Offshoring - Effects on Technology and Implications for the Labor Market

Manisha Goel*
The Ohio State University

May 2012

Abstract

This paper develops and evaluates a novel mechanism through which imports of unskilled intermediates (offshoring) increase wages of *both* skilled and unskilled workers by inducing skill-biased technology adoption and innovation in developed countries. A two-country trade model, calibrated to U.S. manufacturing industry and trade data, shows that an increase in offshoring of unskilled labor intensive intermediates leads to greater use of skill-complementary capital, more product innovation, and higher levels of output, thereby generating absolute wage gains for both skilled and unskilled workers, although increasing the skill premium. While the employment of skilled workers increases, the total employment of unskilled workers falls. The model additionally shows that the increase in offshoring in U.S. industries between 1974 and 2005 could potentially generate a 17% gain in welfare. A model with only the Heckscher-Ohlin channel, with no technology effects, yields a decline in unskilled wages, larger increase in wage inequality, and a significantly smaller welfare gain.

JEL Classifications: F16, J31, O33
Keywords: Technological Change, International Trade, Wages, Skill Premium

*Contact: goel.33@osu.edu. The paper was previously circulated under the title "Offshoring, Technology, and the Skill Premium." I am grateful to Bruce Weinberg without whose constant support and guidance, this endeavor would not have been successful. I especially thank Joseph Kaboski who continued to advise me after his move to University of Notre Dame. Thanks are also due to David Blau, Paulina Restrepo-Echavarria, and Nan Li who gave me valuable suggestions. My work also benefitted from discussions with William Dupor, Saif Mehkari, Laura Crispin, and Karen Bernhardt-Walther. Comments of various conference and seminar participants were also helpful. The support of The Ohio State University Dissertation Year Fellowship is gratefully acknowledged. All remaining errors are my own.

"Long before the recession, jobs and manufacturing began leaving our shores. Technology made businesses more efficient, but also made some jobs obsolete. Folks at the top saw their incomes rise like never before, but most hard-working Americans struggled with costs that were growing, paychecks that weren't, and personal debt that kept piling up...No, we will not go back to an economy weakened by outsourcing..."

— President Barack Obama, State of Union Address, January 2012

1 Introduction

The above quote from President Obama's speech closely reflects the political and popular sentiments surrounding offshoring[1] from the United States to developing countries that grew tenfold from 1.8% in 1974 to 19% in 2005.[2] Indeed, total employment in the U.S. manufacturing sector has shrunk. Inequality, or the skill premium, has also risen remarkably over the last three decades, with the wage gap between college and high school graduates growing nearly 50% (21 log points), between 1979 and 2005.[3] However, is the growth in offshoring the principal underlying cause for these trends? Does offshoring necessarily cause a decline in real wages and employment of domestic unskilled workers or can it generate wage, employment, and welfare gains for them? In this paper, I address these questions by developing a novel technology channel of offshoring in the framework of a general equilibrium trade model. The model shows that offshoring to developing countries induces capital deepening and innovation leading to substantial wage and employment gains for both skilled and unskilled workers in the advanced country.

Previous literature analyzing the wage and employment implications of offshoring only considers the Heckscher-Ohlin (H-O) mechanism and/or assumes that imported and domestic intermediates are perfect substitutes. In this framework, offshoring is found to cause wages and employment of unskilled workers to decline.[4] Grossman and Rossi-Hansberg (2008), however, show that offshoring effectively increases the productivity of unskilled workers, generating wage and employment gains for them. The technology channel developed in this paper provides a new mechanism by which offshoring can create substantial wage gains for unskilled workers,

[1]The distinction between the terms "outsourcing" and "offshoring" is blurred in the economics literature. In this paper, "offshoring" refers to the relocation of tasks (measured as imports of intermediate goods) to a foreign country regardless of whether the provider is external or affiliated with the firm. While this is termed as "offshoring" by some authors, eg. Rodriguez-Clare (2010), some others, eg. Feenstra and Hanson (1996, 1999) have previously referred to this as "outsourcing."

[2]See Figure 1(a). Offshoring is measured as the value of intermediates imported from developing countries, as a proportion of total value of intermediates used by U.S. manufacturing industries. This measure was first proposed by Feenstra and Hanson (1996).

[3]Autor, Katz and Kearney (2008).

[4]Empirical studies find mixed results about the employment effects of offshoring. Alan Blinder (2007) predicts that 22-29% of U.S. manufacturing and service jobs are offshorable over the next decade or two. Other empirical studies, however, find mixed evidence of the effect of offshoring on unskilled employment. See Mankiw and Swagel (2006) for a review.

even beyond the productivity effect. In fact, the labor market impacts of offshoring are overwhelmingly mediated through the technology channel (i.e., investments in skill-complementary capital and innovation); the productivity effect suggested by Grossman and Rossi-Hansberg (2008), and H-O effects through substitution of unskilled labor are small. A model with this channel predicts that offshoring leads to higher wages for both skilled and unskilled workers, and a smaller increase in the skill premium, compared to a model with only the H-O channel.

This paper also bridges the trade and labor literatures studying the factors underlying the evolving wage and employment trends in the U.S. labor market. International economists have linked the growth in wage inequality to the rise in offshoring, measured as imports of intermediate goods, through the H-O mechanism in which imports from unskilled labor-abundant countries substitute for unskilled workers in developed countries.[5] In contrast, labor economists find skill biased technological change (SBTC) to be the chief factor underlying the growth in the skill premium,[6] documenting a remarkable correlation between skill upgrading and the adoption of computer-based technologies within industries. Both literatures have considered offshoring and SBTC as distinct phenomena driving the growth in the skill premium. However, by developing the novel technology channel, I show that SBTC is endogenous to offshoring, and that offshoring, through this channel, creates wage and employment gains for *all* workers, although amplifying the skill premium.

The technology channel is motivated by the observation that the growth in offshoring to developing countries is accompanied by capital deepening and increasing innovation, with all three accelerating after the mid-1990s. Figure 1(a) shows that imported intermediates, as a share of total imports, fluctuated with a declining trend from 1974 until the mid-1990s, but then turned sharply upwards to reach nearly 80% by 2005.[7] However, offshoring to developing countries consistently grew between 1974 and 2005. Simultaneously, the average equipment-labor payments ratio rose from about 115 points to 420 points and the average product R&D-sales ratio grew from 1.5% to 2.4% (corresponding to a growth in average real product R&D expenditure from 95 million dollars to 2,800 million dollars, as shown in Figure 1(b)). The timing suggests that these trends may be causally related. My work below demonstrates that the growth in offshoring to developing countries induces investments in R&D and equipment, benefiting all U.S. workers, although magnifying the skill premium and skill upgrading.

The substitution of domestic unskilled labor by imported unskilled intermediates, as predicted by the Heckscher-Ohlin theory,[8] can trigger two effects, that constitute the technology

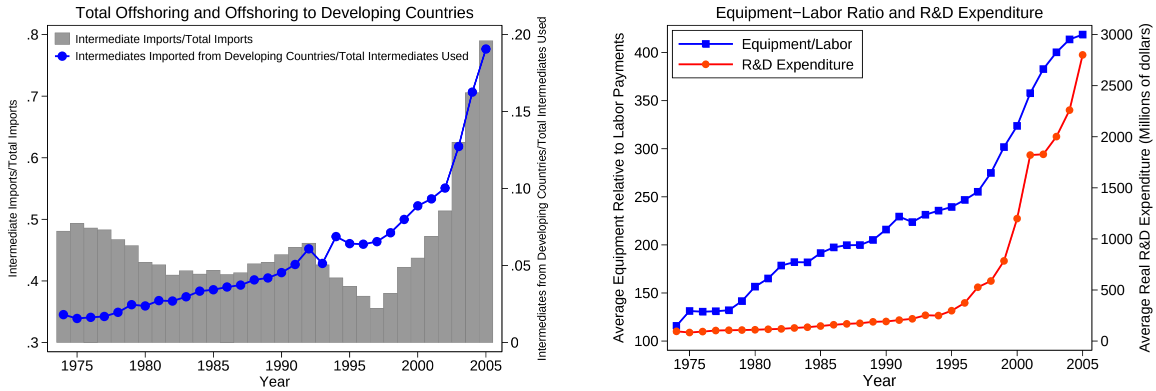
[5]See, for example, the empirical work of Feenstra and Hanson (1996, 1999), and the theoretical work of Grossman and Rossi-Hansberg (2008).

[6]See Katz and Autor (1999), and Katz (2000) for a detailed review.

[7]The upturn in imports of intermediates may have been driven by the Uruguay round of trade negotiations between the advanced and developing countries as well as by the East Asian crisis. The Uruguay round was followed by several subsequent negotiations that liberalized trade regimes even further. The East Asian crisis of 1997-98 also led many countries to depreciate their currencies dramatically.

[8]Grossman and Rossi-Hansberg (2008) have provided two ways by which offshoring of unskilled tasks can increase the skill premium - the relative price effect and the labor supply effect. First, the cost reduction resulting from offshoring can lead to a decline in the relative price of unskilled labor-intensive goods. Second,

Figure 1: Growth in Offshoring with Rise in Equipment & Innovation[a]



(a) (b)

[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Productivity database, Input-Output tables, Compustat. Imported intermediates in each industry are calculated by first multiplying the import penetration ratio for each input to the total dollar value of that input used in the industry, and then aggregating over all inputs used. Offshoring to developing countries is calculated as total intermediates imported from developing countries relative to total value of intermediates used in U.S. industries. Payments to equipment capital stock are measured at prices that are not adjusted for changes in quality. The payments to equipment capital are divided by the total payments to workers for each industry. R&D for each industry is measured as the total expenditures on product R&D of all publicly traded U.S. firms belonging to that industry. Offshoring, equipment-labor ratio and R&D expenditure are averaged across all 459 4-digit SIC (1987) industries.

channel. First, the cost reduction from offshoring induces firms to expand their output, leading to an increase in the skill-intensive tasks required in the production process. This increases the demand for skilled labor and skill-complementary equipment capital (technology adoption).[9] The complementarity between skilled labor and capital also magnifies the relative marginal product of skilled labor, and hence the skill premium. Second, lower costs of production make new products profitable, inducing product innovation. Innovation creates greater demand for skilled workers as well as capital equipment that is complementary to these workers, once again putting an upward pressure on the skill premium. However, offshoring-induced technology adoption and innovation increase the overall productivity of firms, leading to higher wages and

an increase in offshoring increases the effective supply of unskilled labor in the North. Both effects reduce the relative wages of unskilled labor. Further, Feenstra (2008) show that the cost reduction leads to an expansion of output in the North, causing an absolute increase in the skill-intensive tasks and skilled wages.

[9]I use the term "technology adoption" to imply equipment capital deepening. Equipment capital (as against structures capital) embodies technology that favors skilled workers over unskilled workers. In the SBTC literature, an increase in the use of computers in industries, and growth in skill-complementary capital equipment, more generally, have been taken to indicate technological change. I use the relatively conservative term, "adoption," since greater employment of equipment capital may not necessarily be associated with employment of equipment that embodies superior (or different) skill-biased technology. Another, more technical, reason for this terminology is that in the data, capital is measured at prices that are unadjusted for quality. Gordon (1990) showed that quality-adjusted prices declined at a faster rate than unadjusted prices. This decline in quality-constant prices may be the reason why industries may increase their employment of capital (Krusell et al.(2000)). Without such price data, I do not have a way to distinctly identify greater employment of embodied technology from employment of superior technology.

employment for *both* skilled and unskilled workers.

I formalize these mechanisms in a two-country trade model. Monopolistically competitive firms in the North produce differentiated final goods using skilled and unskilled intermediates, and offshore the production of unskilled intermediates to the South. The model is similar in spirit to a standard H-O trade model like Krugman and Venables, but with three additional key features. First, the offshored intermediates are highly, but not perfectly, substitutable for domestically produced unskilled intermediates.[10] Second, the production function of the monopolistically competitive firms allows for capital-skill complementarity. Third, production of new goods, or entry of new firms, requires innovation.

Quantitative results from the model show that the tenfold growth in offshoring to developing countries, between 1974 and 2005, has increased the skill premium in the U.S. by about 15%. Thus, the skilled wage has increased relative to the unskilled wage. But the unskilled wage has also increased by a remarkable 22%. The unskilled employment, however, declined by 6%. Counterfactual experiments show that the technology channel dominates the H-O effects of offshoring, with the latter explaining only a third of these overall changes. The model also allows me to decompose the two parts of the technology channel. These decompositions show that innovation and capital-skill complementarity contribute nearly equally to the overall labor outcomes.

Finally, I show the welfare implications of the technology channel. A calibrated model with only the H-O channel yields lower output and wages for skilled and unskilled labor than in the model with the technology channel. The unskilled wage, in particular, is especially lower than in the model with the technology channel, and *falls* when imported and domestic intermediates are additionally made perfectly substitutable. Moreover, inequality between the two groups is higher in the model with only the H-O channel. This indicates that through the technology channel, offshoring creates important quantitative gains for all workers in the North, and especially for unskilled workers.

