

Does Offshoring Lift All Boats? The Role of Induced Technology Adoption and Innovation

Manisha Goel*
The Ohio State University

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Abstract

This paper develops and evaluates a novel mechanism through which imports of unskilled intermediates (offshoring) indirectly affect the labor market by inducing skill-biased technology adoption and innovation in developed countries. Data for a panel of manufacturing industries in the United States over 1974-2005, strongly support the indirect channel with a doubling of offshoring increasing technology adoption by 13% and innovation intensity by 40%. This is the primary channel through which offshoring increases the skill premium, but also increases the employment and wage-bills of *both* skilled and unskilled workers. The labor market effects through the direct substitution of unskilled workers are small. Predictions from a formal two-country trade model are consistent with these empirical results. A model with only the direct channel yields smaller gains for both groups of workers and higher inequality between them.

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“Increasing numbers of Americans...perceive offshoring...as an actual or potential threat to their jobs or to their wages even if they hold onto their jobs.”

— Jagdish Bhagwati and Alan S. Blinder, 2007, Offshoring of American Jobs

1 Introduction

Offshoring¹ from the United States to developing countries grew tenfold from 1.8% in 1974 to 19% in 2005.² In recent years, offshoring has been an issue of heated political debate, amidst fears that it hurts unskilled workers by creating job losses and a more unequal labor force. Alan Blinder (2007) predicts that 22-29% of U.S. manufacturing and service jobs are offshorable over the next decade or two.³ 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 2005.⁴ International economists have linked the growth in inequality to the rise in offshoring, measured as imports of intermediate goods, through the Heckscher-Ohlin 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.

This paper proposes and evaluates a novel channel through which offshoring affects the labor market in developed countries *indirectly* by inducing technology adoption and innovation. Thus, I show that the SBTC, emphasized in the labor literature, is endogenous to offshoring, and offer a new mechanism through which trade, while amplifying the skill premium, creates wage and employment gains for *all* workers. I show, empirically and theoretically, that the impacts of offshoring on the skill-premium and skill-mix are overwhelmingly mediated through the investments in equipment and innovation; the *direct* Heckscher-Ohlin effects through substitution of unskilled labor are small. Notably, the demand for *both* skilled and unskilled workers rises in response to offshoring through these channels. Normative analysis using the model illustrates the importance of the indirect channel - a model with this channel predicts that

¹The distinction between the terms “outsourcing” and “offshoring” is blurred in the 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.”

²See Figure 1(c). 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.

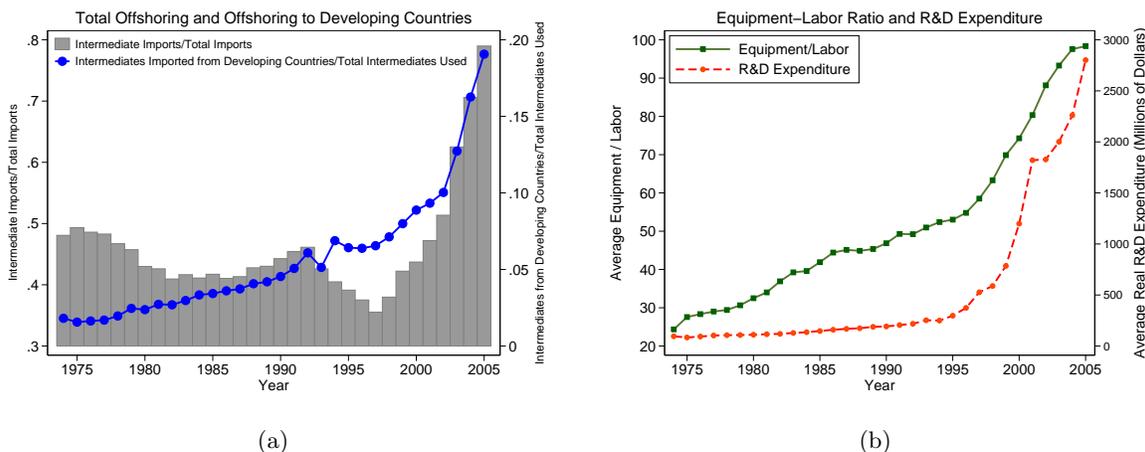
³Other empirical studies, however, find mixed evidence of the effect of offshoring on unskilled employment. See Mankiw and Swagel (2006) for a review.

⁴Autor, Katz and Kearney (2008).

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

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

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



^aSource: 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. Equipment capital stock is measured at prices that are not adjusted for changes in quality. The stock of equipment capital is divided by the total number of employed 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.

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 direct channel.

The indirect channel that I propose 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 ratio rose from about 24 points to 98 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, indirectly benefiting all U.S. workers, although magnifying the skill premium and skill upgrading.

The direct substitution of domestic unskilled labor by imported unskilled intermediates, as

⁷The 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.

predicted by the Heckscher-Ohlin theory,⁸ can trigger two effects, that constitute the indirect 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 innovations. 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 productivity, leading to an expansion in output that generates demand for *both* skilled and unskilled workers, thereby creating wage and employment benefits for all.

To empirically examine the presence of these channels and their implications for the labor market, I combine data for a panel of four-digit manufacturing industries in the United States for the period 1974-2005 (NBER-CES Manufacturing Industry database) with U.S. import and export data, using input-output tables to construct a measure of imported intermediates. I measure offshoring using the industry-specific imports of intermediate inputs from developing countries (middle- and low-income countries in the World Bank income classification).¹⁰ Focussing on imports from unskilled-labor abundant, developing countries, provides a close proxy for imported intermediates that compete with domestic unskilled labor. The key outcome variables are the skill premium, skill-mix, wage-bills of both groups of workers, innovation (measured as R&D expenditures obtained from Compustat), and capital-embodied technology adoption. To identify the exogenous variation in imported intermediates, that reflect choices of firms, I use country-specific exchange rates (obtained from the Penn World Tables), country-specific trade flows, and input-output tables to construct instruments that vary across industries and years.

⁸Grossman 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, 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.

⁹I 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.

¹⁰This measure includes all imported inputs in a given industry, regardless of whether their providers are external or affiliated with the firms in that industry.

Variations across industries and time indicate, that skill upgrading and the skill premium respond strongly to offshoring to low-income countries. My preferred set of estimates show that doubling offshoring leads to 8.6% and 9.6% increase in the relative employment and wage-bill of skilled workers, respectively. Although the wage gap between skilled and unskilled workers increases with offshoring, the total employment and wage-bills of *both* groups of workers in an industry increase, indicating that offshoring benefits *all* workers. Further, a doubling of intermediates also increases the equipment-labor ratio by 13.4% and R&D expenditures by 37.6%. Moreover, my results show that the impacts of imported intermediates on the skill premium and skill-mix are almost entirely due to increases in these technology measures and innovation - controlling for equipment-labor ratio and R&D expenditures yields a small and insignificant coefficient on imported intermediates. Thus, the indirect channel dominates the direct channel.¹¹

To quantify the indirect channel and assess its normative theoretical implications, 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 offshored intermediates are highly, but not perfectly, substitutable for domestically produced unskilled intermediates (unlike previous theoretical work, but consistent with my empirical results).¹² Production of a new good requires innovation. Both innovation and skilled intermediates require skilled labor and skill-complementary capital.

The key theoretical implications of the model are qualitatively consistent with the empirical results. Beyond offering a theoretical explanation for my results, the model allows me to decompose various parts of the indirect channel. These decompositions show that 81% of the total increase in the skill-premium due to offshoring between 1974 and 2005 is explained by the adoption of skill-complementary technology, with 22% explained by increased innovation.

Finally, I show the welfare implications of the indirect channel. A calibrated model with only the direct channel yields lower output and wages for skilled and unskilled labor than in the model with the indirect channel. The unskilled wage, in particular, is especially lower than in the model with the indirect channel. Moreover, inequality between the two groups is higher in the model with only the direct channel. This indicates that through the indirect 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 details the empirical strategy. Section 4 describes the data sources and presents some descriptive statistics. The empirical results are presented in section 5. Section 6 develops a

¹¹Although my empirical analysis is restricted to manufacturing industries for reasons of data availability, the mechanism that I propose is more widely applicable to industries in other sectors of the economy.

¹²The reason for this difference from the previous literature is the empirical finding 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.

general equilibrium model that captures the direct and indirect channels that are evident in the data. Section 7 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 indirect channel. The last section concludes.

2 Contribution to Related Literature

A growing literature examines the implications of offshoring for labor markets in advanced countries. In particular, studies have found that imports of unskilled intermediates increase 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 direct effects of offshoring that work through the Heckscher-Ohlin forces. But, as I show, offshoring may also increase the skill premium indirectly by inducing innovation and technology adoption. To my knowledge, this is the first study to consider the impact of offshoring on skill-biased technology adoption.

