December.

[36] Heatcote, J., F. Perri, and G. Violante (2010). “Cross-Sectional Facts for Macroeconomists”, *Review of Economic Dynamics*, Vol. 13(1), 1-14.

[37] Helpman, E., (1993). "Innovation, Imitation, and Intellectual Property Rights," *Econometrica*, vol. 61(6), pages 1247-80, November.

[38] Hornstein, A., P. Krusell, and G. Violante (2005). "The Effects of Technical Change on Labor Market Inequalities," *Handbook of Economic Growth*, (P. Aghion and S. Durlauf, Editors), North-Holland.

[39] Howitt, P. (1999). "Steady Endogenous Growth with Population and R&D Inputs Growing." *Journal of Political Economy* 107, August: 715-30.

[40] Hsieh, C.T., and R. Ossa (2011), "A Global View of Productivity Growth in China," mimeo University of Chicago.

[41] Impullitti, G. (2010). "International Competition and US R&D Subsidies: a Quantitative Welfare Analysis," *International Economic Review*, Vol. 51, issue 4.

[42] Jappelli, T., and L. Pistaferri (2010). "Does consumption inequality track income inequality in Italy?", *Review of Economic Dynamics*, vol. 13, 133-153.

[43] Jones C. (1995). "Time Series Tests of Endogenous Growth Models", *Quarterly Journal of Economics* 110, 495-525.

[44] Jones C. and J. Williams, "Too Much of a Good Thing? The Economics of Investment in R&D", *Journal of Economic Growth*, 5(1) (2000), 65-85.

[45] Juhn, C., K. Murphy, and K. Pierce (1993), "Wage Inequality and the Rise in Returns to Skill", *Journal of Political Economy*, 101 (3), pp. 410-42.

[46] Kambayashi, R., D. Kawaguchi, and I. Yokoyama,(2008) "Wage Distribution in Japan: 1989-2003," *Canadian Journal of Economics*, Vol. 41 (4), pp. 1329-1350.

[47] Kawaguchi, D., and Y. Mori (2008), "Stable Wage Distribution in Japan, 1982-2002: A Counter Example for SBTC?" RIETI 08-E -020.

[48] Keller, W., (2004), "International Technology Diffusion," *Journal of Economic Literature*, Volume 42, No. 3 (1)1, 752-782.

[49] Kortum, S.,(1993) "Equilibrium R&D Ratio and the Patent-R&D Ratio: US Evidence," *American Economic Review, P & P* 83, 450-457.

[50] Krueger, D., N. Fuchs-Schuendeln and M. Sommer. (2010) "Inequality Trends for Germany: A Tale of Two Countries," *Review of Economic Dynamics*, Vol 13 (1), 103-132

[51] Lemieux, T. "Increasing Residual Wage Inequality: Composition Effects, Noisy Data, or Rising Demand for Skill?", *American Economic Review*, Vol. 96, No. 3, pp.461-498.

[52] Mehra,R., and E.C.Prescott.(2003)."The Equity Premium in Retrospect," in *Handbook of the Economics of Finance*. Volume 1B, pp. 889-938, Handbooks in Economics, v. 21, Elsevier, North Holland.

[53] Mowery, David, and Nathan Rosenberg (1989). Technology and the Pursuit of Economic Growth, Cambridge University Press.

[54] Naghavi, A. and G. Ottaviano (2009). "Offshoring and product innovation," *Economic Theory,* 38, 517-532.

[55] National Vital Statistics Reports (2010), Vol. 58, No. 21, June 28.

[56] Nelson, R., (1993). *National Innovation Systems: A Comparative Analysis*, Oxford: Oxford University Press.

[57] Pijoan-Mas J., and V. Sanchez-Marcos (2010). "Spain is different: falling trends in inequality", *Review of Economic Dynamics*, 13 (1), p.157-178.

[58] Rodriguez-Claire, A. (2007) " "Trade, Diffusion, and the Gains from Openness," November 2007", mimeo.

[59] Roeger, W. (1995). "Can Imperfect Competition Explain the Difference between Primal and Dual Productivity Measures? Estimates for US Manufacturing", *Journal of Political Economy* 103, 2, 316-330.

[60] Tyson, L., (1992). *Who's Bashing Whom? Trade Conflict in High-Tech Industries* (Washington, DC: Institute for

[61] International Economics, 1992).

[62] Violante, G. (2002). "Technological Acceleration, Skill Transferability and the Rise of Residual Inequality," *Quarterly Journal of Economics*, vol. 117(1), 297-338.

[63] Yeaple, S. (2005). "A Simple Model of Firm Heterogeneity, International Trade, and Wages," Journal of International Economics, 2005, 65(1): 1-20.