The rest of the paper is organized as follows. Section 2 discusses the related literature. Section 3 provides empirical evidence in support of the technology channel. Section 4 develops a general equilibrium model that captures the H-O and technology channels that are evident in the data. Section 5 discusses the quantitative comparative static predictions of the model, and decomposes the distinct contributions of the channels to the skill premium and skill-upgrading. This is followed by a comparison of the welfare implications of the models with and without the technology channel. The last section concludes.

[10] This is a departure from previous literature that presumes that imported and domestic intermediates are perfect substitutes. The reason for this difference is the empirical finding in Goel (2012) that employment of unskilled workers increases with offshoring even when the industrial output is held fixed - a result inconsistent with perfect substitution between imported and domestic intermediates.

2 Contribution to Related Literature

A growing literature establishes, both theoretically and empirically, that offshoring to developing countries increases the skill premia in advanced countries (see, for example, Feenstra and Hanson (1996, 1999), Grossman and Rossi-Hansberg (2008)). The extant studies interpret the total impact of offshoring on the skill premium as reflective of only the H-O effects of offshoring. But, as I show, offshoring may also increase the skill premium by inducing innovation and technology adoption. To my knowledge, this is the first study to consider the impact of offshoring on technology adoption.

Studying the relationship between offshoring and technology adoption also contributes to the large literature on skill biased technological change. Thus far, SBTC and offshoring have been considered to be independent phenomena underlying the rising skill premium in the U.S. and other advanced countries. While some economists argue that the magnitude of trade in final goods is too small to cause the observed increase in the skill premium (see, for example, Katz and Murphy (1992), and Berman, Bound and Griliches (1994)),[11] others, such as Feenstra and Hanson (1996, 1999) showed that imports of intermediate inputs raise the skill premium within industries, and find that 15-40% of the growth in the skill premium is attributable to the growing importance of trade. My paper contributes to this debate by showing that the adoption of skill-biased technology in firms in advanced countries is reinforced by trade in intermediates. This suggests that policies that influence the offshoring decisions of firms will also have implications for their innovation activities and the level of embodied technology that they use domestically.[12]

The evidence on the employment impact of offshoring is mixed. Theoretically, the presumption is that imported unskilled intermediates perfectly substitute for domestic unskilled intermediates, both in H-O and Ricardian frameworks. But, as Grossman and Rossi-Hansberg (2008) show, while the substitution of unskilled workers by imported intermediates implies a decline in unskilled employment, the cost savings and resulting expansion in domestic output can also increase employment of both skilled and unskilled labor. This "productivity effect,"

[11]Several observations have led scholars to conclude that trade is not an important factor underlying the rising skill premia in the developed countries. Katz and Murphy (1992), and Berman, Bound and Griliches (1994) argued that trade, by creating competition in the product markets, only leads to demand shifts between industries. Since most of the skill-upgrading has occurred within industries, they consider the contribution of trade small.Lawrence and Slaughter (1993) showed that the relative price of skill-intensive goods did not increase - an observation they argued to be inconsistent with the possibility of trade increasing wage inequality. Berman, Bound and Machin (1998) showed that the unskilled labor-abundant countries also witnessed an upsurge in inequality. If the predictions of the Heckscher-Ohlin-Samuelson (HOS) trade model were to hold empirically, inequality should have fallen in these countries.

[12]A related strand of literature analyzes consequences of trade for SBTC in *developing* countries. Studies show that as developing countries increasingly liberalize their trade regimes, they import capital equipment that embodies skill-biased technology developed in the North. This phenomenon, known as skill-biased trade, is theoretically modeled (eg. Burstein, Cravino and Vogel (2011), Parro (2011)) and documented in several empirical studies (eg. Robbins (1996), Chamarbagwala (2006), among others). Other channels by which trade with advanced countries can lead to skill upgrading and rising skill-premia in developing countries have also been analyzed. See, for example, Verhoogen (2008), and Trefler and Zhu (2005).

has also been emphasized by Ottaviano, Peri and Wright (2011), among others. Empirically, the results are mixed with some studies finding a small negative effect of offshoring on unskilled employment (see, for example, Mann (2005), and Groshen, Hobijn and McConnell (2005)) and others finding a positive effect (see, for example, Goel (2012) and Landefeld and Mataloni (2004)). Under the technology channel presented in this paper, I show that while offshoring induced innovation leads to increased employment of unskilled labor, skill-complementary capital deepening works to reduce it, with the net impact of the technology channel on unskilled employment being negative.

Very few studies have analyzed how offshoring influences innovation. Glass and Saggi (2001) argue that higher profits resulting from offshoring makes innovation affordable for firms, and Rodriguez-Clare (2010) shows that innovation increases as the North reallocates its resources with increased offshoring. Naghavi and Ottaviano (2008), however, argue that offshoring to the South reduces innovation because of less information generated from production tasks. The mechanism that I develop suggests a novel channel by which offshoring can create incentives for firms to invest in innovative activity.

Finally, the argument that the adoption of skill-biased technology may be endogenous to offshoring adds to the broader literature on endogenous skill-biased technical change. Acemoglu (1998, 2002a, 2002b) shows that the skill-bias of new technologies responds to autonomous changes in the supply of skilled labor. The technology channel that I propose instead generates endogenous SBTC from the demand side. The increase in the production of skilled intermediates and innovation, resulting from offshoring, generates higher demand for skilled labor, leading to the adoption of skill-complementary (capital-embodied) technology. Another strand of this literature explores how trade in *final* goods with developing countries induces technological change in advanced countries (see, for example, the theoretical analysis Thoenig and Verdier (2003) and the empirical work of Bloom, Draca and Van Reenen (2011)). While these studies consider final goods-trade induced technical change, I suggest a mechanism by which intermediate goods trade can induce technical change.

3 Empirical Evidence

In the introduction, I already showed the similarity between the trends in offshoring, equipment-capital deepening, and R&D expenditures in U.S. manufacturing industries. Now, I present four stylized facts that motivate the model and the technology channel developed in this paper.

3.1 Data

The data used to document these facts are combined from several sources. I provide a brief overview of these data. More detail is available in the data appendix. U.S. manufacturing imports and exports data (c.i.f. values) are available from the Center for International Data at the University of California, Davis at a highly disaggregated level. The countries of origin of these imports have been classified by the World Bank into five groups on the basis of their per capita income levels - High Income OECD, High Income non-OECD, Upper Middle Income, Lower Middle Income and Low Income. I combine the high-income OECD and non-OECD countries into the group of high-income countries. Similarly, I combine the other three groups into the group that I refer to as low-wage (income) or developing countries. Following the method developed by Feenstra, Romalis and Schott (2002), I aggregate these data to bring them to level of domestic Standard Industrial Classification (1987).

I then use the direct requirement coefficients[13] available from the benchmark input-output tables (provided by the Bureau of Economic Analysis) to map U.S. imports as intermediate inputs used in U.S. manufacturing industries. The benchmark tables are provided every five years between 1972 and 2002. For the interim years, I linearly interpolate (extrapolate for 2003-2005) the direct requirement coefficients. Multiplying these coefficients with the output of each industry gives me the total dollar value of each good used as an input in the production of an industry every year. Combining these two data sources, I follow Feenstra and Hanson (1999) to define offshoring as $\frac{1}{X_{jt}}\sum_{k=1}^{n} r_{jkt} * Q_{jt} * (\frac{\text{Imp}^G_{kt}}{Q_{kt} + \text{Imp}_{kt} - \text{Exp}_{kt}})$, where r_{jkt} is the direct requirement coefficient in year t for commodity k used as an input in industry j, Q_{jt} is the output (value of shipments) of industry j, Imp_{kt} and Exp_{kt} are the total imports and exports belonging to industry k, respectively, and X_{jt} is the value of non-energy materials used in industry j.

I obtain annual data on output (shipments), employment, wages, and capital stocks in 459 four-digit manufacturing industries (classified according to the Standard Industrial Classification, 1987) from the NBER-CES Manufacturing Industry Database (Bartelsman and Gray, 1996).[14] Employees are classified as production and non-production workers. I consider non-production workers as high skilled and production workers as low skilled.[15] Nominal wage bills for both categories of workers are provided. I use the value of shipments as the measure of output of industries. The database separately provides real values of stocks of capital equipment and structures.

Data on innovation expenditures incurred in these industries are not available in the NBER database. Compustat is a database that provides financial statistics for all the publicly traded firms in the United States. Among other things, these data include information on sales and the non-federally funded R&D expenditures of these firms. I aggregate these firm level sales and R&D expenditures to create a series of 4-digit industry level annual sales and innovation expenditures for the sample period. According to the documentation for Compustat, the R&D expenditures include all costs incurred to develop new products and services but excludes the costs to improve the quality of existing products. Thus, this measure captures all expenditures

[13]Direct requirement coefficients are defined as the amount of a commodity required as an input to produce one unit of output in a given industry.

[14]The NBER database includes variables from yearly rounds of the Annual Survey of Manufactures.

[15]Berman, Bound and Griliches (1994) show that the classification of workers as production/non-production closely corresponds to the educational levels of high school and college respectively.

made to develop new products that may be both horizontally and vertically differentiated (since the new products may also be better in terms of quality). An alternative measure of innovation that I use for my analysis is R&D intensity (R&D expenditure/Sales).[16]

In my final sample, I have panel of 459 four-digit SIC 1987 industries spanning 32 years from 1974 to 2005. All nominal values are deflated, wherever needed, using the U.S. CPI obtained from the Bureau of Labor Statistics. The shipments of four digit industries are deflated using the shipments deflator available in the NBER-CES manufacturing industry database.

3.2 Empirical Facts

Figure 2 shows a scatter plot of the average changes in the wage-bill ratios of non-production to production workers against the average changes in offshoring levels in two-digit U.S. manufacturing industries between 1975 and 2005. The industries are weighted by their shares in total manufacturing wage bill of the U.S. in 2005. The larger the marker for each industry, the larger its weight. The graph shows that the industries that witnessed the most expansion in offshoring, like transportation, electronics, and instruments, also had the largest increases in the wage-bill ratios. Thus, offshoring is positively associated (with a correlation of 0.7) with the relative wage-bills of skilled to unskilled workers in U.S. manufacturing industries. This fact is well established in the empirical literature on offshoring, and is often taken as evidence to conclude that offshoring has a negative impact on unskilled wages and employment.

But Figure 3 shows that offshoring and real unskilled wages are in fact positively correlated, with the correlation coefficient equal to 0.4. We again see that the industries with the maximum increases in offshoring also increased the wages they paid to production workers the most.[17] This fact is contradictory to the conventional wisdom about the impact of offshoring on unskilled wages, and the underlying mechanism. The H-O mechanism cannot explain a simultaneous increase in wage inequality and the real unskilled wage[18] Thus, we need to have an alternate mechanism that can explain these two facts simultaneously. My model with the technology channel and imperfect substitution of domestic and imported intermediates will show how offshoring can in fact generate unskilled wage gains even as inequality increases.

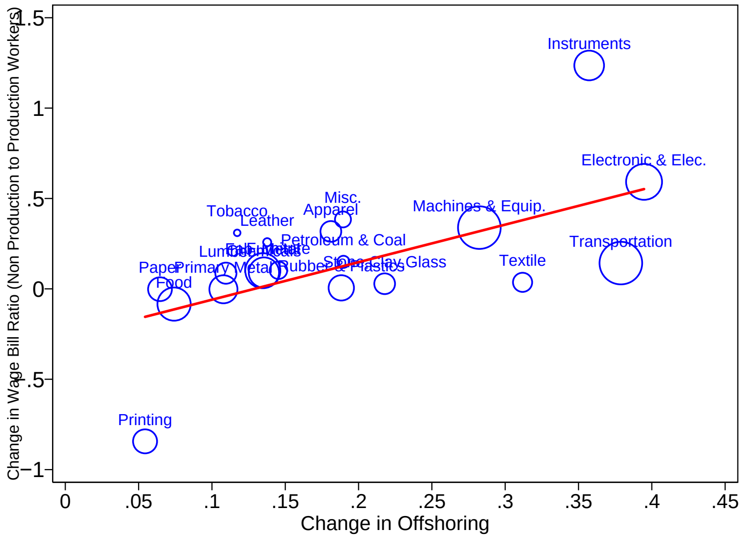
Next, I present two more data facts that support the technology channel of offshoring. In Figure 5, I show that the average changes in R&D intensity in U.S. industries are strongly positively correlated with changes in offshoring, with the correlation being 0.5. In this graph R&D intensity is defined as R&D expenditures divided by sales. Finally, Figure 6 reveals that

[16]Patents can provide another measure of innovation activity. The measure, however, may not be ideal for two reasons. First, not all firms patent the knowledge created from their innovation efforts. Second, often the patenting firm may sell the license for use by other firms. In such cases, the industry that the patenting firm belongs to may not be the industry benefiting from the innovation.

[17]The time series trends in offshoring and wages of three groups of unskilled workers - high school dropouts, high school graduates, and those with some years of college (see Figure 2 in Autor, Katz and Kearney (2008)) - are also similar in that they all increased simultaneously in the late 1990s.