Methodologically, my empirical work complements that of Feenstra and Hanson (1999), who use a two-step estimation strategy to assess the impact of offshoring on wage-bill shares of skilled workers in U.S. manufacturing industries. In the first stage, they regress changes in effective productivity and value added prices on various structural variables, including offshoring and high-technology capital. In the second stage, they decompose changes in factor prices (in particular, the wage-bill shares of non-production workers) into distinct shares attributable to offshoring and purchases of high-technology capital. This methodology does not address the endogeneity of imports and high-technology capital in the equations for factor prices. In my estimation strategy, instead of employing this two-step procedure, I adopt a fixed-effects, instrumental variables strategy in order to identify the exogenous variations in imported intermediates and purchase of equipment capital. Also, I establish that there is a causal relationship between equipment capital purchase to offshoring. Further, the measure of offshoring used by Feenstra and Hanson (1996, 1999) was imported intermediates from all countries, regardless of their stage of development. However, skill-intensive intermediate inputs from skill-abundant countries may not substitute for the unskilled workers employed in domestic firms. In my empirical analysis, I measure offshoring by including imports only from developing countries.

The evidence on the employment impact of offshoring is mixed. Theoretically, the presumption is that imported unskilled intermediates perfectly substitute for domestic unskilled intermediates. In this environment, while a direct 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. The latter “productivity effect,” first suggested by Grossman and Rossi-Hansberg (2008), 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, Landefeld and Mataloni (2004)). My empirical findings suggest that imports of unskilled intermediates have a large positive impact on the total employment of unskilled workers in U.S. manufacturing industries. Further, my results indicate that this positive impact is not only because of the productivity effect but also because imports substitute imperfectly for domestically produced intermediates.

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. I also provide empirical evidence that R&D investment increases in response to a rise in offshoring. This empirical analysis complements the largely theoretical analyses of Glass and Saggi (2001) and Rodriguez-Clare (2010).

This paper also relates to the large literature on skill biased technological change. Many previous studies analyzing the increase in the skill premium in the United States and other OECD countries argue that SBTC is the primary cause and that trade plays a secondary role. Katz and Murphy (1992), and Berman, Bound and Griliches (1994), among others, argue 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.¹³ However, 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 “trade versus SBTC” debate by showing that skill-biased technology adoption is driven by trade. Imports of intermediates induce industries to innovate and adopt skill-biased technology. 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.¹⁴

¹³Several other observations have led scholars to conclude that trade is not an important factor underlying the rising skill premia in the developed countries. 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.

¹⁴A 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).

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 indirect 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 Strategy

I first describe the strategy to estimate the total impact of offshoring on skill-upgrading, the skill premium, and the absolute wage payments to skilled and unskilled workers. Next, I focus on the outcomes of the indirect channel. Specifically, I describe the strategy to estimate the effect of offshoring on innovation, technology adoption, the number of varieties, and their aggregate prices. Finally, I explain the strategy to parse out the distinct contributions of the two channels to the total effects of offshoring on absolute and relative wages.

3.1 Effects of Offshoring: Direct and Indirect Channels

My first objective is to analyze how the skill premium,¹⁵ skill-mix, and wage-bills of unskilled workers are impacted by increases in intermediate goods imported from developing countries. For this purpose, I estimate the following fixed effects regressions:

$$\ln \left(\frac{S}{U} \right)_{jt} = a_1 \ln M_{jt}^{\text{low}} + b_t + c_j + \epsilon_{1jt} \quad (3.1)$$

$$\ln \left(\frac{WB_s}{WB_u} \right)_{jt} = a_2 \ln M_{jt}^{\text{low}} + b_t + c_j + \epsilon_{2jt} \quad (3.2)$$

$$\ln WB_{ujt} = a_3 \ln M_{jt}^{\text{low}} + b_t + c_j + \epsilon_{3jt} \quad (3.3)$$

¹⁵Note that, conventionally, the skill premium is defined as the wages of skilled workers relative to the wages of unskilled workers. I follow this definition in the theoretical model. This definition is valid when labor is perfectly mobile across all firms or industries, as in the model. However, in reality, workers may not be perfectly mobile across industries. If they were perfectly mobile, we would have a unique wage-ratio across all industries. That is not substantiated in the data, suggestive of industry-specific skills or other labor market frictions. And yet, workers are not completely immobile across industries either; this would entail each industry to have a different wage-ratio uninfluenced by the wages that similar workers receive in other industries. Thus, in my empirical analysis, I measure the skill premium as the ratio of the wage-*bills* of skilled and unskilled workers, instead of wage-ratios. This alternative measure allows for some, but not perfect, mobility of workers across industries.

In the above equations, M_{jt}^{low} denotes all intermediate goods imported from developing or low-wage countries and used as inputs in industry j in year t . $M_{jt}^{\text{low}} = \sum_{k=1}^n r_{jkt} * Q_{jt} * \left(\frac{\text{Imp}_{kt}^G}{Q_{kt} + \text{Imp}_{kt} - \text{Exp}_{kt}} \right) / X_{jt}$, 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 . As constructed, the measure of imported intermediates corresponds to the “broad measure of foreign outsourcing”¹⁶ developed by Feenstra and Hanson (1999). The employment ratio, $(\frac{S}{U})_{jt}$, and the wage-bill ratio, $(\frac{WB_s}{WB_u})_{jt}$ are the measures for within-industry skill-mix and skill premium, respectively. To consider the absolute outcomes for unskilled workers, I consider the impact of imported intermediates on WB_{ujt} , as shown in equation 3.3. Other outcome variables that I examine are the total employment of unskilled workers, the wage-bill and employment of skilled workers and gross industrial output. All variables are in natural logarithms. Additionally, the regressors also include time and industry fixed effects denoted by b_t and c_j , respectively.

3.2 The Indirect Channel

To quantify the effects of offshoring via the indirect channel, I estimate regressions with the same set of regressors as above, but innovation and technology adoption (measured by the real capital stock, or capital relative to labor) as the outcomes. Thus, I estimate the following regressions:

$$\ln \left(\frac{K}{L} \right)_{jt} = a_4 \ln M_{jt}^{\text{low}} + b_t + c_j + \epsilon_{4jt} \quad (3.4)$$

$$\ln \text{RD}_{jt} = a_5 \ln M_{jt}^{\text{low}} + b_t + c_j + \epsilon_{5jt} \quad (3.5)$$

Here, $(\frac{K}{L})_{jt}$ is the real value of capital stock relative to the total number of workers employed and reflects embodied technology adoption in the industry. RD_{jt} , is the real R&D expenditure in industry j in year t and is a measure of the innovation activity performed in an industry. Again, consistent with the indirect channel, I expect the coefficients on imports in both the equations to be positive.¹⁷ Alternative outcome measures are real capital stock (for technology adoption), and R&D intensity (for innovation).

To delve further into the indirect channel, I analyze the effects of imported intermediates

¹⁶The narrow measure of foreign outsourcing is obtained by considering only those inputs that belong to the same two digit industry as the one to which the output industry belongs. This measure captures offshoring of only those production activities that could have been performed within the same two-digit industry domestically.

¹⁷I also estimate specifications in which I include the industrial output as an additional control variable. The resulting estimates for the coefficients on imports are close to those obtained from regressions that do not control for output.

on real final goods prices and the number of varieties. I expect a rise in the number of varieties and the prices of these goods. To assess the effect of offshoring on final goods prices, I estimate regressions similar to those described above. However, the number of varieties produced within each industry is a count variable. Hence, a non-linear estimation is required. I estimate a FE Poisson regression model for this purpose.

Since imports may be correlated with disturbances in these equations, the above fixed effects (FE) regressions will give biased and inconsistent estimates of the impact of imports on the outcome variables. Ex ante, the direction of bias is unclear, with both upward and downward bias possible. For instance, an unobserved technology shock may make some capital equipment cheaper for an industry. This equipment may make it cheaper to perform some tasks domestically rather than offshore them. Such shocks will reduce intermediate imports and increase the relative employment and wages of skilled workers. In this case, our estimates will be biased towards zero. Alternatively, policy changes, such as an increase in the real minimum wage, may increase the relative wages of unskilled labor, making it more expensive for industries to employ unskilled labor. Such a policy may simultaneously increase the relative employment of skilled labor and offshoring, biasing the estimated coefficient on imports upwards. Other factors, like demographic and policy changes, may also bias the coefficient estimates in either direction. Moreover, the imported intermediate input measure are constructed from raw data as described earlier and hence potentially includes some measurement error leading to attenuation bias.