[18]Real unskilled wage, under the H-O mechanism, can increase only if the final good price decline is greater than the decline in nominal unskilled wages. In my model, I show, instead, that because of the variety effect, prices in fact increase.

Figure 2: Average Changes in Offshoring and Relative Non-Production Wage Bill[a]

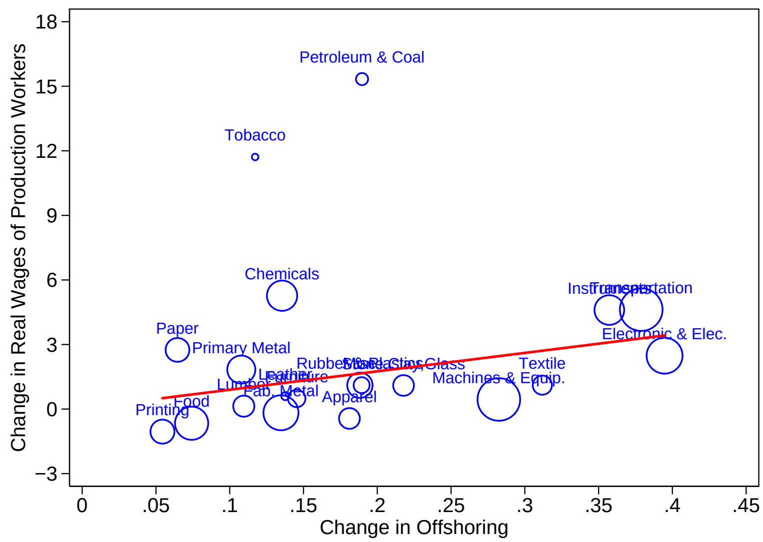


[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, World Bank Income Classification. Imported intermediates in each 4 digit industry are calculated by first multiplying the import penetration ratio for each input to the total dollar value of that input used in the industry, and then aggregating over all inputs used. Offshoring to developing countries is calculated as total intermediates imported from developing countries relative to total value of intermediates used in U.S. industries. Changes between 1975 and 2005 in offshoring and wage bill ratios in all 4 digit industries are calulated and then averaged over 2 digit industries. To plot the scatter and to calculate the correlations, all 2 digit industries are weighted by size, measured as the share of each industry in total manufacturing wage bill in the U.S. in 2005.

changes in offshoring are negatively correlated with the changes in the shares of equipment capital in total output of manufacturing industries. This correlation stands at -0.5. Similarly the correlation between changes in offshoring and skilled workers' share in total output is also negative. Note that if we considered a Cobb-Douglas production function where output is produced using capital, skilled and unskilled labor, the shares of all factors of production will stay constant. The last fact that I present here shows the need to move away from Cobb-Douglas to an alternative production function that matches these data facts and allows for capital-skill complementarity.

Furthermore, in a companion paper (Goel (2012), using exchange rates to construct instruments for the endogenous offshoring measure, I show that an increase in offshoring induces equipment capital deepening and higher R&D intensity, i.e., the technology effects of offshoring are strongly supported in the empirical results. Offshoring growth also causes an increase in the relative employment and wage-bills of non production workers. But production workers' absolute real wage-bills and employment also respond very strongly to a rise in offshoring. Moreover, decomposing these composite labor market effects of offshoring into that due to technology effects, and that due to independent H-O substitution effects, shows that the technology effects are the key driving force behind these labor market responses. Conditioning on the technology variables, offshoring only has a negligible effect on these labor outcomes.

Figure 3: Average Changes in Offshoring and Real Wages of Production Workers[a]



[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, World Bank Income Classification. Imported intermediates in each 4 digit industry are calculated by first multiplying the import penetration ratio for each input to the total dollar value of that input used in the industry, and then aggregating over all inputs used. Offshoring to developing countries is calculated as total intermediates imported from developing countries relative to total value of intermediates used in U.S. industries. Changes between 1975 and 2005 in offshoring and real production wages in all 4 digit industries are calulated and then averaged over 2 digit industries. To plot the scatter and to calculate the correlations, all 2 digit industries are weighted by size, measured as the share of each industry in total manufacturing wage bill in the U.S. in 2005.

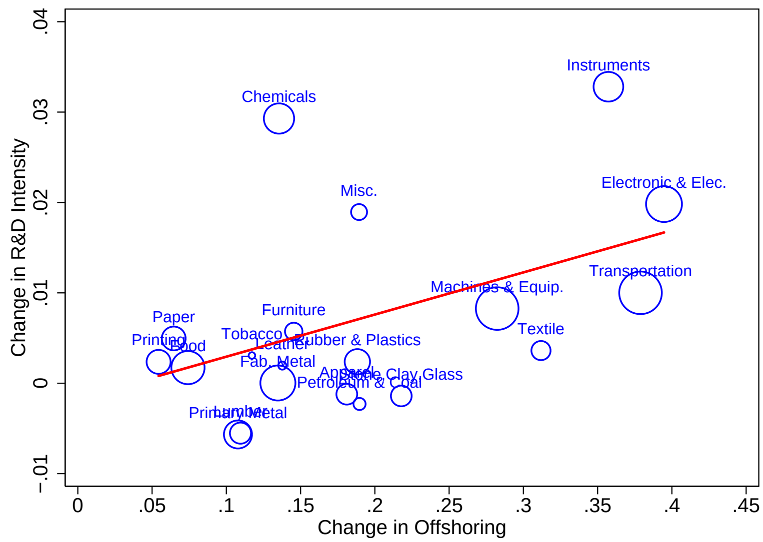
Thus, the empirical evidence indicates a strong technology effects of offshoring and that these effects dominate the H-O effects leading to gains for unskilled workers in terms of employment and wage bills, even though skilled workers benefit relatively more. I now present a model to show how the technology channel operates and its implications for labor market outcomes and the overall welfare.

4 Model

To formalize how the H-O and technology channels operate and influence labor markets in advanced countries, I present a model of trade in intermediates between a developed and a developing country. In the model, final goods in both countries are produced using intermediate inputs. The developed country imports the unskilled intermediates from the developing country as the latter has a comparative advantage in producing these goods. These imports serve as substitutes for the domestically produced unskilled intermediates in the developed country. This substitution triggers other technology effects that I will describe below.

Consider two countries: the skill-abundant "North," and the unskilled-labor abundant "South." The North has three factors of production: skilled labor, unskilled labor, and cap-

Figure 4: Average Changes in Offshoring and Relative Non-Production Wage Bill[a]



[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, Compustat, World Bank Income Classification. Imported intermediates in each 4 digit industry are calculated by first multiplying the import penetration ratio for each input to the total dollar value of that input used in the industry, and then aggregating over all inputs used. Offshoring to developing countries is calculated as total intermediates imported from developing countries relative to total value of intermediates used in U.S. industries. Changes between 1975 and 2005 in offshoring and R&D intensity (R&D/Sales) in all 4 digit industries are calulated and then averaged over 2 digit industries. To plot the scatter and to calculate the correlations, all 2 digit industries are weighted by size, measured as the share of each industry in total manufacturing wage bill in the U.S. in 2005.

ital equipment - S, U, and K, respectively, while the South has only unskilled labor[19] and capital, denoted by U^*, and K^*, respectively. The respective factor payments are denoted by W_s, W_u (W_u^* in the South), and R (R^* in the South). Time periods (years) are indexed by t $\in \{1, 2, ..., \}$.

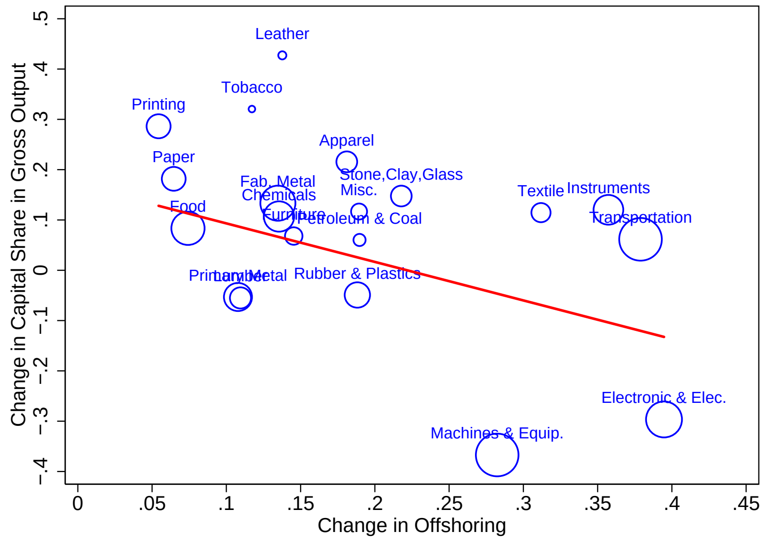
4.1 The North

Households

A representative household owns the firms and supplies capital, skilled, and unskilled labor to these firms. It uses the composite good of the economy for consumption, investment and the purchase of new firms. While making its decisions, the household takes W_s, W_u, and R as given. Letting the composite good be the numeraire and assuming perfect foresight, the household faces the following optimization problem:

[19]This paper focuses on the implications of offshoring for the wage distribution in the North. The South is modeled to have homogeneous (unskilled) labor. Thus, the model does not yield any prediction for the wage distribution in the South. In related work, I study whether and to what extent offshoring can explain the simultaneous rise in the skill-premia in both the North and the South. That paper use a similar model, but also allows the South to have skilled and unskilled labor.

Figure 5: Average Changes in Offshoring and Relative Non-Production Wage Bill[a]



[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, World Bank Income Classification. Imported intermediates in each 4 digit industry are calculated by first multiplying the import penetration ratio for each input to the total dollar value of that input used in the industry, and then aggregating over all inputs used. Offshoring to developing countries is calculated as total intermediates imported from developing countries relative to total value of intermediates used in U.S. industries. Changes between 1975 and 2005 in offshoring and capital shares (payments to equipment relative to gross shipments) in all 4 digit industries are calulated and then averaged over 2 digit industries. To plot the scatter and to calculate the correlations, all 2 digit industries are weighted by size, measured as the share of each industry in total manufacturing wage bill in the U.S. in 2005.

$$\underset{C_t,S_t,U_t,K_{t+1},N_t}{\text{Max}} \mathcal{U} = \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \theta_s \frac{S_t^{1+\chi_s}}{1+\chi_s} - \theta_u \frac{U_t^{1+\chi_u}}{1+\chi_u} \right)$$

subject to

$$C_t + I_t + v_t N_t^E = W_{st} S_t + W_{ut} U_t + R_t K_t + \pi_t N_t \tag{4.1}$$

$$K_{t+1} = (1 - \delta^K) K_t + I_t \tag{4.2}$$

$$\text{and } N_t = (1 - \delta^N) N_{t-1} + N_t^E \tag{4.3}$$

where C_t denotes consumption, I_t is investment, N_t is the mass of operating firms, N_t^E is the mass of new firms entering, v_t is the value of the new firms, and π_t denotes the profits of each firm that accrue to the households, in period t. The discount factor is given by $\beta \in (0, 1)$, and $\delta^K, \delta^N \in (0, 1)$ are the depreciation rate of capital and the exit rate of firms, respectively. In the utility function, $\theta_s, \theta_u > 0$ are the disutility weights on skilled and unskilled labor supply, and $\chi_s, \chi_u \geq 0$ are the inverse Frisch elasticities of skilled and unskilled labor supply, respectively.[20] Optimization yields the following Euler and asset-pricing conditions (in addition

[20]This set-up is similar to Jaimovich and Floetotto (2008) in a few respects. Specifically, the utility function

to two consumption-leisure conditions), respectively:

$$1 = \beta \left[\frac{C_t}{C_{t+1}} \left(R_{t+1} + 1 - \delta^K \right) \right] \tag{4.4}$$

$$v_t = \pi_t + \beta(1 - \delta^N) \left(\frac{C_t}{C_{t+1}} v_{t+1} \right) \tag{4.5}$$

Industries and Firms

There is a continuum of industries of measure one, indexed by j. The households aggregate the industrial goods into a composite good, Y, before using it for consumption, investment, and purchase of new firms:

$$Y_t = \left[\int_0^1 Q_t(j)^\omega \, dj \right]^{\frac{1}{\omega}} \quad , \omega < 1 \tag{4.6}$$

Within each industry, there is a continuum of monopolistically competitive firms of mass N_t, indexed by i. These firms produce differentiated goods, $g_t(j,i)$, that are aggregated over all firms to yield the industrial good, $Q_t(j)$. Thus,

$$Q_t(j) = \left[\int_{i=0}^{N_t} g_t(j,i)^\tau \, di \right]^{\frac{1}{\tau}} \quad , \tau < 1 \tag{4.7}$$

The CES aggregation helps to build the consumers' preference for variety into the set-up of the model. This feature, along with innovation required to produce a new product (described next) are the key components that I use to formalize the second technology effect of offshoring - a change in offshoring affects the number of varieties produced, and hence innovation. I assume that each firm produces a single differentiated good. Thus, the mass of firms, N_t, in any period is also the mass of varieties or differentiated products produced in that period.[21] The differentiated goods are produced with a CES technology using skilled and unskilled intermediate goods, denoted x_{st} and x_{ut}, respectively. The unskilled intermediate goods can also be offshored (i.e., imported from the South). These imports, denoted by m_{ut}, are highly substitutable for domestically produced unskilled intermediates. This is the key assumption that triggers the H-O and technology effects of offshoring. Thus, the production function for the differentiated goods is:

$$g_t(j,i) = [\lambda[x_{ut}(j,i)^\sigma + m_{ut}(j,i)^\sigma]^{\frac{\gamma}{\sigma}} + (1-\lambda)x_{st}(j,i)^\gamma]^{\frac{1}{\gamma}} \quad , \lambda \in (0,1)\, , \gamma < 1, 0 < \sigma < 1 \tag{4.8}$$

is similar in their model except that labor is homogeneous. The firm entry and exit process is the same.

[21] Again, the set-up here draws upon Jaimovich and Floetotto (2008).

I introduce trade barriers by assuming the presence of a trade cost of offshoring. The South exports the unskilled intermediates at price, p^*_{ut}. However, suppose that the firm in the North pays an ad valorem cost, d, to import these goods, so that the effective import price for the North is $(1+d)p^*_{ut}$. The cost, d, is a real cost in terms of units of the good and can be broadly interpreted to represent any costs associated with trade such as transport costs, tariffs, or changes in exchange rates. A change in d constitutes an exogenous shock that triggers changes in offshoring.

The intermediate good producing firms are perfectly competitive. Skilled intermediates are produced using equipment capital and skilled labor, while unskilled intermediate goods are produced using only unskilled labor:

$$x_{st} = k_t^{\mu} s_t^{1-\mu} \ , \mu \in (0,1) \,, \tag{4.9}$$

$$x_{ut} = u_t \tag{4.10}$$

In this framework, capital is complementary to skilled labor. This is the key ingredient yielding the first technology effect of offshoring - an increase in production of skilled intermediates resulting from offshoring increases the demand for both skilled labor and skill-complementary capital.

The above framework implies that the demand function for the industrial aggregate is:

$$Q_t(j) = \left(\frac{p_t(j)}{P_t}\right)^{\frac{1}{\omega-1}} Y_t \tag{4.11}$$

where P_t is the price of the composite good, $p_t(j)$ is the price of industrial good j, and

$$P_t = \left[\int_0^1 p_t(j)^{\frac{\omega}{\omega-1}}\, dj\right]^{\frac{\omega-1}{\omega}} \tag{4.12}$$

Since I assume the composite good of the North to be the numeraire, $P_t = 1$. The industrial demand for the differentiated goods produced by firms is given by:

$$g_t(j,i) = \left[\frac{p_t(j,i)}{p_t(j)}\right]^{\frac{1}{\tau-1}} \left[\frac{p_t(j)}{P_t}\right]^{\frac{1}{\omega-1}} Y_t \tag{4.13}$$

where $p_t(j,i)$ is the price of the differentiated good, $g_t(j,i)$, and

$$p_t(j) = \left[\int_{i=0}^{N_t} p_t(j,i)^{\frac{\tau}{\tau-1}} di\right]^{\frac{\tau-1}{\tau}} \tag{4.14}$$

The differentiated goods producing firms optimize in two stages. In stage one, they choose the price taking the marginal cost implied by factor prices as given. This gives us the price as a markup ($\frac{1}{\tau}$), over their marginal costs, $MC_t(j,i)$. In the second stage, they maximize profits, taking the prices of intermediate goods as given. I assume that these firms exit each period at a constant exogenous rate δ^N. The skilled and unskilled intermediates producing firms also solve the standard profit-maximization problems.

Innovation and Entry

New or existing firms enter the markets for new varieties or differentiated goods. Entry into new markets requires innovation which in turn is carried out by skilled workers using skill-complementary capital equipment. Innovation is performed by a representative R&D firm with the following technology:

$$\Psi_{nt} = [\varphi k_{nt}^{\alpha} + (1-\varphi) s_{nt}^{\alpha}]^{\frac{1}{\alpha}} \quad , \alpha < 1 \tag{4.15}$$

The innovation good firm faces the standard profit-maximization problem. To enter, ψ_t units of the innovation good are bought by the new monopolistically competitive firms in any industry at price p_{nt}. Firms start producing in the same period as the one in which they enter.

4.2 The South

Households

There is a continuum of identical households of mass one. They face the following optimization problem:

$$\underset{C_t^*, C_{mt}^*, U_t^*}{\text{Max}} \mathcal{U}^* = \sum_{t=0}^{\infty} \beta^{*t} \left(\log \, (C_t^{*\rho} + C_{mt}^{*\rho})^{\frac{1}{\rho}} - \Delta_U \frac{U_t^{*1+\xi}}{1+\xi} \right)$$

subject to

$$P_t^* C_t^* + C_{mt}^* + P_t^* I_t^* = W_{ut}^* U_t^* + R_t^* K_t^* \tag{4.16}$$

$$\text{and } K_{t+1}^* = (1-\delta) K_t^* + I_t^* \tag{4.17}$$

where $\rho < 1$ is the curvature parameter that governs the elasticity of substitution between consumption of goods that are imported, C_{mt}^*, and domestically produced, C_t^*. The assumption here is that imports are used only for consumption, while domestic goods produced in the South can be used for both consumption and investment. P_t^* is the price of the final goods produced in the South and δ is the rate of depreciation of capital. Besides the consumption-leisure tradeoff, optimization yields the following two conditions:

$$P_t^* = \left(\frac{C_t^*}{C_{mt}^*} \right)^{\rho - 1} \tag{4.18}$$

$$1 = \beta^* \left[\frac{C_t^{*\rho} + C_{mt}^{*\rho}}{C_{t+1}^{*\rho} + C_{mt+1}^{*\rho}} \frac{C_{t+1}^{*\rho-1}}{C_t^{*\rho-1}} \right] \left[\frac{R_{t+1}^*}{P_{t+1}^*} + 1 - \delta \right] \tag{4.19}$$

Firms

Perfectly competitive firms in the South produce unskilled intermediate goods and final goods. The final goods are produced using the following technology:

$$Y_t^* = [X_{hut}^{*\zeta} + K_t^{*\zeta}]^{\frac{1}{\zeta}} \ , \zeta < 1 \tag{4.20}$$

where X_{hut}^* is the amount of South-produced intermediates used in the production of final goods in the South. Intermediates are produced with a linear technology using unskilled labor. Firms face the standard profit maximization problem.

4.3 Equilibrium

Since all households and firms are symmetric in their utility functions and technologies, respectively, I focus on symmetric equilibria. Given this normalization and symmetry, I solve for an equilibrium, which consists of: prices of intermediate goods, $(p_{ut}, p_{st}, p_{ut}^*)$, prices of final goods, $(P_t, p_t(j), p_t(j,i), P_t^*)$, factor prices, $(W_{ut}, W_{st}, R_t, W_{ut}^*, R_t^*)$, price of innovation goods, p_{nt}, and price of firms, v_t, allocations of labor, $(u_t, s_t, s_{nt}, u_t^*)$, and capital, (k_t, k_{nt}), the total supplies of labor, (U_t, S_t, U_t^*), and capital, (K_t, K_t^*), and quantities of intermediates, $(x_{st}, x_{ut}, X_{st}, X_{ut}, X_{ut}^*, X_{hut}^*)$, imports of intermediate goods by the North, (m_{ut}, M_{ut}), and exports to the South, C_{mt}^*, final goods, (Y_t, Q_t, g_t, Y_t^*), and innovation goods, Ψ_{nt}, the mass of firms, N_t, new firms, N_t^E, and profits, π_t, that satisfy the consumers' optimization, firms' profit maximization, firm's innovation optimality, market clearing conditions, and balanced trade.

Symmetry implies

$$Y_t = Q_t = N_t^{\frac{1-\tau}{\tau}} g_t \tag{4.21}$$

$$\pi_t = \left(\frac{z-1}{z}\right) g_t \tag{4.22}$$

The equilibrium mass of new varieties in the North is determined where the cost of innovation is equal to the present discounted value of future profits from selling the new varieties. Since ψ_t is the fixed average quantity of innovation goods required for each firm to enter, we have:

$$v_t = p_{nt}\psi_t \tag{4.23}$$

The market clearing conditions in the North are as follows:

$$K_t = N_t k_t + k_{nt} \tag{4.24}$$

$$U_t = N_t u_t \tag{4.25}$$

$$S_t = N_t s_t + s_{nt} \tag{4.26}$$

$$X_{st} = N_t x_{st} \tag{4.27}$$

$$X_{ut} = N_t x_{ut} \tag{4.28}$$

$$M_{ut} = N_t m_{ut} \tag{4.29}$$

The market clearing condition in the South is:

$$X^*_{ut} = M_{ut} + X^*_{hut} \tag{4.30}$$

where M_{ut} is the quantity of intermediates exported from the South to the North. Finally, we have the trade balance equation:

$$C^*_{mt} = (1 + d)p^*_{ut} M_{ut} \tag{4.31}$$

The complete system of steady state equations is provided in Appendix A. I use numerical methods to solve for the steady states in autarky and trade. For this purpose, in the next section, I describe the calibration of the structural parameters in the model.

4.4 Calibration of Structural Parameters

The parameter values in the baseline calibration are listed in Table 1. I focus first on the calibration of the parameters in the North. After describing the choice of some parameters based on previous literature, I discuss the calibration of others to the data.

Following Krusell et. al. (2000), I set the curvature parameter, γ, in the production of $g_t(j, i)$, such that the elasticity of substitution between unskilled intermediates and skilled intermediates is 1.67. This is higher than the substitution elasticity of 1 between capital and skilled labor in the production of skilled intermediates. Hence, this set up allows for capital-skill complementarity in production. Since innovation may require more high-tech or sophisticated equipment than production tasks, I expect equipment capital to be more skill-complementary in innovation than in production. Thus, the curvature parameter, α, in the production function for innovation goods is set such that the elasticity of substitution between skilled labor and capital equipment equals 0.67 (less than 1 in the production of skilled intermediates) as estimated by Krusell et. al. (2000).

I fix τ to yield a markup of 1.225 - the average of the range of values (1.05 to 1.4) estimated in the literature.[22] In the sensitivity analysis, I vary the value of τ such that the markup varies over the range 1.05 to 1.4 found in previous studies. Following Jaimovich and Floetotto (2008), the value for ω, that governs the elasticity of substitution between the industrial goods, is set at 0.001.

According to the estimates of Kimball and Shapiro (2008), the aggregate Frisch elasticity of labor supply is around 1. In the baseline calibration, I set the elasticities of both kinds of labor at 1. Kimball and Shapiro (2008) also show that for more highly educated workers, the elasticity is somewhat lower. As part of sensitivity analysis, I calibrate the elasticities of skilled and unskilled labor such that the elasticity of skilled labor is slightly less than 1 and that of unskilled labor is somewhat larger than 1; and their linear combination, with weights on skilled and unskilled labor fixed at 0.7 and 0.3, respectively, is one.[23]

The yearly discount factor is set at the standard value of 0.96. The depreciation rate for capital is fixed at the standard value of 8%. Krusell et. al. (2000) set the depreciation rate of equipment capital at 0.125. I test the sensitivity of my model to this higher depreciation rate. The exogenous exit rate of firms is set at the standard value of 10%. I test the sensitivity of my model to this parameter value. The fixed cost of innovation, ψ, for each firm is set at 0.6 in the baseline specification. I vary the value of this parameter in the sensitivity analysis.

According to the NBER manufacturing industry data, over my sample period (1974-2005), about 70% of the employed workers are production workers. Normalizing the total amount of labor supply in autarky to 1, the disutility weights on the skilled and unskilled labor supplies are calibrated to match these relative shares of non-production to production workers in the total labor force employed in the manufacturing sector.

The weight on unskilled intermediates, λ, in the production of $g_t(j,i)$ is set at 0.465, and the share of skilled workers, $(1-\mu)$, in the production of skilled intermediates is set at 0.528 to match the average skill premium of 1.6 in the data in 1974, and the fact that the share of capital in the total output is close to 0.3 (Krusell et. al. (2000)). I set the weight, φ, on capital in the technology for innovation also at 0.3.

Assuming that imported unskilled intermediates are highly substitutable for domestically produced unskilled intermediates, I set the elasticity of substitution between them at 2.5 (i.e., $\sigma = 0.6$) in the baseline specification. I vary this parameter in the sensitivity analysis.

For the parameters in the South, I keep the calibration close to the Northern economy, except that the South only has unskilled labor (normalized to 1). The curvature parameter, ζ in the production of the composite final good, the yearly discount factor, β^*, and the depreciation rate, δ, are set at levels similar to the North - 0.5, 0.96 and 0.08 respectively. In the utility function, the inverse Frisch elasticity of labor supply, ξ, is set at 1, as in the North. Finally, ρ,

[22] See Jaimovich and Floetotto (2008).