To address these biases, I use fixed effects with instrumental variables (FE-IV). Following Revenga (1992), I construct source-weighted industry nominal exchange rates. These are constructed as the natural logarithm of the weighted geometric mean of the nominal exchange rates of source countries vis-a-vis the U.S. dollar. The weights used are the shares of each source country in the total U.S. imports in a given industry in 1980. I average these industry exchange rates over all inputs used in an industry (weighted by the average direct requirement coefficient of each input used in the industry over the entire sample period). These exchange rate constructs vary over years and four-digit industries. Exchange rates determine import prices and, thus, are highly correlated with imported intermediates used in the U.S. industries.

The validity of these instruments is also plausible for two reasons. First, to the extent that exchange rates are influenced mainly by macroeconomic factors rather than by industry-level shocks, they are likely to be independent of the unobservable industry-year variations in my dependent variables. This is especially plausible since the specifications include industry and year fixed effects. Second, using static country-specific weights, and weighting the observations by constant industry size, avoid the possibility that instruments may be endogenous due to joint determination of import shares of countries and exchange rates in any given year.¹⁸

¹⁸Tariff rates imposed by the U.S. on imports from foreign countries can also be used as instruments. Instrumental variables using tariff rates are constructed following the same approach as described above for exchange rates.

3.3 Decomposing Contributions of the Direct and Indirect Channels

To isolate the indirect effects of offshoring from those via the direct channel, I control for the variables that change in the indirect channel. In this specification, the coefficient on imports is an estimate of the effect of an increase in offshoring on the outcome variable via only the direct channel. The difference between these and the former set of estimates provides a measure of the impact of the indirect channel.

While I do not have instruments to identify the exogenous variations in all control variables, I use the ratio of the lagged price index for investment as an instrument for capital-labor ratio,¹⁹ which should result in smaller estimates of the coefficients on imports in the following regressions:

$$\ln \left(\frac{S}{\bar{U}} \right)_{jt} = a_6 \ln M_{jt}^{\text{low}} + q_1 \ln \left(\frac{K}{L} \right)_{jt} + b_t + c_j + \epsilon_{6jt} \quad (3.6)$$

$$\ln \left(\frac{WB_s}{WB_u} \right)_{jt} = a_7 \ln M_{jt}^{\text{low}} + q_2 \ln \left(\frac{K}{L} \right)_{jt} + b_t + c_j + \epsilon_{7jt} \quad (3.7)$$

$$\ln WB_{ujt} = a_8 \ln M_{jt}^{\text{low}} + q_3 \ln \left(\frac{K}{Y} \right)_{jt} + b_t + c_j + \epsilon_{8jt} \quad (3.8)$$

But these regressions underestimate the quantitative impact of the indirect channel as the other variables are not held fixed. I expect the estimated coefficients on capital-labor ratio in these equations to be positive, reflective of capital-skill complementarity. It is noteworthy that in the equations for wage-bills and employment of skilled and unskilled workers, the control used for technology adoption is $\left(\frac{K}{Y}\right)_{jt}$. The ideal control, instead, is $\left(\frac{K}{L}\right)_{jt}$. However, using this measure creates a division bias. Again, this may result in underestimation of the impact of the indirect channel on these outcomes variables.

I weight each industry-year observation by the square root of the average share of the industry in the total wage-bill of U.S. manufacturing industries over the sample period. These static weights control for any sectoral shifts and changes in industry size that may have occurred over the period, which can otherwise potentially influence the exchange rates used as instruments.²⁰ The standard errors are robust to arbitrary heteroskedasticity and are clustered at the level of four-digit industries.

I measure offshoring as the shift of some fraction of the production tasks to a foreign country,

¹⁹The data provide me with a price index for investment, but not for capital stocks. Since changes in the current cost of investment may affect future capital stocks, I use the lagged price index of investment to construct the instrument. Further, I only present results that use one year-lagged values of this index as the instrument. I estimated regressions using upto four lags of this index as instruments. After the first lag, the future lags become insignificant. The results obtained are also qualitatively similar. The validity of this instrument is plausible because the cost of purchasing physical capital affects the outcome variables in these regressions only through its effect on the the demand for capital. Hence, conditional on including the capital-labor ratio, it is valid to exclude this instrument from the second stage regression.

²⁰As a robustness check, I also use the square root of the industry's average share in the total manufacturing output over the sample period as weights. Results using both weights are qualitatively similar.

regardless of whether the offshored activity is performed by a firm that is external or affiliated to the offshoring firm. This is consistent with the definitions adopted by Feenstra and Hanson (1996, 1999), Grossman and Rossi-Hansberg (2008), and Rodriguez-Clare (2010), among others. However, the relocation of production tasks is no longer limited to the intermediate stages of production. Increasingly, the assembly of final goods for domestic consumption also takes place offshore. Thus, the extent of offshoring is not entirely captured by measuring the imports of intermediate goods. To the extent that imported intermediates do not capture the entire extent of offshoring activity, the results in this paper serve as lower bounds for the true effects of offshoring.

4 Data and Descriptive Statistics

4.1 Data

I combine data from several sources. In this section, I provide an overview of these data sources. More detail is available in the data appendix.

U.S. Imports and Exports

Highly disaggregated U.S. imports and exports data are available from the Center for International Data at the University of California, Davis. The data on manufacturing industries are classified according to 4-digit SIC 1987 codes. I first aggregate the imports (exports) data to four-digit imports (exports)-based Standard Industrial Classification (MSIC (XSIC))²¹ (1987) using various concordances. Next, I follow the method developed by Feenstra, Romalis and Schott (2002) to bring these imports and exports to the (domestic) SIC 1987 classification. After this conversion, there still are some industries (in the domestic SIC 1987 classification) for which there are no imports or exports (see Feenstra, Romalis and Schott, 2002, for details). Additionally, there are some industries in which imports and/or exports are reported for certain years but do not appear in the data in some other years.²²

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 combined the high-income OECD and non-OECD countries into the group of high-income countries. Similarly, I combined the other three groups into the group that I refer to as low-wage (income) or developing countries. In my analysis, I make a distinction between the imports coming from high-income countries and those coming from low-income countries. Imports values used in the

²¹As detailed in Feenstra, Romalis and Schott (2002), MSIC and XSIC differ from domestic-based SIC because the latter often depends on the method of processing used to manufacture the good which is not known for imports or exports. Thus, no imports or exports are reported for a few SIC categories.

²²These include SIC classifications 2024, 2141, 2259, 2387, 2512, 2732, 2791, 3263, 3273, 3322, 3365, 3451, 3462, 3645, 3731, 3761, 3769, 3953 and 3995.

analysis are the c.i.f. (cost, insurance, freight) values of imports for consumption.²³ The c.i.f values are available only after 1973.

Industrial Characteristics

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).²⁴ Employees are classified as production and non-production workers. I consider non-production workers as high skilled and production workers as low skilled.²⁵ 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. The industrial classification changed in 1997 from the Standard Industrial Classification to the North American Industrial Classification System (NAICS). The NBER database provides a uniform SIC 1987 classification over all the years by concurring the two classification systems. But, as described in Feenstra, Romalis and Schott (2002) the change in industrial classification does not yield a clean concordance; i.e., the mapping is not always one-to-one. This affects some industry definitions. Observing the raw data shows that for some industries there are substantial differences in the employment or wage ratios, amongst other variables, between 1996 and 1997 after which the series follow similar trends as before. This is chiefly attributable to altered industry classifications. To control for this change in industrial classification, in all the regressions I include a vector of interactions of 2-digit industry dummies with an indicator for whether the year is before or after 1997 (the year of the classification change).²⁶ The last year for which these data are available is 2005.

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. Keeping only the firms legally incorporated in the U.S., 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. To the extent that innovation activity is also performed in the unincorporated firms in the country, these data provide lower bounds for the total innovation expenditures incurred in the 4 digit industries. Note that this measure of R&D primarily reflects product innovation. According to the documentation for Compustat, the R&D expenditures include all costs incurred to develop

²³General imports are a better measure of imports. However, until 1994, only the consumption values of imports are available.

²⁴The NBER database includes variables from yearly rounds of the Annual Survey of Manufactures.

²⁵Berman, 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.

²⁶As a robustness check, I estimate all regressions with data only until 1996 so that I have a uniform industrial classification throughout the sample period. Results are qualitatively similar to those obtained using the full sample.

new products and services but excludes the costs to improve the quality of existing products. Thus, this measure captures all expenditures 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).²⁷

Input-Output Tables

In order to assign imports as inputs into the manufacturing industries, I use the direct requirement coefficients in the benchmark input-output tables available from the Bureau of Economic Analysis.²⁸ 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.²⁹ 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.³⁰ 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.