[23] Thus, I fix χ_u at 0.9091 and χ_s at 1.3044. The implied supply elasticities are 1.1 and 0.77, respectively for unskilled and skilled labor.

Table 1: Calibration

Parameter	Description	Value	Target
		North	
ω	Governs elasticity of substitution between industrial goods	0.001	Jaimovich and Floetotto (2008)
τ	Governs elasticity of substitution between firm level goods	0.8163	Markup=1.25
λ	Share of unskilled labor in production of differentiated goods	0.465	Average skill premium=1.6
γ	Governs the elasticity of substitution between skilled and unskilled intermediates	0.401	Krusell et. al. (2000)
μ	Share of capital in production of skilled intermediates	0.472	Overall share in production=0.3
φ	CES weight on capital in the production of innovation goods	0.3	Overall share in total output = 0.3
α	Governs elasticity of substitution between skilled labor and capital in production of innovation goods	-0.495	Krusell et. al. (2000)
χ^L	Frisch elasticity of unskilled labor supply	1	Kimball and Shapiro (2008)
χ^H	Frisch elasticity of skilled labor supply	1	Kimball and Shapiro (2008)
σ	Governs elasticity of substitution between home produced and imported low-skilled intermediates	0.6	Baseline assumption
ψ	Fixed cost of entry	0.6	Baseline assumption
β_N	Time discount factor	0.96	Standard for annual data
δ^k	Depreciation rate for capital	0.08	Standard
δ^F	Exit rate of firms	0.10	Standard
		South	
ρ	Governs the elasticity of substitution between home produced and imported final goods	0.4	(Close to) Armington elasticity=1.5
ζ	Share of unskilled intermediates in total output	0.5	Close to North
ξ^L	Frisch elasticity of unskilled labor supply	1	Kimball and Shapiro (2008)
β_S	Time discount factor	0.96	Standard
δ	Depreciation rate for capital	0.08	Standard

is set at 0.4 so that the elasticity of substitution between consumption of home produced and imported goods is 1.67.[24]

5 Quantitative Results

This section demonstrates the effects of an increase in offshoring using the experiment of a reduction in trade costs. I then decompose the distinct contributions of the H-O and technology channels (and separately of innovation and technology adoption) to the total changes in wages and employment of skilled and unskilled workers. Next, I present normative analysis comparing the labor market outcomes of the model with a model that only captures the H-O channel. Lastly, I discuss the sensitivity of my results.

5.1 Comparative Statics

With this calibration, I numerically solve for steady states for various levels of the trade cost, d. Autarky corresponds to a trade cost of infinity, and free trade corresponds to a trade cost of 0. In the intermediate cases, trade costs are positive, with lower values of d leading to higher levels of offshoring. According to the data, the average level of offshoring in an industry (defined as the value of imported intermediates as a proportion of the value of all intermediates used in the industry, $\frac{(1+d)p_{ut}^{*}M_{ut}}{(1+d)p_{ut}^{*}M_{ut}+p_{st}X_{st}+p_{ut}X_{ut}}$)[25] in 1974 was a negligible 0.018. By 2005, this figure had grown to 0.19. I start with a high trade cost of 18000 so as to match the 1974 level of offshoring (1.8%) and reduce the trade cost to 3.8 which matches the 2005 level of offshoring (19%).

The steady state values (corresponding to $d = 18000$ and $d = 3.8$) for the outcomes of interest in the North are presented in Table 2.[26] I report the values (prices multiplied by quantities) of the outcomes of interest, wherever applicable, since I generally observe only the dollar values of the various variables in the data. The table demonstrates that both H-O and technology channels play a role in moving from low to high offshoring levels. According to my mechanism, movements in both channels have implications for employment and wage outcomes.

Consider first the total effect of an increase in offshoring on skill-upgrading and the skill premium. The skill premium, or the wages of skilled workers relative to unskilled wages, rises by 14.5% from 1.68 to 1.92. Also, the relative employment (and supply) of skilled labor rises by 14.4% from 0.43 to 0.49. Although the skilled wage rises more than the unskilled wage, the unskilled wage also rises by a substantial 22%. In terms of employment, while the skilled workers' employment rises by 7%, that of unskilled workers falls by 6%. The increased output per firm combined with a greater number of firms yields a higher value of the composite (and

[24]The elasticity of 1.67 is close to the standard value of 1.5 for the Armington elasticity of substitution between final goods produced by different firms. Also, setting $\rho = 0.4$ yields a relatively elastic supply curve of unskilled intermediates in the South. Lower values of ρ yield more inelastic supply curves.

[25]This measure closely corresponds to the measure of offshoring suggested by Feenstra and Hanson (1999).

[26]Since the paper focuses on the outcomes in the North, I do not report the steady state values for the Southern economy. These values are available upon request.

Table 2: Quantitative Results

	Steady state with offshoring=1.8% (corresponding to 1974)	Steady state with offshoring=19% (corresponding to 2005)	% change in model	% change in the data
	(1)	(2)	(3)	(4)
Overall				
Relative Employment of Skilled Labor	0.43	0.49	14	30
Relative Wage of Skilled Labor	1.68	1.92	15	2
Skilled Employment	0.30	0.32	7	-17
Unskilled Employment	0.70	0.66	-6	-34
Skilled Wage	0.60	0.83	40	9
Unskilled Wage	0.35	0.43	22	5
Output	0.59	0.94	60	300
H-O Channel				
Skilled Intermediates/ Unskilled Intermediates	0.93	1.19	27.72	n.a.
Technology Channel				
Equipment capital employed to produce skilled intermediates	0.11	0.16	46	n.a.
Equipment Capital	0.13	0.19	46	163
Equipment Capital/Labor	0.13	0.19	49	304
Innovation	0.08	0.12	54	2842
Varieties	1.52	1.81	19	14 (1989-2005)

industrial) output. Comparing these changes to the changes in the data between 1974 and 2005 shows that the growth in offshoring over this time period can explain 49% of the skill upgrading, and 20% of the expansion in manufacturing output. The changes in wages of skilled and unskilled workers are larger than in the data. These changes in the skilled and unskilled wage levels in the NBER manufacturing industry database are smaller than those found for college and high school graduates in the Current Population Survey. As for employment of both skilled and unskilled workers, the data show a decline. This is driven by the general shrinking of the manufacturing sector in the United States over the years.

These changes in wages and employment, and the total output, as predicted by the model, are a result of the underlying H-O and technology channels. In the H-O channel, the imported intermediates substitute for the domestic unskilled intermediates. There is an increase in, skilled intermediates relative to unskilled intermediates. This prediction of the H-O channel is evident from a comparison of the steady states. The skilled intermediates relative to unskilled intermediates used in the industry increase by 27.7% when we move from low to high offshoring levels. This variable does not have an empirical counterpart.

Now, consider the technology channel. Recall that this channel has two parts. First, the skilled intermediates require skill-complementary capital in addition to skilled labor. Therefore, an increase in the output of these intermediates resulting from offshoring, should lead to an increased demand for equipment capital (technology adoption). Second, I expect offshoring to lead to a larger number of firms implying a higher level of innovation (which in turn requires skilled labor and equipment). A comparison of the two steady states shows that the corresponding variables move in directions consistent with the technology channel. Between columns (1) and (2), the skill-complementary equipment capital employed to produce skilled intermediates rises by 46%. The total mass of varieties rises by 20%, while innovation increases by 54%. The two parts of the technology channel together imply substantial technology adoption resulting from offshoring; the total value of equipment capital in the North rises from 0.128 to 0.186 - an increase of nearly 46%. Relative to labor, equipment capital grows 49%. Comparing these changes to the total changes in the data shows that via the technology channel, offshoring can explain 28% of the growth in equipment capital stock and 16% of the increase in equipment-labor ratio. The model can explain only 1.9% of the total increase in innovation expenditures in the data. This may be because innovation in the U.S. increased for several other reasons. Also, there could be alternative mechanisms by which offshoring can induce innovation, and I capture only one of these mechanisms in the model. The empirical results in Goel (2012) show that innovation responds much more strongly to offshoring.

Appendix Table B.1 shows the changes in these variables if the economy moves to free trade (trade cost = 0). The percentage changes relative to autarky for all variables are larger than the changes presented in Table 13. This shows that these variables move monotonically with offshoring.

To summarize, the comparative static predictions from the model are as follows. As offshoring increases, via the H-O channel, we observe (1) a higher relative production of skilled intermediates. Via the technology channel, we observe (2) a higher level of skill-complementary capital employed to produce skilled intermediates, and (3) an increase in innovation required to produce more varieties. These effects of offshoring lead to an increase in the both skilled and unskilled wages (with skilled wages rising more), an increase in skilled employment and a decline in unskilled employment, and a rise in the total output in the North.

5.2 Counterfactuals

Counterfactual experiments with the model can be used to quantify the distinct contributions of the H-O and technology channels to relative and absolute wages of skilled and unskilled labor. The experiments can also be used to quantify the importance of the two parts of the technology channel.

With capital-skill complementarity, increased accumulation of capital results in an increase in the relative marginal product of skilled relative to unskilled workers. On the other hand, with neutral capital, increase in capital increases the marginal products of skilled and unskilled workers equally. This has implications for the wages and employment of skilled and unskilled workers. In the first counterfactual experiment, I eliminate capital-skill complementarity by making capital equally substitutable for skilled and unskilled workers. In particular, I rewrite the production function of the monopolistically competitive firms such that capital has an elasticity of substitution equal to one with skilled and unskilled intermediates (which in turn are produced with linear technologies using skilled and unskilled labor, respectively).[27] The resulting percentage changes between steady states are presented in Table 3, column 2.

Offshoring creates an incentive for new firms to innovate and produce differentiated products. I can quantify the effect of this channel on wages and employment by shutting off any offshoring induced increase in innovation. For this purpose, I hold the mass of varieties produced every period constant at its level in the steady state corresponding to 1974. This implies that in response to the greater profit opportunity resulting from offshoring, firms do not produce any more new products than they did in the initial steady state. This, in turn, keeps the level of innovation constant at its initial level. Results from this experiment are presented in column 3 of Table 14.

Finally, I simultaneously eliminate capital-skill complementarity and hold innovation constant to quantify the contribution of the technology channel. These results are presented in the last column of Table 3.

Comparing the baseline results with the results from the counterfactual simulations suggest that capital-skill complementarity and innovation contributed almost equally to the total changes in the baseline model. With neutral capital, skill premium and the relative employment of skilled workers increase by 8%, while holding innovation constant yields a 9% increase in both. Unskilled wages also increase similarly by 15% and 14%, respectively in the two experiments. Shutting off capital-skill complementarity and innovation simultaneously shows that the technology channel accounts for nearly two-thirds of the baseline changes. While in the baseline model skill premium increases by 15%, with the technology channel shut off, skill premium increases only by 5%. Similarly, while there is a 22% increase in the unskilled wage in the baseline model, it increases only by 8% when the technology channel is shut off.

Note that, unskilled employment in the baseline falls by 6%, but when the technology channel is shut off, it falls by 2 percentage points less. This is because capital-skill complementarity and innovation affect unskilled employment in opposite directions. When capital is skill-complemetary, it is relatively more substitutable for unskilled than for skilled labor. Given the parameterization, this elasticity is greater than 1. So, when the marginal cost of production falls with a decline in trade cost, the firms expand output and can easily substitute capital for unskilled labor. However, when capital is equally substitutable with both types of labor (with elasticity equal to 1) then the firms use more unskilled intermediates and cannot easily substitute for them using capital. Thus, unskilled employment falls by less than in the baseline where capital is skill-complementary. On the other hand, innovation works to increase the employment of unskilled labor. Hence, when innovation is held constant, employment of

[27] There are multiple ways of eliminating capital-skill complementarity, i.e., making capital equally substitutable for skilled and unskilled labor. The method that I follow is the closest counterpart to the Heckscher-Ohlin model that I compare the baseline model to.

unskilled labor declines more between steady states than in the baseline model. The effect of capital-skill complementarity is stronger than the effect of innovation so that when the two are simultaneously shut off, the total decline in unskilled employment is less than in the baseline.

Table 3: Contribution of the Technology Channel

	Baseline	No Capital Skill Complementarity	No Increase in Innovation	Technology Channel Shut Off
Percentage Changes Between Steady States				
Skill Premium	15	8	9	5
Employment Ratio	14	8	9	5
Unskilled Wage	22	15	14	8
Unskilled Employment	-6	-3	-6	-4

5.3 Comparison of Labor Outcomes and Welfare with H-O Model

So far, I have presented results that suggest that the technology channel is the dominant mechanism underlying the positive relationship between offshoring and the skill premium. Next, I examine the relative welfare implications of the H-O and technology channels. For this purpose, I write an alternative model to only capture the features of the H-O channel. In particular, there is a fixed mass of perfectly competitive firms that produce final products using a Cobb Douglas technology that combines capital with skilled and unskilled intermediates. The skilled (unskilled) intermediates are produced with linear technologies using only skilled (unskilled) labor. I consider two variants of the model with only the H-O channel: in the first variant I keep the elasticity of substitution between domestic and imported unskilled intermediates the same as that in the baseline model, in the second variant I allow for perfect substitution between them, consistent with the previous literature. In both variants, I calibrate the shares of capital, and the skilled and unskilled intermediates in the output of the final products to match the skill premium of 1.6 in the data in 1974. The model and the calibration are briefly presented in Appendix B.