Exchange Rates

The exchange rate data needed to construct instruments for the potentially endogenous import variables are obtained from the Penn World Tables. These tables provide data on nominal exchange rates for all countries vis-a-vis the U.S. dollar. As an alternative to exchange rates, I also use tariffs to construct instruments in order to identify the exogenous variation in imported intermediates. Average industry level tariff rates imposed by the U.S. on commodities imported from various countries are calculated from the U.S. imports data files (available from the Center for International Data, University of California, Davis) as $100 * \frac{\text{Total Duties Paid}}{\text{Total Customs Value of Imports}}$ for all imported product categories belonging to each 4 digit SIC (1987) industry.

In my final sample, I have 14563 observations on 459 four-digit SIC 1987 industries spanning 32 years from 1974 to 2005.³¹ 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.

²⁷Patents 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.

²⁸I establish concordances between the SIC 1987 codes and the industry codes that are different for each year of the input-output tables.

²⁹These coefficients are not directly available for 1972 and 1977 and need to be computed.

³⁰Voigtlander (2011) shows that the use values of inputs in various industries are quite stable over time. So it is reasonable to linearly interpolate the direct requirement coefficients for the interim years and extrapolate for the years 2003-2005.

³¹No import data are available for some industries in a few years.

4.2 Descriptive Statistics

It is highly informative to see the patterns in the data that help us relate the changes in industrial characteristics to the growth in offshoring. I begin by documenting several trends that reveal the growing importance of various developing countries in U.S. imports. Next, I show how various characteristics of U.S. manufacturing industries have evolved over time as the extent of offshoring increases.

Patterns in U.S. Imports

Figure 1 showed the growth in the share of U.S. imports from developing countries as a whole. This growth is not a result of rising imports from just one or two developing countries. The first graph in Figure 2 plots the shares of different (income) groups of countries in the total final good imports of the United States. The second graph plots the corresponding shares for the intermediate good imports. It is evident that the final and intermediate goods imported from lower-middle income countries (including China) grew the most, followed closely by those from upper-middle income countries. Although the share of OECD countries continues to be the largest, it fell sharply from around 70% (75%) to nearly 50% (45%) of all final (intermediate) good imports. The share imported from high income non-OECD countries has been almost constant after falling slightly until the mid-1980s. The U.S. imported only a negligible share from low-income countries.

Table 1 shows the top 20 exporting countries for the years 1975, 1990 and 2005, and their shares in total U.S. imports. In each year, the developing countries are in boldface. The number of developing countries among the top exporters increases over time. While China did not even appear in the top 20 countries in 1975, in 2005 it accounted for the largest share of imports of the U.S. (18%), displacing Canada and Japan from their top positions in 1975 and 1990, respectively. The shares imported from other developing countries like Mexico, Brazil and Thailand also increased considerably. In contrast, the shares of the advanced countries like Canada, Germany, and the United Kingdom fell overtime.

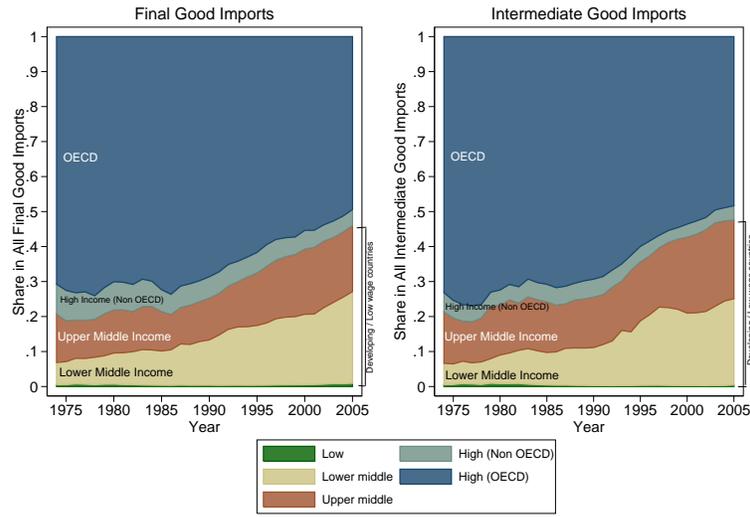
Industrial Trends

Figure 3 shows the rising skill-premia and skill upgrading in manufacturing.³² The figure plots the (weighted) average ³³ wages and employment of non-production workers relative to production workers over the 32-year period from 1974 to 2005. The relative wages of skilled (non-production) workers grew from 1.55 in 1974 to more than 1.69 in 2000, but then they declined to 1.59. Even as the relative wages of skilled workers grew, the industries upgraded

³²The rise in the relative wages and employment of non-production workers in U.S. manufacturing industries is very well established.

³³The average (over the sample period) shares of the industries in the total manufacturing output of the economy are used as weights.

Figure 2: Shares of Income Groups in Final and Intermediate Good Imports^a



^aSource: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, World Bank Income Classification. 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.

Table 1: Top Twenty Exporters of Manufactured Goods to United States

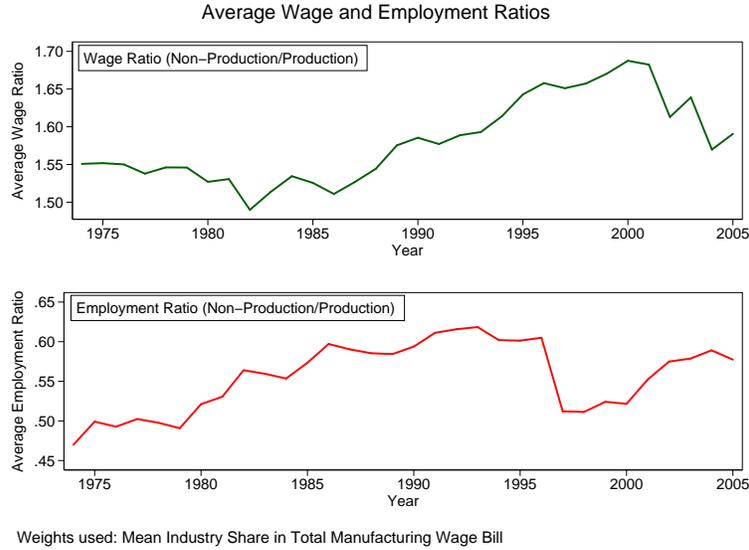
1975		1990		2005	
Country	Share*	Country	Share*	Country	Share*
Canada	23.02	Japan	21.36	China	17.79
Japan	17.12	Canada	18.24	Canada	14.84
Germany	7.86	Germany	6.50	Japan	9.61
United Kingdom	5.15	Taiwan	5.51	Mexico	9.54
Italy	3.60	Mexico	4.94	Germany	5.73
Taiwan	2.98	South Korea	4.47	South Korea	3.08
France	2.87	United Kingdom	3.94	United Kingdom	3.05
Mexico	2.59	China	3.48	Taiwan	2.43
Belgium/Luxembourg	2.36	Italy	3.03	Malaysia	2.36
Hongkong	2.32	France	2.87	France	2.18
Venezuela	2.26	Singapore	2.25	Italy	2.15
South Korea	2.15	Hongkong	2.24	Ireland	1.95
Netherlands Antilles/Aruba	1.70	Brazil	1.75	Brazil	1.56
Australia	1.51	Thailand	1.16	Thailand	1.34
Netherlands	1.44	Malaysia	1.15	India	1.30
Bahamas	1.28	Sweden	1.15	Israel	1.15
Sweden	1.27	Belgium/Luxembourg	1.08	Venezuela	1.00
Spain	1.23	Netherlands	1.06	Singapore	0.99
Brazil	1.14	Switzerland	1.00	Russia	0.97
Switzerland	1.10	Venezuela	0.96	Sweden	0.95

Notes: *: Share of country in total imports of the U.S.

Bold indicates developing country

their skill-mix. The average employment ratio increased from 0.46 to 0.54 over the same period, except during the late 1970s and mid-1990s.³⁴

Figure 3: Rising Relative Wages and Employment of Skilled Workers^a



^aSource: NBER-CES Manufacturing Industry database. The top figure plots the ratio of average annual wages of non-production to production workers. The bottom figure plots the ratio of number of non-production to production workers employed. Both ratios are averaged over all 4 digit SIC (1987) industries.

Capital used in manufacturing industries also rose relative to labor. Until the mid-1990s this upward trend was driven mainly by equipment, with structures remaining nearly constant relative to labor. However, as offshoring picked up in the mid-1990s, both components accelerated.