In Table 4, I compare results of these variants of the alternative model with the baseline model with the objective of assessing the welfare implications of offshoring as seen in models with and without the technology channel. In the first column, I present the percentage changes in the baseline model for a few variables of interest when the economy moves from an autarky steady state (corresponding to 1974) to the steady state in which offshoring increases to 0.19 as in 2005. In the second column I present the analogous percentage changes in the alternative model with only the H-O channel but the same elasticity of substitution between domestic and imported intermediates as in the baseline model. In the third column, I present the results from the model with H-O channel considering imported and domestic inputs as perfect substitutes in production.

Comparing across columns, the baseline model predicts a smaller decline in the employment of unskilled labor than both variants of the alternative model. This result suggests that a model with the technology channel predicts fewer job losses for unskilled workers than a model without. This finding is broadly consistent with the empirical studies that find no significant impact of offshoring on the employment of unskilled workers in the U.S. (see, for example, Amiti and Wei (2005)). Total employment of labor falls by less in the baseline than in the alternative model. Looking at the real wage changes, I find that, the baseline and model with only the H-O channel implies an increase in both the unskilled and skilled wages, but the baseline implies substantially larger increases (22% and 39%, respectively) than the latter model. However, these results stand in sharp contrast to those from the variant with perfect substitution which implies only a 12% increase in skilled wages but a *decline* of 8% in unskilled wages. Further, the skill premium is *lower* in the baseline than in the alternative model. Finally, the baseline model also implies substantially larger growth in output and consumption than the alternative model.

Table 4: Comparison of Baseline and Heckscher-Ohlin Models

	Full model	Model with only H-O channel	Model with only H-O and perfect substitution between imported and domestic intermediates
Unskilled Employment	-6	-10	-10
Skilled Employment	7	9	9
Total Employment	-2	-4	-4
Unskilled Wage	22	7	-8
Skilled Wage	40	31	12
Skill Premium	15	22	22
Output	60	44	23
Consumption	30	20	2

These results suggest that although the distributional and employment consequences of offshoring are unfavorable to unskilled workers in the advanced countries, offshoring increases their real wages as long as offshored inputs do not substitute perfectly for domestic inputs. And with perfect substitution, this favorable result is reversed with unskilled wages declining as offshoring increases. The analysis also shows that skilled workers gain both in terms of employment and wages. Finally, an increase in offshoring is akin to a productivity increase leading to growth in output (and, hence, consumption of households). The increases in output and consumption are much larger with the baseline model that captures both H-O and technology channels.

Finally, I compare the welfare implications of the baseline model with those of the H-O model with perfect substitution between imported and domestic intermediates. For this purpose, I use the dynamic equations of the model to calculate the transition paths. I compare the overall welfare gains in the North from the two models taking the transitional dynamics into account. The welfare metric that I use is the equivalent variation in consumption from a change in trade costs, i.e. the extra consumption needed by households for them to be indifferent between the old steady state with and transition to the new steady state. Using this metric, the baseline model shows a substantial 17% increase in welfare. In contrast, the H-O model with perfect substitution between imported and domestic intermediates yields only a 3% increase in welfare.

5.4 Sensitivity Analysis

I examine sensitivity of the baseline results to the values of some parameters. First, I consider sensitivity to the elasticity of substitution between imported and domestically produced unskilled intermediates. As mentioned before, the existing literature assumes perfect substitutability between the two. In the baseline specification, I consider a more general framework in which I set the elasticity at 2.5, so that the imported and domestic intermediates are highly but not perfectly substitutable. The Armington elasticity of substitution between *final* products produced by different firms is usually set around 1.5 in the business cycle literature. Arguably, intermediate unskilled inputs are more substitutable than final products. I vary the elasticity of substitution over the range 1.5 ($\sigma = 0.33$) to 100 ($\sigma = 0.99$), i.e., near perfect substitutes. The results remain qualitatively similar. For values of σ higher than the baseline value of 0.6, when the economy moves from autarky to free trade, employment and wage ratios increase by about 19%, similar to the change in the baseline. For values of σ smaller than 0.6, I find that the employment and wage ratios increase by less than in the baseline. For instance, when $\sigma = 0.4$, moving from autarky to free trade, the employment and wage ratios increase by 13.7% and 13.9% respectively, compared to around 19.5% in the baseline. At $\sigma = 0.95$, i.e., at an elasticity of substitution of 20, unskilled workers stop gaining in terms of real wages.

Next, I briefly describe the sensitivity results for the other parameters. Krusell et. al. (2000) set the depreciation rate for equipment capital at 0.125, higher than the standard value of 0.08 that I use in the baseline specification. The results from the model with the higher depreciation rate of capital (=0.125) remain qualitatively similar to the baseline results. Note that moving from autarky to free trade, this model results in similar increases in the skill premium and relative employment of skilled workers, with both going up by about 19%, as with the baseline model.

In the baseline calibration, I set the exogenous exit rate of firms at 0.10. The model results are not sensitive to the value of the exit rate of firms. In particular, the employment and wage ratios increase by similar amounts as with the baselines, moving from autarky to free trade. The results are also not very sensitive to the cost of entry. In particular, lower values of ψ (i.e., cheaper entry) result in slightly larger increases in the employment and wage ratios than in the baseline, moving from autarky to free trade.

For the baseline calibration, I set the markup at 1.225 - the average of the range of 1.05 to 1.4. To examine the sensitivity to this value, I vary the τ to yield a markup over this range. The results remain qualitatively similar for different values of the markup. In particular, moving from autarky to free trade, the model results in smaller (larger) increases in the employment and wage ratios for values of the markup lower (higher) than the baseline.

Finally, I examine sensitivity to the Frisch elasticities of unskilled and skilled labor supply, both set at 1 in the baseline calibration. I set χ_u at 0.9091 and χ_s at 1.3044. The implied supply elasticities are 1.1 and 0.77, respectively for unskilled and skilled labor. The linear combination of these elasticities, with weights of 0.7 and 0.3, respectively, is 1.[28] The results from the model remain qualitatively similar. In particular, moving from autarky to free trade, the employment ratio increases by 26.7% (more than baseline) and the skill premium increases by 12.7% (less than baseline).

6 Conclusion

Motivated by the strong empirical support for the technology channel proposed in Goel (2012), this paper develops a general equilibrium model to formalize the mechanism. The model shows that a rise in offshoring to developing countries induces the adoption of skill-complementary technology and innovation, generating real wage gains for both skilled and unskilled workers in advanced countries. although increasing wage inequality. Results show that this channel is the dominant mechanism underlying the effect of offshoring on the relative wages and employment of skilled labor. Decomposition results from the model confirm the importance of this mechanism. Normative analysis suggests that without the technology channel, the wages of both groups of workers would be much lower, especially for unskilled workers, and the inequality between them would be considerably more. Thus, induced technology adoption and innovation generate quantitatively important gains for all workers. These results suggest that instead of discouraging offshoring, policies that encourage innovation, and facilitate investment will prove helpful.

Future work will enrich the analysis by extending the model in three directions. I will allowing for heterogeneous firms, influenced to different degrees by similar changes in trade costs. I will model households separately as skilled and unskilled and will incorporate costs incurred by the latter to acquiring skills explicitly. Finally, the model will include confounding factors like declining costs of capital to examine how these factors interact with offshoring to shape the overall labor market responses.

[28] This follows the estimate of Kimball and Shapiro (2008) that the overall elasticity is 1, and their observation that the skilled labor supply may be somewhat less elastic than skilled labor supply.

References

Acemoglu, Daron, 1998, "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality" *The Quarterly Journal of Economics* Vol. 113, pp. 10551090.

Acemoglu, Daron, 2002a, "Technology and the Labor Market," *Journal of Economic Literature*, Vol. 40, pp.772.

Acemoglu, Daron, 2002b, "Directed Technical Change," *Review of Economic Studies*, Vol. 69, pp. 781810.

Amiti, Mary and Shang-Jin Wei, 2009, "Service Offshoring and Productivity: Evidence from the US," *The World Economy*, Vol. 32, No. 2, pp. 203-220.

Amiti, Mary and Shang-Jin Wei, 2005, "Fear of Service Outsourcing: Is It Justified?," *Economic Policy*, CEPR, CES, MSH, Vol. 20, No. 42, pp. 308-347.

Antras, Pol and Esteban Rossi-Hansberg, 2009, "Organizations and Trade," *Annual Review of Economics*, Vol. 1, pp. 43-64.

Autor, David H., Lawrence F. Katz and Melissa S. Kearney, 2008, "Trends in U.S. Wage Inequality: Revising the Revisionists," *Review of Economics and Statistics*, Vol. 90, No.2, pp. 300-323.

Bartelsman, Eric J. and Wayne Gray, October 1996, "The NBER Manufacturing Productivity Database," NBER Technical Working Paper No. 205.

Berman, Eli, John Bound and Zvi Griliches, May 1994, "Changes in the Demand for Skilled Labor Within U.S. Manufacturing: Evidence from the Annual Survey of Manufacturers," *The Quarterly Journal of Economics*, Vol. 109, No. 2, pp. 367-397.

Berman, Eli, John Bound and Stephen Machin, November 1998, "Implications Of Skill-Biased Technological Change: International Evidence," *The Quarterly Journal of Economics*, Vol. 113, No. 4, pp. 1245-1279.

Bernard, Andrew B., Jonathan Eaton, Bradford Jensen and Samuel Kortum, 2003, "Plants and Productivity in International Trade," *The American Economic Review*, Vol. 93, No. 4, pp. 1268-1290.

Bernard, Andrew B., Bradford Jensen, Stephen Redding and Peter Schott, May 2009, "The Margins of U.S. Trade," *The American Economic Review Papers and Proceedings*," Vol. 99, No. 2, pp. 487-493

Bernard, Andrew B., Stephen Redding and Peter Schott, March 2010, "Multi-Product Firms and Product Switching," *The American Economic Review*, Vol. 100, pp. 70-97

Bhagwati, Jagdish, Arvind Panagariya and T. N. Srinivasan, Fall 2004, "The Muddles Over Outsourcing," *Journal of Economic Perspectives*, Vol. 18, No. 4, pp. 93-114.

Bloom, Nicholas, Mirko Draca and John Van Reenen, 2011, "Trade Induced Technical Change? The Impact of Chinese Imports on IT and Productivity," CEPR Discussion Papers No. 8236.

Burstein, Ariel, Javier Cravino and Jonathan Vogel, December 2010, "Importing Skill-Biased Technology," Working Paper.

Chamarbagwala, Rubiana, December 2006, "Economic Liberalization and Wage Inequality in India," *World Development*, Vol. 34, No. 12, pp. 1997-2015.

Chaney, Thomas, September 2008, "Distorted Gravity: The Extensive and Intensive Margins of International Trade," *The American Economics Review*, Vol. 98, No. 4, pp. 1707-1721.

Deardorff, Alan V., 2001, "Fragmentation in Simple Trade Models," *North American Journal of Economics and Finance*, Vol. 12, pp. 121-137.

Deardorff, Alan V., 2005, "A Trade Theorist's Take on Skilled-Labor Outsourcing," *International Review of Economics and Finance*, Vol. 14, No. 3, pp. 259-271.

Deardorff, Alan V., 2005, "Gains from Trade and Fragmentation," RSIE Discussion Papers No. 543, University of Michigan.

Deardorff, Alan V. and Dalia S. Hakura, 1995, "Trade and Wages - What Are the Questions?," in Jagdish Bhagwati and Marvin H. Kosters, eds., *Trade and Wages: Leveling Wages Down?* Washington, D.C.: The AEI Press, pp. 76-107.

Feenstra, Robert C., 2008, "Offshoring in the Global Economy," The Ohlin Lectures.

Feenstra, Robert C., March 1996, "U.S. Imports, 1972-1994: Data and Concordances," NBER Working Paper No. 5515.

Feenstra, Robert C. and Gordon H. Hanson, May 1996, "Globalization, Outsourcing and Wage Inequality," *The American Economic Review*, Vol 86, No. 2, pp. 240-245.

Feenstra, Robert C. and Gordon H. Hanson, August 1999, "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the United States, 1979-1990," *The Quarterly Journal of Economics*, Vol. 114, No. 3, pp. 907-940.

Feenstra, Robert C., John Romalis and Peter K. Schott, November 2002, "U.S. Imports, Exports and Tariff Data: 1989-2001," NBER Working Paper No. 9387.

Glass, Amy J. and Kamal Saggi, 2001, "Innovation and Wage Effects of International Outsourcing," *European Economic Review*, Vol 45, pp. 67-86.

Gordon, R.J., 1990, "*The Measurement of Durable Goods Prices*," NBER Monograph Series, Chicago: University of Chicago Press.