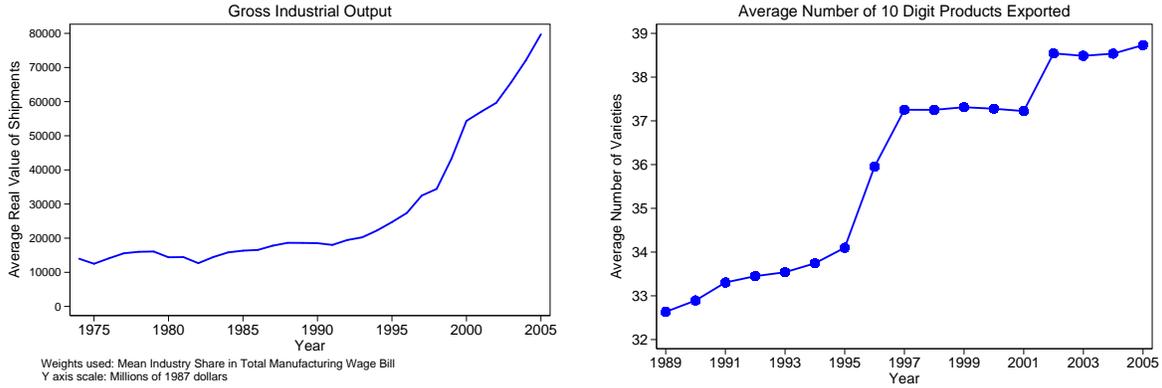
The average real value of industrial shipments has uniformly risen over the sample period, accelerating after the mid-1990s when offshoring starts rising rapidly (Figure 4). The total output of an industry is the aggregate of the output of each product or variety produced within that industry. In the absence of firm level data, I do not have a precise measure for the number of varieties produced in an industry. One proxy for the number of varieties produced is the number of ten-digit exported product categories in each 4-digit industry. The number of exported varieties may be less than the total number of varieties produced domestically. Also, the product classification changes over time.³⁵ To minimize changes in classification, I construct the number of varieties exported for only the post-1988 period. The maximum number of exported varieties in an industry increased from 302 in 1990 to 398 in 2005. The

³⁴The break in the relative employment series between 1996 and 1997 is because of the change in the industrial classification from SIC 1987 to NAICS 1997 mentioned earlier. The trends in the series before and after the break are similar, however.

³⁵Until 1988, the products were classified at the 7-digit level under the TSUSA classification. After 1988, the classification changed to HS 10-digit level. Even within these classifications, the definitions change over the years.

average trend in the number of varieties is clearly positive (see second graph in Figure 4), albeit it seems to rise in discontinuous jumps. These jumps may be an artifact of changing definitions of product categories.

Figure 4: Rising Output and Average Number of Products^a



^aSource: NBER-CES Manufacturing Industry database. Figure 5(a) plots the real value of annual shipments averaged over all 4 digit SIC (1987) industries. Figure 5(b) plots the total number of 10-digit product categories (under the Harmonized System classification) exported by U.S. manufacturing industries.

Table 2 presents the average characteristics of two-digit industries for the years 1975 and 2005 along with the average intermediate imports from developing countries within each industry.³⁶ For both the years, I also rank the industries in decreasing order of imported intermediates. In 2005, the electronics industry (code 36) had the highest proportion of imported inputs. Even in 1975, it was second only to “miscellaneous” manufacturing (which includes jewelry, toys and sporting goods, silverware, musical instruments, office supplies etc.). Note that the proportion of imported inputs was only 2.6% for the electronics industry in 1975 but rose to 42% in 2005. Even the lowest ranking industry in 2005 (printing and publishing) had a higher proportion of imported inputs than the highest ranking industry in 1975. It is clear that all industries witnessed a dramatic increase in the extent of offshoring. Simultaneously, several characteristics of these industries changed. The high positive correlations of the employment and wage-bill ratios with offshoring in both years suggest that the industries with a higher proportion of non-production workers in their total employment and wage bill offshored more. The same is true of real R&D expenditures. In regard to the real wage-bills of production workers, while the correlation was negative in 1975, it is positive and large in 2005. In both years, the industries that are more high-tech (i.e. have a higher equipment to labor ratio) offshore less to low income countries. However, but the sharp decline in this negative correlation from -0.24 in 1975 to -0.08 in 2005 suggests that, over time, increasingly more high-tech industries are importing their intermediate inputs.

³⁶The intermediate imports are reported as a percentage of the non-energy materials used in an industry.

Trends in Exchange Rates and Tariffs

Finally, a brief note on the trends in the source weighted industry exchange rates and tariff rates. These are the instrumental variables I use to identify the exogenous variation in the imported intermediate goods measure. On average, the U.S. dollar appreciated vis-a-vis the currencies of developing countries over time. Moreover, there was substantial variation in these exchange rates within each year with considerably more spread after 1997. These trends reflect the liberalization of their trade regimes by several developing countries over this time period. On the other hand, the U.S. tariffs on the imports from these countries were low on average and their spread fell throughout the time span. The mean tariff rate fell by about 6 percentage points and the range in any given year was never more than 8 to 9 percentage points. The variation in tariffs is considerably smaller after 1997.

5 Empirical Results

Using the empirical strategy described in section 3, I now present results that provide evidence that the industrial trends described in the previous section are causally related to increased offshoring by U.S. manufacturing industries. First, I briefly describe the results obtained from fixed effects (FE) regressions. Next, I describe the results obtained from fixed effects - instrumental variables (FE-IV) regressions. Lastly, I decompose the direct and indirect effects of offshoring on the real and relative employment and wages of skilled and unskilled workers.

5.1 Fixed Effects Estimates

Table 3 presents the FE estimates of the effects of offshoring on several outcome variables. The results are categorized on the basis of whether I expect the dependent variables to be influenced via the indirect channel only or also in the direct channel. The employment and wage-bills ratios (and levels) of non-production to production workers are affected via both the channels. In the direct channel, the relative wages and employment of non-production workers are expected to rise as offshoring unskilled inputs causes a shift towards skilled tasks. In the indirect channel, these ratios rise due to capital-skill complementarity and increased innovation. Consistent with this intuition, Table 3, columns 1 and 2, show that offshoring is positively associated with employment and wage ratios. The levels of employment and wage-payments to both groups of workers also rise via both channel due to cost-savings and expansion of output (see columns 3 to 6). Gross output is also affected by both channels - directly because firms' outputs rise with offshoring, and indirectly because the number of firms within industries also increases. The positive coefficient on imports in column 7 is consistent with this intuition. The indirect channel relies on offshoring leading to higher R&D investment and technology adoption. Furthermore, I expect prices to be positively correlated with offshoring (because of increased variety). For the indirect channel (Table 3, columns 8 to 10), all coefficients except for R&D and equipment-labor ratio is in line with expectations.

Table 3: Fixed Effects Estimates for Various Outcome Variables

	Both Channels						Indirect Channel				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9a)	(9b)	(10)
	Employment Ratio ¹	Wage Bill Ratio ¹	Non-Production Wage Bill	Non-Production Employment	Production Wage Bill	Production Employment	Gross Output	R&D ²	Equipment	Equipment / Labor	Price ³
Imported Intermediates ⁴	0.009 (0.007)	0.010 (0.008)	0.013 (0.013)	0.015 (0.013)	0.003 (0.013)	0.005 (0.013)	0.004 (0.025)	-0.138*** (0.043)	0.007 (0.015)	-0.003 (0.012)	-0.003 (0.018)
Observations	14,569	14,568	14,568	14,569	14,570	14,570	14,570	13,746	14,570	14,570	14,570
R-squared	0.259	0.326	0.122	0.162	0.272	0.302	0.260	0.124	0.587	0.762	0.348
Number of 4 digit industries	459	459	459	459	459	459	459	456	459	459	459

Notes:

*** p<0.01, ** p<0.05, * p<0.10

¹: Ratios are for non-production workers relative to production workers.

²: Real R&D Expenditure for the firms for which data on R&D expenditure are available.

³: Price Index for industry deflated by U.S. CPI.

⁴: As a proportion of total non-energy materials used in the industry.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996. Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries. All variables are in natural logs.

Though largely qualitatively supportive of the mechanism, the coefficients estimated from the fixed effects regressions are small in magnitudes and likely to be biased because of endogeneity and measurement error as discussed in section 3. Thus, these coefficients do not have a causal interpretation. The negative coefficients in the equations for capital and equipment relative to labor may just be reflecting the pattern that more high-tech industries offshore less, as shown in Table 5.³⁷To address endogeneity and attenuation bias, I turn to FE-IV estimates.³⁸ This approach provides me with consistent estimates of the causal effects of offshoring on the variables of interest.

5.2 Fixed Effects - Instrumental Variables Estimates

First Stage Results

I use contemporaneous and lagged exchange rate constructs as IVs for imports.³⁹ Results from the first stage estimates from various specifications are presented in Table 4. From columns 1 to 3, I successively increase the number of lags of exchange rates. While the contemporaneous and one year lagged exchange rate is significant, the two years lagged exchange rate is not. The coefficients on the exchange rates in these three specifications are economically and statistically highly significant. Also, they reveal the familiar J-curve effect (see, for example, Guadalupe and Cunat (2009)). Immediately after an appreciation of the U.S. dollar vis-a-vis another currency (ie, an increase in the exchange rate), imports become cheaper. But the quantity of imports demanded rises only after some time has elapsed. Thus, we see that the total dollar value of imports falls in the first year, but rises thereafter. In all three specifications, the F-statistic is well above ten indicating that the instruments are powerful predictors of imported intermediates.

³⁷I also regress employment and wage-bill ratios, respectively, on imported intermediates, controlling for the variables expected to change only as part of the indirect channel. As explained in section three, this would be an appropriate strategy to parse out the quantitative effects of imports on employment and wage-bill ratios via the two channels only if the control variables were exogenous. But here, all the regressors are endogenously chosen by the firms belonging to these industries. Thus, the estimates do not reflect causal effects. The coefficients are also small and statistically insignificant as in Table 3.

³⁸Measurement error in the dependent variable does not bias the estimates of the coefficients on the regressors. However, the standard errors are larger. Also, the IV strategy corrects for measurement error in the constructed variable denoting imported intermediates under the condition that the error is classical, i.e., errors are independent of truth, have a mean of zero and a constant variance.

³⁹In other specifications (not reported), I use lagged tariffs as instruments. Following Guadalupe and Cunat (2009), I do not include contemporaneous tariffs as they may be endogenous with industrial characteristics due to political economy reasons. However, in these specifications, the coefficients do not match my expectations; an increase in tariffs imposed by United States on imports from foreign countries makes imports more expensive. So over time I expect to see a fall in imports. However, the coefficients are positive, suggesting a rise in the value of imports even after two years. The reason for such estimates is not quite clear. I expect the imports to respond similarly to prices, regardless of whether the price change occurs because of a change in exchange rates or a change in tariffs. The small range over which these tariffs vary across years and industries, as described in the previous section, may be driving this result. Further, including both exchange rates and tariffs, I find a similar pattern.

Table 4: FE-IV Estimation - First Stage

Dependent Variable: Imported Intermediates¹			
Exchange Rate	-0.197*** (0.038)	-0.272*** (0.044)	-0.287*** (0.057)
One Year Lagged Exchange Rate		0.109*** (0.042)	0.098*** (0.030)
Two Years Lagged Exchange Rate			0.052 (0.048)
Observations	14,568	14,103	13,638
Number of Industries	459	459	459
F statistic ^{2,3}	26.36	19.05	14.07
Shea's Partial R-squared	0.014	0.013	0.012

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$ ¹: As a proportion of total non-energy materials used in the industry.

²: Kleibergen-Paap Wald rk F statistic with degrees of freedom = $L1 - K1 + 1$; $K1$ = no. of endogenous regressors, $L1$ = no. of excluded instruments

³: Degrees of freedom correction for F statistic = $((N - L)/L1) * ((N - 1)/N) * (N_{clust} - 1)/(N_{clust})$. So F-statistic is slightly different when the dependent variable in second stage is R&D. Reason: Sample size and number of clusters are different due to some missing observations.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996. Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries. All variables are in natural logs.

Second Stage Results

In Table 5, I present the second stage results for variables that are influenced by offshoring through both channels. Panel A identifies the exogenous variation in imports using only the contemporaneous exchange rates. Panels B and C successively include one and two lags of exchange rates. All variables are in logs. The specification with contemporaneous and one lag of exchange rates fails to reject the joint null hypothesis of instrument validity, and has the strongest first stage. Hence, the results in Panel B are my preferred estimates. I describe these estimates below.

In columns 1 and 2 of Table 5, I present the FE-IV estimates for the employment and wage-bill ratios that measure the skill-mix and skill-premia within industries. Columns 3-6 present results for the wage-bills and employment of non-production and production workers, respectively. Column 7 presents the FE-IV estimate for the gross real outputs of industries. These variables are impacted by imports via both the direct and indirect channels. Panel B shows that doubling imported intermediates within a year and industry leads to 8.6% increase in the employment ratio and 9.6% increase in the wage-bill ratio of non-production workers relative to production workers. Thus, offshoring leads to substantial increases in the relative wage-bill and employment of skilled workers. However, estimates in columns 3-6 show that both groups of workers benefit in terms of absolute wage-bill and employment. Doubling offshoring

Table 5: FE-IV Estimation Second Stage - Both Channels

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Excluded Instruments - Contemporaneous Exchange Rate							
	Employment Ratio	Wage Bill Ratio	Non-Production Wage Bill	Non - Production Employment	Production Wage Bill	Production Employment	Gross Output
Imported Intermediates	0.068 (0.048)	0.087* (0.050)	0.290** (0.120)	0.317*** (0.118)	0.203* (0.111)	0.249** (0.110)	0.126 (0.138)
Observations	14,569	14,568	14,568	14,569	14,570	14,570	14,570
F statistic	35.31	26.37	19.40	16.87	45.44	43.30	28.82
Panel B: Excluded Instruments - Contemporaneous and One Year Lagged Exchange Rate							
	Employment Ratio	Wage Bill Ratio	Non-Production Wage Bill	Non - Production Employment	Production Wage Bill	Production Employment	Gross Output
Imported Intermediates	0.086** (0.042)	0.096** (0.044)	0.282*** (0.109)	0.300*** (0.106)	0.186* (0.099)	0.215** (0.097)	0.119 (0.114)
Observations	14,104	14,103	14,103	14,104	14,105	14,105	14,105
F statistic	34.06	21.84	18.78	16.34	44.80	44.74	28.94
Hansen's J statistic (p-value) ¹	.11 (.75)	1.45 (.23)	3.28(.07)	3.16(.08)	1.90(.17)	3.21(.07)	.08 (.78)
Panel C: Excluded Instruments - Contemporaneous, One Year and Two Years Lagged Exchange Rate							
	Employment Ratio	Wage Bill Ratio	Non-Production Wage Bill	Non - Production Employment	Production Wage Bill	Production Employment	Gross Output
Imported Intermediates	0.100** (0.043)	0.105** (0.045)	0.294*** (0.109)	0.301*** (0.105)	0.189** (0.096)	0.201** (0.093)	0.166* (0.099)
Observations	13,639	13,638	13,638	13,639	13,640	13,640	13,640
F statistic	34.56	21.68	17.54	16.54	42.46	45.70	24.33
Hansen's J statistic (p-value)	6.74 (.04)	6.58 (.04)	6.29(.04)	6.17(.05)	2.54(.28)	3.17(.21)	2.03 (.36)
Number of 4-digit industries	459	459	459	459	459	459	459

Notes:

*** p<0.01, ** p<0.05, * p<0.10

¹: The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Under the null, the test statistic is distributed as chi-squared in the number of (L-K) overidentifying restrictions. The p-value shows that in all cases (except in the regression for R&D intensity in the bottom panel) we are unable to reject the null hypothesis that the instruments are valid. In the first panel, the equations are exactly identified. So overidentification test is not possible.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of 2 digit industry dummies with an indicator for whether the year is post 1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

leads to 18.6% increase in the wage-bill and 21.5% increase in the employment of production workers. Gross output also rises by an economically significant amount, although the estimate is imprecise.⁴⁰ These coefficients imply that a one standard deviation change in imported intermediates (=1.22) leads to 0.18 and 0.21 standard deviation changes in the relative employment and wages of non-production workers. However, for the same change in imported intermediates, production workers' employment and wage-bill also rise by 0.25 and 0.2 standard deviations. The estimates in Panels A and C are also similar to those in B. Including two lags of exchange rates (Panel C), I find that the coefficients on imports in the regression for gross output is statistically significant and suggest that the total industrial output rises by 16.6% when offshoring doubles.

The increase in the wage-bill and employment of unskilled workers who might be substituted for by imported unskilled intermediates is consistent with some existing work. Even under perfect substitution, Feenstra (2008) and Grossman and Rossi-Hansberg (2008) have shown the possibility of a positive effect. Feenstra (2008) shows that offshoring can generate an increase in real wages of domestic unskilled workers if it leads to a larger decline in final good prices than in nominal wages. Grossman and Rossi-Hansberg (2008) showed that real wages can rise due to "productivity effect." This effect derives from the cost savings that result from offshoring. Cost savings in the unskilled stages of production are akin to an unskilled labor augmenting technological change that increases the unskilled labor productivity. These cost savings create incentives for industries to expand their output causing them to demand more unskilled workers putting an upward pressure on their wages. If these effects dominate the negative effects of offshoring on unskilled wages and employment, then we expect to see a net positive relationship between the two.