Griliches, Zvi, November 1969, "Capital-Skill Complementarity," *The Review of Economics and Statistics*, Vol 51, No. 4, pp. 465-468.

Groshen, Erica L., Bart Hobijn, and Margaret M. McConnell, 2005, "U.S. Jobs Gained and Lost Through Trade: A Net Measure," *Federal Reserve Bank of New York Current Issues in Economics and Finance*, Vol. 11, No. 8.

Grossman, Gene M. and Elhanan Helpman, January 2005, "Outsourcing in a Global Economy," *The Review of Economic Studies*, Vol. 72, No. 1, pp. 135-159.

Grossman, Gene and Esteban Rossi-Hansberg, 2006, "The Rise of Offshoring: It's Not Wine for Cloth Anymore," Manuscript, Princeton University.

Grossman, Gene M. and Estaban Rossi-Hansberg, 2008, "Trading Tasks: A Simple Theory of Offshoring," *The American Economic Review*, Vol. 98, No. 5, pp. 1978-1997.

Guadalupe, Maria and Vicente Cuat, April 2009, "Globalization and the Provision of Incentives Inside the Firm: The Effect of Foreign Competition," *The Journal of Labor Economics*, Vol. 27, No. 2, pp. 179-212.

Hummels, David and Peter J. Klenow, June 2005, "The Variety and Quality of a Nation's Exports," *The American Economic Review*, Vol. 95, pp. 704-723.

Jaimovich, Nir and Max Floetotto, October 2008, "Firm Dynamics, Markup Variations, and the Business Cycle," *Journal of Monetary Economics*, Vol. 55, No. 7, pp. 1238-1252.

Katz, Lawrence F., 2000, "Technological Change, Computerization, and the Wage Structure" , in E. Brynjolfsson and B. Kahin (Eds.), *Understanding the Digital Economy* (Cambridge: MIT Press)

Katz, Lawrence F., and David H. Autor, 1999, "Changes in the Wage Structure and Earnings Inequality," in O. Ashenfelter and D. Card (Eds.), *Handbook of Labor Economics*, Vol. 3 (Amsterdam: NorthHolland).

Katz, Lawrence F. and Kevin M. Murphy, February 1992, "Changes in Relative Wages, 1963-87: Supply and Demand Factors," *The Quarterly Journal of Economics*, Vol. 107, No. 1, pp. 35-78.

Kimball, Miles S. and Matthew D. Shapiro, 2008, "Labor Supply: Are the Income and Substitution Effects Both Large or Both Small?," NBER Working Paper No. 14208.

Krugman, Paul, February 2008, "Trade and Wages, Reconsidered," Spring Meeting, Brookings Panel of Economic Activity.

Krusell, Per, Lee E. Ohanian, Jos Victor Rios-Rull, and Giovanni L. Violante, 2000, "Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis," *Econometrica*, Vol. 68, No. 5, pp. 1029-1053.

Landefeld, J. Steven, and Raymond Mataloni, 2004, "Offshore Outsourcing and Multinational Companies," BEA working paper WP2004-06.

Lawrence, Robert Z. and Matthew J. Slaughter, 1993, "International Trade and American Wages in the 1980s: Giant Sucking Sound or Small Hiccup," *Brookings Papers on Economic Activity: Microeconomics* , Vol. 2, pp. 161-226.

Leamer, Edward E., 1996, "What's the Use of Factor Contents?," NBER Working Paper No. 5448.

Mann, Catherine, 2005, "Globalization, Information Technology, and U.S. Economic Performance," January mimeo.

Melitz, Marc J., November 2003, "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, Vol. 71, No. 6, pp. 1695-1725.

Naghavi, Alireza and Gianmarco I. P. Ottaviano, 2009, "Offhoring and Product Innovation," *Economic Theory*, Vol. 38, pp. 517-532.

Ottaviano, Gianmarco I.P., Giovanni Peri and Greg C. Wright, 2010, "Immigration, Offshoring and American Jobs," NBER Working Paper 16439.

Parro, Fernando, December 2010, "Capital-Skill Complementarity and the Skil Premium in a Quantitative Model of Trade," Working Paper.

Revenga, Ana L., February 1992, "Exporting Jobs? The Impact of Import Competition on Employment and Wages in U.S. Manufacturing," *The Quarterly Journal of Economics*, Vol. 107, No. 1, pp. 255-284.

Robbins, D., 1996, “HOS Hits Facts: Facts Win; Evidence on Trade and Wages in the Developing World,” Unpublished paper.

Rodrguez-Clare, Andrs, April 2010, “Offshoring in a Ricardian World,” *American Economic Journal: Macroeconomics*, Vol. 2, No. 2, pp. 22758.

Samuelson, Paul A., Summer 2004, “Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization,” *The Journal of Economic Perspectives*, Vol. 18, No. 3, pp. 135-146.

Schott, Peter, January 2008, “The Relative Sophistication of Chinese Exports,” *Economic Policy* 53, pp. 5-49.

Mankiw, Gregory N. and Phillip Swagel, July 2006, “The Politics and Economics of Offshore Outsourcing,” *Journal of Monetary Economics*, Vol. 53, No. 5, pp. 1027-1056.

Thoenig, Mathias and Thierry Verdier, June 2003, “A Theory of Defensive Skill-Biased Innovation and Globalization,” *The American Economic Review* Vol. 93, No. 3 , pp. 709-728.

Zhu, Susan Chun and Daniel Trefler, January 2005, “Trade and Inequality in Developing Countries: A General Equilibrium Analysis,” *Journal of International Economics*, Vol. 65, No, 1, pp. 21-48.

Verhoogen, Eric, May 2008, “Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector,” *The Quarterly Journal of Economics*, Vol. 123, No. 2, pp. 489-530.

Violante, Giovanni L., 2008, “Skill-Biased Technical Change,” *The New Palgrave Dictionary of Economics*, Second Edition.

Voigtlander, Nico, March 2011, “Skill Bias Magnified: Intersectoral Linkages and White-Collar Labor Demand in U.S. Manufacturing,” Working Paper.

Appendices

Appendix A Data Appendix

U.S. Imports and Exports Data

The imports data for the United States are obtained from the Center for International Data at University of California, Davis. The c.i.f. (cost, insurance, freight) values of imports are available for the years after 1973. Thus, the first year of my sample is 1974. For years up to 1994, the Center for International Data also provides imports data aggregated to the 4 digit domestic SIC 1972 level. I directly use these aggregated data for the period until 1994. I concord these data at SIC 1972 to the domestic SIC 1987 classification (for uniformity with manufacturing industry data). Also, I group the imports from various countries into two groups - imports from developed, and miports from developing countries using the World Bank Income Classification. For the period 1995-2005, I use the disaggregated imports data. These data are available at the level of 10 digit HS categories. Grouping the source countries as developed and developing, I aggregate the dollar value of imports in each product category from these two sets of countries. The next step is to aggregate these imports to the level of 4 digit industries under the SIC 1987 classification. For this purpose, I first aggregate these imports to the level of 4 digit import based SIC 1987 and then map them into the domestic SIC 1987 classification using the procedure described in Feenstra, Romalis and Schott (2002).

NBER-CES Manufacturing Productivity Database

Data on 459 four digit manufacturing industries in the United States are available from the NBER website. These data are available for the period 1958 to 2005 at a uniform Standard Industrial Classification of 1987, i.e., the data are adjusted for changes in industry definitions and classifications over time. Many of the variables are taken from the Census Bureau's Annual Survey of Manufactures and the quinquennial Census of Manufactures. The variables that I obtain from this databse include nominal values of annual shipments, the number of non-production and production workers employed and their average wages, nominal values of non-energy materials, real values of total capital stocks, and of equipment and structures (calculated according to the perpetual inventory method), and the industry level price indexes for shipments and investment.

Compustat

Compustat is a database that provides data on all publicly traded firms in the United States. From these data, I obtain annual expenditures of public firms on research and development and their annual sales. The R&D data include all non-federally funded expenditures of the firms in any given year for the purpose of producing and improving their products and services. The database includes firms that are not legally incorporated in the U.S. I drop these firms from the sample so as to retain only the domestic firms. Each firm is identified uniquely with a GV key. The four digit SIC 1987 industry that a firm belongs to is also provided. I aggregate the R&D expenditures incurred by all firms belonging to the same SIC 1987 industry to create an industry level R&D measure. Similarly, I aggregate the sales of all firms belonging to any given industry to create an industry level sales measure. R&D divided by sales gives me a measure of R&D intensity in an industry. Some firms may belong to more than one 4 digit SIC industry. In this case, Compustat provides only a 2 digit SIC 1987 code. I assign the R&D expenditures of these firms to the constituent 4 digit industries using the following procedure: I calculate the share of each constituent 4 digit industry in the total value of shipments in the broader 2 digit industry for each year. Using these shares as weights I split the R&D expenditures of the firm over all the 4 digit industries it belongs to. Also, for a few firms, the R&D and sales data are reported in Canadian dollars. I convert them to U.S. dollars using the exchange rates prevailing in those years.

Input-Output Tables

The Bureau of Economic Analysis provides detailed benchmark Input-Output (I-O) Accounts (make tables, use tables, and direct requirements coefficients tables) every five years. I use the direct requirement coefficients tables provided every five years for the period 1972-2002. For 1972 and 1977, the direct requirement coefficients were not provided. I constructed them from the use tables. The I-O industry codes for various years are based on the Standard Industrial Classification of various years until 1992. The I-O codes for 1997 and 2002 are based on NAICS 1997 and 2002, respectively. I concorded the I-O codes for all the years to 4-digit SIC 1987. Direct requirement coefficients are defined as the dollar value of an input required by an industry to produce one dollar of its output. Voigtlander (2010) shows that these coefficients are stable across years. For this reason, and following Feenstra and Hanson (1996), I linearly interpolate the coefficients for the interim years between each pair of years for which the benchmark I-O tables are available. For the period 2003-2005, I linearly extrapolate the coefficients for the year 2002.

Other Data Sources

Penn World Tables: From this database, I obtained the annual averages of the nominal exchange rates of the currencies of foreign countries relative to the U.S. dollar. for the period 1974 to 2005. An increase in the exchange rate implies an appreciation of the U.S. dollar vis-a-vis the foreign currency.
World Bank Income Classification: The World Bank classifies all countries into one of five categories: High Income: OECD, High Income: non-OECD, Upper Middle Income, Lower Middle Income and Low Income. These classifications are uniform over the sample period 1974-2005. I obtain these classifications

from the World Bank website. For the empirical analysis in this paper, I group upper middle income, lower middle income and low income countries together as "developing" or "low income" countries. High income OECD and non-OECD countries are grouped together as "advanced," "developed," or "high income" countries.

Tariffs: I construct a series of average tariffs for intermediates imported in an industry using data on the customs value of imports and the duties paid on them. I aggregate the total customs value and total duties paid for all imported product categories belonging to a given 4 digit industry, separately for imports from developed and developing countries. Taking the ratio of total duties to total customs value, and multiplying by 100, provides a measure of the average tariff rate in the 4 digit industry for each year, separately for imports from developed and developing countries. Between 1974 and 1988, the data provide the four digit SIC 1972 industries that the imported product categories belong to. For the years after 1988, the data provide the import based SIC 1987 industries that the products belong to. I concord the SIC 1972 and import based SIC 1987 classifications to domestic SIC 1987 classification using the same method as described above for the U.S. imports data. This provides me with the average tariff rates imposed on imports belonging to all 4 digit SIC 1987 industries. To get a measure of tariffs imposed on imported intermediates, I follow the same procedure as that used for exchange rates.

CPI: The U.S. consumer price index data are obtained from the Bureau of Labor Statistics. This price index is used to construct a series of real prices for 4 digit industries by dividing the industry level price index by the U.S. CPI.