I show that, in addition to these effects, the gains for unskilled workers are also driven by imperfect substitution between imported and domestic intermediates, and more importantly by the indirect channel. The productivity effect exists only when there is an expansion in the output of the industry that offshores; if output remained constant, then there is no increase in the demand for unskilled workers. This, however, is not supported in the data. I find that the aggregate time series correlation between offshoring and production workers' wages, weighted by constant industry size, is 0.08. Additionally, offshoring has a large positive effect on the wage-bill of unskilled workers, controlling for output. Since in the direct channel that considers imported intermediates as perfect substitutes for unskilled workers, wages could increase only through expansion in output, these results suggest that imported intermediates are not perfect substitutes for domestically produced unskilled intermediates. Further, as I will show in the empirical decompositions and in the theoretical model, the indirect channel creates large wage and employment gains for unskilled workers. The indirect channel is not only a theoretical possibility, but is also strongly supported in the data. These are the results I present next.

⁴⁰To the extent that offshoring takes the form of sub-contracting the production of final products themselves, the theoretically predicted rise in domestic output of industries may fall in magnitude.

Table 6: FE-IV Estimation Second Stage - Indirect Channel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Excluded Instruments - Contemporaneous Exchange Rate								
	Equipment	Total Capital	Equipment / Labor	Total Capital / Labor	R&D	R&D Intensity	Number of Exported Varieties	Price
Imported Intermediates	0.362*** (0.115)	0.362*** (0.115)	0.097 (0.088)	0.104 (0.084)	0.344 (0.252)	0.442** (0.192)	0.054 ² (0.091)	0.195** (0.094)
Observations	14,570	14,570	14,570	14,570	13,746	13,746	6,589	14,570
F statistic	31.72	20.79	133.0	105.1	13.36	37.25	–	30.62
Panel B: Excluded Instruments - Contemporaneous and One Year Lagged Exchange Rate								
	Equipment	Total Capital	Equipment / Labor	Total Capital / Labor	R&D	R&D Intensity	Number of Exported Varieties	Price
Imported Intermediates	0.374*** (0.106)	0.365*** (0.101)	0.134* (0.078)	0.125* (0.073)	0.324 (0.227)	0.399** (0.174)	0.054 (0.091)	0.180** (0.076)
Observations	14,105	14,105	14,105	14,105	13,293	13,293	6,589	14,105
F statistic	31.74	21.39	121.0	102.7	12.68	36.50	–	31.19
Hansen's J statistic (p-value) ¹	2.93 (.09)	3.89 (.05)	.09 (.76)	.32 (.57)	1.48(0.23)	7.22 (.01)	–	3.08 (.08)
Panel C: Excluded Instruments - Contemporaneous, One Year and Two Years Lagged Exchange Rate								
	Equipment	Total Capital	Equipment / Labor	Total Capital / Labor	R&D	R&D Intensity	Number of Exported Varieties	Price
Imported Intermediates	0.419*** (0.111)	0.393*** (0.104)	0.182** (0.079)	0.156** (0.073)	0.376* (0.228)	0.398** (0.179)	0.054 (0.091)	0.153** (0.063)
Observations	13,640	13,640	13,640	13,640	12,839	12,839	6,589	13,640
F statistic	28.79	19.59	109.7	99.02	12.19	35.25	–	34.00
Hansen's J statistic (p-value)	7.62 (.02)	7.71 (.02)	3.52 (.17)	2.38 (.30)	2.84(0.24)	12.3 (.00)	–	6.17 (.05)
Number of 4-digit industries	459	459	459	459	394	459	456	456

Notes:

*** p<0.01, ** p<0.05, * p<0.10

¹: The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Under the null, the test statistic is distributed as chi-squared in the number of (L-K) overidentifying restrictions. The p-value shows that in all cases (except in the regression for R&D intensity in the bottom panel) we are unable to reject the null hypothesis that the instruments are valid. In the first panel, the equations are exactly identified. So overidentification test is not possible.

²: The marginal effect in all three panels = 0.047 with a standard error of 0.064. The bootstrapped standard errors are in parenthesis. The standard errors need to be bootstrapped because the fitted residuals from the first stage regression (of imported intermediates on excluded instruments, and year and industry dummy variables) are included as a regressor in the second stage Poisson regression to correct for the endogeneity of imports.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of 2 digit industry dummies with an indicator for whether the year is post 1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

Consider the outcomes of the indirect channel (Table 6). The most important outcome variables of interest are innovation (measured by R&D expenditure and R&D intensity) and technology adoption (measured by real stocks of equipment or total capital, or as ratios of total labor employed). In Panel B (my preferred set of estimates), the effects of offshoring on these outcome variables are economically and statistically significant. Doubling the imports of inputs from low-wage nations leads to about 40% rise in the innovation intensity. In response to the same increase in offshoring, real equipment stock increases by 37.4%, while the equipment-labor ratio increases by 13.4%. Thus, the data strongly support my indirect channel. In terms of standard deviations, these estimates imply that a one standard deviation change in imported intermediates leads to a 0.17 standard deviation change in equipment-labor ratio and a 0.3 standard deviation change in R&D intensity.

Moreover, the product variety mechanism is supported in the data. According to the model, offshoring induces firms to produce new varieties leading to an increase in the number of products and final goods prices. The results for these two variables are presented in columns 7 and 8. We can see that offshoring positively impacts the number of exported varieties within an industry, although the estimates are imprecise. Since this coefficient is obtained from a non-linear (Poisson) regression, I look at the marginal effect. At the mean of the dependent variable, the number of products increases by 4.7% when offshoring doubles.⁴¹ Column 8 in Panel B indicates that doubling offshoring from low-wage countries causes 18% growth in an industry's final goods price level. Thus, in net terms, the rise in prices because of the variety effect more than compensates for the decline in the price level due to a fall in costs of production. The estimates in Panels A and C are also similar to those in Panel B. These results indicate strong indirect effects of offshoring on developing countries.

The results presented so far are for regressions in which the outcome variables are measured contemporaneously with offshoring. However, capital deepening and innovation are relatively slower process than changes in labor employment and wage bills. In Table 7, I present results for estimations in which current values of technology adoption and innovation are regressed on lagged values (1-3 years) of offshoring. Results are qualitatively similar to those presented in Tables 5 and 6. As expected, innovation is more responsive to lagged than to contemporaneous offshoring. The magnitudes for technology adoption are very close to those obtained from contemporaneous regressions. This indicates that the dynamic effects of offshoring on technology adoption and innovation are larger than the short run effects. Offshoring also impacts the future non-production and production workers' wage bills, although the latter is statistically insignificant.

⁴¹To ascertain the causal effect of offshoring on the number of varieties, I perform a two-step estimation. In the first step, I regress the imported intermediates on the current and lagged values of exchange rates, along with the year and industry fixed effects. In the second step, I estimate a fixed-effects Poisson regression of the number of exported varieties on imports and other fixed effects, additionally including the fitted residuals from the first step as a regressor. This procedure controls for the endogeneity of imports. I also bootstrap the standard errors so as to account for the two-step estimations.

Table 7: Dynamic Effects of Offshoring

	Equipment / Labor	Total Capital / Labor	R&D Intensity	Production Wage Bill	Non Production Wage Bill
			One Year Lag		
Imported Intermediates ¹	0.129* (0.077)	0.126* (0.073)	0.579*** (0.193)	0.153 (0.094)	0.260** (0.103)
			Two Years Lag		
Imported Intermediates	0.105 (0.066)	0.106* (0.061)	0.421** (0.165)	0.130 (0.079)	0.219** (0.086)
			Three Years Lag		
Imported Intermediates	0.113* (0.062)	0.125** (0.059)	0.491*** (0.165)	0.078 (0.074)	0.175** (0.079)

Notes:

*** p<0.01, ** p<0.05, * p<0.10

Excluded instruments: Current and lagged exchange rates, lagged price deflator for investment

¹: As a proportion of total non-energy materials used in the industry.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

Decomposing the Direct and Indirect Channels

Summarizing the results so far, a rise in offshoring to low income countries leads to substantial increases in innovation, technology adoption, and wages and employment of both skilled and unskilled workers, with skilled workers benefiting more. However, the quantitative estimates for wages and employment confound the distinct impacts of offshoring via the direct and the indirect channels. Estimating the distinct effects of the two channels is empirically challenging as I do not have a way to identify the exogenous variations in all the variables that must be held constant on the right hand side. However, the lagged price deflator for investment can serve as an instrument for capital-labor ratio. Thus, I control for capital (or equipment) to labor ratio on the right hand side in addition to the imports measure. In addition to exchange rates, I use the lagged price deflator for investment as an excluded instrument.