Appendix B Model Appendix

Steady State Equations

The complete system of steady state equations for the model economy are presented below. First the equations for the North:

$$K = (1-\delta^K)K + I \tag{B.1}$$

$$N = (1-\delta^N)N + N^E \tag{B.2}$$

$$1 = \beta(R + 1 - \delta^K) \tag{B.3}$$

$$v = \frac{\pi}{1-\beta(1-\delta^N)} \tag{B.4}$$

$$Y = Q \tag{B.5}$$

$$Y = N^{\frac{1}{\tau}} \tag{B.6}$$

$$g = [\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}} + (1-\lambda)x_s^\gamma]^{\frac{1}{\gamma}} \tag{B.7}$$

$$x_u = u \tag{B.8}$$

$$x_s = k^\mu s^{1-\mu} \tag{B.9}$$

$$P = 1 \tag{B.10}$$

$$p(j) = 1 \tag{B.11}$$

$$p(j,i) = N^{\frac{1-\tau}{\tau}} \tag{B.12}$$

$$z = \frac{1}{\tau} \tag{B.13}$$

$$p_u = \frac{p(j,i)}{z}[\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}} + (1-\lambda)x_s^\gamma]^{\frac{1}{\gamma}-1}\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}-1}x_u^{\sigma-1} \tag{B.14}$$

$$(1+d)p_u^* = \frac{p(j,i)}{z}[\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}} + (1-\lambda)x_s^\gamma]^{\frac{1}{\gamma}-1}\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}-1}m_u^{\sigma-1} \tag{B.15}$$

$$p_s = \frac{p(j,i)}{z}[\lambda(x_u^\sigma + m_u^\sigma)^{\frac{\gamma}{\sigma}} + (1-\lambda)x_s^\gamma]^{\frac{1}{\gamma}-1}(1-\lambda)x_s^{\gamma-1} \tag{B.16}$$

$$W_u = p_u \tag{B.17}$$

$$W_s = p_s(1-\mu)k^\mu s^{-\mu} \tag{B.18}$$

$$R = p_s\mu k^{\mu-1}s^{1-\mu} \tag{B.19}$$

$$\Psi_n = [\varphi k_n^\alpha + (1-\varphi)s^\alpha]^{\frac{1}{\alpha}} \tag{B.20}$$

$$\Psi_n = \psi N^E \tag{B.21}$$

$$W_s = p_n(1-\varphi)s^{\alpha-1}[\varphi k_n^\alpha + (1-\varphi)s^\alpha]^{\frac{1}{\alpha}-1} \tag{B.22}$$

$$R = p_n\varphi k_n^{\alpha-1}[\varphi k_n^\alpha + (1-\varphi)s^\alpha]^{\frac{1}{\alpha}-1} \tag{B.23}$$

$$v = p_n\psi \tag{B.24}$$

$$\pi = (\frac{z-1}{z})g \tag{B.25}$$

$$\theta_u = (\frac{W_u}{L_u^{\chi_u} * C} \tag{B.26}$$

$$\theta_s = (\frac{W_s}{L_s^{\chi_s} * C} \tag{B.27}$$

$$X_u = Nx_u \tag{B.28}$$

$$M_u = Nm_u \tag{B.29}$$

$$X_s = Nx_s \tag{B.30}$$

$$K = Nk + k_n \tag{B.31}$$

$$S = Ns + s_n \tag{B.32}$$

$$U = Nu \tag{B.33}$$

$$Y = C + I + vN^E + C_m^* \tag{B.34}$$

The equations for the South are as follows:

$$K^* = (1-\delta)K^* + I^* \tag{B.35}$$

$$P^* = \left[\frac{C^*}{C_m^*}\right]^{\rho-1} \tag{B.36}$$

$$\Delta U^{*\xi} = \frac{C_m^{\rho-1}W_u^*}{C^{*\rho} + C_m^\rho} \tag{B.37}$$

$$1 = \beta^*\left[\frac{R^*}{P^*} + 1 - \delta^*\right] \tag{B.38}$$

$$Y^* = [X_{hu}^{*\zeta} + K^{*\zeta}]^{\frac{1}{\zeta}} \tag{B.39}$$

$$p_u^* = P^*[X_{hu}^{*\zeta} + K^{*\zeta}]^{\frac{1}{\zeta}-1}X_{hu}^{*\zeta-1} \tag{B.40}$$

$$R^* = P^*[X_{hu}^{*\zeta} + K^{*\zeta}]^{\frac{1}{\zeta}-1}K^{*\zeta-1} \tag{B.41}$$

$$X_u^* = U^* \tag{B.42}$$

$$W_u^* = p_u^* \tag{B.43}$$

$$X_u^* = X_{hu}^* + M_u \tag{B.44}$$

$$Y^* = C^* + I^* \tag{B.45}$$

$$C_m^* = (1+d)p_u^*M_u \tag{B.46}$$

Numerical Method

The steady state equations are solved numerically. The method to solve involves two inner loops and an outer loop. The two inner loops are used to solve the systems of equations in the South and the North, respectively. These two economies are linked through trade in intermediate and final goods. The outer loop serves to solve for the unique set of prices and quantities in which the two economies are simultaneously in a steady state equilibrium.

In the first inner loop, I start with an initial guess of the total quantity of intermediates exported from the South to the North, M_u. Then, I use fixed point iteration to solve the system of equations for the South. In the second inner loop I solve for the system of equations in the North. Fixing the value for the trade cost, d and import price, p_u^*, I provide the system with guesses for three more variables - capital used in innovation, k_n, skilled labor used in innovation, s_n, and the imported intermediates used per firm, m_u. The second loop is solved using a combination of fixed point iteration and the Newton-Raphson algorithm. With the initial guesses, I obtain the values for the other variables in the system of equations. This leaves me with three equations that cannot provide me with closed form solutions for the initially guessed variables. I solve these three equations using the Newton-Raphson method. The resulting values for the three variables are again used as the initial guesses and the loop runs again until the system converges.

In the outer loop, the systems for the North and the South are solved together. The loop for the North yields a new value for M_u that is used as an initial guess to solve the system for the South using the first inner loop. This provides me with a value for the price at which the intermediates are exported to the North. This value, marked up by the trade cost - $(1 + d) * p_u^*$, serves as an initial guess for the second loop that solves the system for the North. The outer loop runs until the systems for the North and South converge simultaneously at a unique set of prices and quantities.

Model Results - Moving from Autarky to Free Trade

As shown in the results presented in section 3, all the variables of interest increased as offshoring increased from 0 to 0.19. As the trade costs fall further and the economy moves to free trade, these variables increase even more relative to autarky. This suggests that the variables of interest change monotonically with offshoring. These results are presented in the table below.

Counterfactuals - Moving from Autarky to Free Trade

The results presented in Table B.2 show the contributions of the technology channel when the North moves from autarky to free trade. While capital-skill complementarity explains 65% of the total increase in the skill premium, the increase in innovation explains 22%. Suppressing the technology channel entirely shows that the H-O channel in fact reduces the skill premium when the economy moves from autarky to trade.

There are alternative ways of eliminating capital-skill complementarity. One can rewrite the production function for g such that capital is neutral and interacts with a Cobb-Douglas technology with the CES aggregate of skilled and unskilled intermediates (in turn produced linearly using only skilled and unskilled labor, respectively). In this set up, the elasticity of substitution between capital and both kinds of labor is equal to one. But the elasticity of substitution between skilled and unskilled intermediates is 1.67. Alternatively, I can retain the original functional form of g but rewrite the production functions for skilled and unskilled intermediates s.t. they are both produced with Cobb-Douglas technologies with respective labor and capital. Again in this set up, the elasticity of substitution between capital and both kinds of labor is equal to one, and the elasticity of substitution between skilled and unskilled intermediates is 1.67. Yet another option is that skilled and unskilled intermediates are modeled to be produced with linear technologies using skilled and unskilled labor, respectively, but the firm's final good is produced with a nested CES (capital interacts through a CES technology with the CES aggregate of intermediates). In this case, while the elasticity of substitution between skilled and unskilled intermediates is 1.67, their substitution elasticity with capital is no longer restricted to 1; it can be varied over a reasonable range.

Table Appendix B.1: Quantitative Results - Changes between Autarky and Free Trade

	Autarky	Free Trade (Trade cost=0)	% change relative to autarky
Offshoring	0	0.240	
	Overall		
Relative Employment of Skilled Labor	0.43	0.51	19
Relative Wage of Skilled Labor	1.68	2.01	20
Skilled Employment	0.30	0.33	10
Unskilled Employment	0.70	0.64	-9
Skilled Wage	0.60	0.93	55
Unskilled Wage	0.35	0.46	31
Output	0.586	1.090	86
	H-O Channel		
Skilled Intermediates/ Unskilled Intermediates	0.929	1.280	38
	Technology Channel		
Equipment capital employed to produce skilled intermediates	0.109	0.179	65
Equipment Capital	0.128	0.209	64
Equipment Capital/Labor	0.128	0.215	68
Innovation	0.076	0.134	77
Varieties	1.518	1.915	26

Table B.2: Counterfactual Results - Moving from Autarky and Free Trade

	Panel A: Baseline Model		
	(A1)	**(A2)**	**(A3)**
	Autarky	Free Trade (Trade cost=0)	Percentage change
Employment Ratio	0.429	0.511	19.33
Wage Ratio	1.678	2.005	19.49
	Panel B: Counterfactual 1 (No capital skill complementarity)		
	(B1)	**(B2)**	**(B3)**
	Autarky	Trade with no capital skill complementarity	Percentage change
Employment Ratio	0.429	0.457	6.53
Wage Ratio	1.678	1.791	6.31
	Panel C: Counterfactual 2 (No increase in innovation relative to autarky)		
	(C1)	**(C2)**	**(C3)**
	Autarky	Trade with innovation constant at autarky level	Percentage change
Employment Ratio	0.429	0.492	14.69
Wage Ratio	1.678	1.933	15.20
	Panel D: Counterfactual 3 (Technology Channel Shut Off)		
	(D1)	**(D2)**	**(D3)**
	Autarky	Trade with technology channel shut off	Percentage change
Employment Ratio	0.429	0.414	-3.50
Wage Ratio	1.678	1.627	-3.04

Table B.3: Counterfactuals for Firms With Different Characteristics

Change in Offshoring from 0 (1974) to 0.19 (2005)				
		Total percentage change	% of total change explained by capital skill complementarity	% of total change explained by increase in innovation
More skill intensive (Share in production of skilled intermediates=0.7)	Employment Ratio	12.40	44.95	21.50
	Wage Ratio	12.12	42.35	20.19
More unskilled (Share in production of differentiated goods=0.6)	Employment Ratio	12.38	82.55	28.53
	Wage Ratio	13.65	81.19	31.57
More susbtitutable imported intermediates (Elasticity=7.69)	Employment Ratio	18.89	56.73	11.20
	Wage Ratio	19.42	56.23	10.92
More expensive innovation (Fixed cost of entry=0.9)	Employment Ratio	15.12	76.49	24.44
	Wage Ratio	14.99	74.24	23.68

Predictions for Industries with Different Characteristics

I consider the model's predictions for firms with characteristics different from the baseline. I consider firms with four specific characteristics: more skill intensive (also less capital intensive) ($1-\mu=0.7$), more unskilled intensive ($\lambda=0.6$), domestic intermediates more substitutable for imported intermediates ($\frac{1}{1-\sigma}=7.69$), and higher cost of innovation/entry ($\psi=0.9$). I solve for the steady states corresponding to 1974 and 2005, and do the counterfactual experiments for these industries. The results are presented in Table B.3. In all cases, employment and wage ratios increase substantially when offshoring increases from 0 to 0.19. While the contributions of the technology channel to these changes in the employment and wage ratios continue to be large, the magnitudes differ across firms with different characteristics.

Alternative Model With Only H-O Channel

To compare the relative welfare implications of the models with and without the technology channel, I write an alternative model that captures only the H-O channel and recalibrate it to the data. I briefly describe the model and the calibration below.

I describe the economy in the North first. In every period there is a fixed mass of firms, indexed by $i \in (0,1)$. These firms produce final products $g_t(i)$ in period t with the following technology:

$$g_t(i) = K_t(i)^{\mu}(I_{ut}(i)^{\sigma} + M_{ut}(i)^{\sigma})^{\frac{\gamma}{\sigma}} I_{st}(i)^{1-\mu-\gamma} \tag{B.47}$$

where K_t is capital, and I_{ut} and I_{st} denote unskilled and skilled intermediates that are produced by perfectly competitive firms with linear technologies using only unskilled and skilled labor, respectively. The final good producing firms take the rental rate on capital, R_t, and the prices, p_{ut} and p_{st}, of unskilled and skilled intermediates, as given. The unskilled intermediates can also be offshored to the South for a price, p^*_{ut}. These imports are denoted by M_{ut}. The final good and intermediate good producing firms face the standard profit maximization problems.

The households aggregate the firm level goods into a composite (numeraire) good, Y_t before using it for consumption and investment. This aggregrate is given by:

$$Y_t = \left[\int_0^1 g_t(i)^{\omega}\, di\right]^{\frac{1}{\omega}} \quad ,\omega < 1 \tag{B.48}$$

The households solve the following problem:

$$\underset{C_t,S_t,U_t,K_{t+1}}{\text{Max}} \mathcal{U} = \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \theta_s \frac{S_t^{1+\chi_s}}{1+\chi_s} - \theta_u \frac{U_t^{1+\chi_u}}{1+\chi_u} \right)$$

subject to

$$C_t + I_t = W_{st}S_t + W_{ut}U_t + R_tK_t \tag{B.49}$$

$$K_{t+1} = (1-\delta^K)K_t + I_t \tag{B.50}$$

While taking their decisions, households take the rental rate on capital, R_t, and the skilled and unskilled wages, W_s and W_u, as given.

The economy for the South remains the same as before. The trade balance equation also remains the same as in the baseline. The overall resource constraint in the North is:

$$Y_t = C_t + I_t + C^*_{mt} \tag{B.51}$$

where C_{mt}^* is the quantity of final composite good exported to the South.

I calibrate the share, μ, of capital in the production of firms' output at 0.3 and the share of unskilled labor, γ, at to match the skill premium of 1.6 in the data in 1974. The rest of the parameter values are the same as in the baseline model.