The first stage results are presented in Table 8. There are two first stage regressions for two endogenous regressors: offshoring and technology adoption (measured as total capital-labor or equipment-labor ratio). The first three columns include only the contemporaneous exchange rates while columns (2a)-(2c) also include a lag. Results in both specifications are very similar. We can again see the J-curve effect. The negative coefficients on the price deflator in columns 1b and 1c show that industries invest less in capital when investment becomes more expensive. The Kleibergen-Paap Wald rk F statistic is greater than ten in all cases, suggesting a strong first stage.

As Table 9 shows, including the capital-labor ratio, substantially reduces the 2sls coefficients

Table 8: First Stage - Decomposing the Direct and Indirect Channels

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
	Imported Intermediates ¹	Total Capital / Labor	Equipment / Labor	Imported Intermediates	Total Capital / Labor	Equipment / Labor
Lagged Price Deflator for Investment	0.184 (0.332)	-1.029*** (0.101)	-1.239*** (0.102)	0.191 (0.332)	-1.029*** (0.101)	-1.238*** (0.102)
Exchange Rate	-0.185*** (0.040)	-0.017 (0.015)	-0.016 (0.016)	-0.275*** (0.044)	-0.014 (0.010)	-0.017 (0.011)
Lagged Exchange Rate				0.110*** (0.041)	-0.003 (0.010)	0.001 (0.010)
Observations	14,109	14,109	14,109	14,103	14,103	14,103
Number of 4 digit industries	459	459	459	459	459	459
Kleibergen-Paap rk Wald F statistic	11.04	51.71	74.52	13.43	34.94	50.43
Shea's Partial R-squared	0.012	0.104	0.13	0.013	0.104	0.13

Notes:

*** p<0.01, ** p<0.05, * p<0.10

¹: As a proportion of total non-energy materials used in the industry.²: Kleibergen-Paap Wald rk F statistic with degrees of freedom = L1-K1+1; K1 = no. of endogenous regressors, L1 = no. of excluded instruments

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

on offshoring relative to those in Table 4. The coefficients also become statistically insignificant. And yet, technology adoption is just one of the variables that change in the indirect channel. Not controlling for the other variables means that the direct effects of imports are surely overestimated. Controlling for innovation using R&D intensity (columns 1(b) and 1(d)), albeit without treating endogeneity, the estimated effects of import fall even more. These results suggest that the effect of offshoring on the relative wages and employment of skilled workers is almost entirely through the induced investment in innovation and capital. Finally, it is noteworthy that the positive coefficients on the equipment-labor ratio in these equations for employment and wage-bill ratios reflect capital-skill complementarity.⁴²

The decomposition of channels is more challenging when the outcome variables are the levels of employment and real wage-bills of non-production and production workers. Controlling for technology adoption using the equipment-labor ratio is infeasible as this measure creates division bias. Hence, I use equipment relative to output as an alternative measure. The lagged price deflator for investment, that I have so far used as the instrument for technology adoption, however, is a weak instrument for capital-output ratio; the first stage Kleibergen-Paap Wald rk F statistic is less than 10. Instead, I use the lagged price deflator for investment divided by the price deflator for output as an alternative instrument. The first stage results using this as

⁴²The results presented in Table 9 are for the specifications in which the excluded regressors are current and one-year lagged exchange rate constructs, and lagged price deflator for investment; results with only the contemporaneous or an additional lag of exchange rate-based excluded instruments are very similar.

Table 9: Second Stage - Decomposing the Direct and Indirect Channels

	Employment Ratio				Wage Bill Ratio			
	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(2c)	(2d)
Imported Intermediates ¹	0.028 (0.045)	0.020 (0.045)	0.034 (0.043)	0.031 (0.043)	0.040 (0.046)	0.039 (0.046)	0.046 (0.044)	0.050 (0.045)
Total Capital / Labor	0.459*** (0.125)	0.462*** (0.130)			0.450*** (0.135)	0.445*** (0.139)		
Equipment / Labor			0.383*** (0.106)	0.387*** (0.111)			0.375*** (0.113)	0.371*** (0.119)
R&D Intensity		-0.002 (0.006)		-0.004 (0.006)		0.003 (0.007)		0.001 (0.007)
Observations	14,104	13,292	14,104	13,292	14,103	13,291	14,103	13,291
Number of 4 digit industries	459	456	459	456	459	456	459	456
F statistic	39.29	38.52	41.28	40.18	26.83	37.71	27.89	40.01
Hansen's J statistic (p-value) ²	0.02 (.90)	.05 (.82)	.01 (.91)	.02 (.90)	.62 (.43)	.54 (.46)	1.08 (.30)	1.15 (.28)

Notes:

*** p<0.01, ** p<0.05, * p<0.10

Excluded instruments: Current and lagged exchange rates, lagged price deflator for investment

¹: As a proportion of total non-energy materials used in the industry.²: The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Under the null, the test statistic is distributed as chi-squared in the number of (L-K) overidentifying restrictions. The p-value shows that in all cases we are unable to reject the null hypothesis that the instruments are valid. In the left panel, the equations are exactly identified. So overidentification test is not possible.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

variable as the excluded instrument show that it is a strong IV with the Kleibergen-Paap Wald rk F statistic well above 10. Results from the second stage are presented in Table 10. As expected, controlling for technology adoption reduces the coefficient on imported intermediates for all outcome variables. Additionally controlling for R&D intensity shows that higher investments in innovation are associated with higher wage-bills and employment for both groups of workers.

The small drop in the coefficients on imports in these specifications may suggest that the positive impact of offshoring on wages and employment of production and non-production workers is primarily through the direct channel. However, this decomposition strategy has several limitations, so that the results should be interpreted with caution. First, as already mentioned, instead of measuring technology adoption as equipment relative to labor, I measure it as equipment relative to output. Second, R&D intensity is endogenous in these regressions (and other variables like number of varieties and prices would also be endogenous control variables). Third, the validity of the instrument for technology adoption is suspect because the price deflator for output may have an independent effect on the outcome variables in addition to its effect through the capital-output ratio. Theoretical analysis using the model presented in the next section overcomes these limitations of empirical decomposition and indicate that gains for non-production workers are largely mediated through the indirect channel.

A few concerns remain. First, it is possible that the results for imported intermediates are

Table 10: Second Stage - Decomposing the Direct and Indirect Channels

	Non-Production Workers Wage Bill		Non-Production Workers Employment		Production Workers Wage Bill		Production Workers Employment	
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Imported Intermediates ¹	0.270** (0.106)	0.238** (0.104)	0.288*** (0.103)	0.259** (0.102)	0.189* (0.098)	0.163* (0.097)	0.209** (0.096)	0.194** (0.095)
Equipment / Output	0.049 (0.087)	0.030 (0.079)	0.052 (0.075)	0.035 (0.069)	-0.011 (0.089)	-0.023 (0.085)	0.024 (0.086)	0.013 (0.084)
R&D Intensity		0.042*** (0.015)		0.033** (0.015)		0.030** (0.014)		0.025* (0.014)
Observations	14,103	13,291	14,104	13,292	14,105	13,293	14,105	13,293
Number of 4 digit industries	459	456	459	456	459	456	459	456
F statistic	17.95	16.50	15.70	15.94	44.30	39.45	43.35	41.33
Hansen's J statistic (p-value) ²	3.19 (.07)	1.90 (.17)	3.03 (.08)	1.90 (.17)	2.05 (.15)	1.19 (.28)	3.21 (.07)	2.34 (.13)

Notes:

*** p<0.01, ** p<0.05, * p<0.10

Excluded instruments: Current and lagged exchange rates, lagged price deflator for investment

¹: As a proportion of total non-energy materials used in the industry.²: The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Under the null, the test statistic is distributed as chi-squared in the number of (L-K) overidentifying restrictions. The p-value shows that in all cases we are unable to reject the null hypothesis that the instruments are valid. In the left panel, the equations are exactly identified. So overidentification test is not possible.

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of two digit industry dummies with an indicator for whether the year is post-1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

being driven by movements in final good imports. To address this concern, I divide the sample of industries into two halves based on the average import penetration from developing countries in these industries. The top half industries have above-median import penetration from low-wage countries and the industries in the bottom half have below-median import penetration from low-wage countries.⁴³ If the final good imports are driving the main results, I expect to see that the results are very similar to the main results for the industries in the top half but much less so for the industries in the bottom half. The first stage for the top half sub-sample of industries has a F-statistic greater than ten (13.69) when the contemporaneous and one lag of exchange rates are used as the excluded instruments. For the bottom half sub-sample of industries, the specification with the contemporaneous exchange rate used as the excluded instrument yields the strongest first stage with a F statistic of 14.07. The second stage results for these specifications are presented in Table 11. The top panel presents results for the industries in the top half of the sample. The estimates suggest that offshoring in these industries has negative effects on employment and wage-bill ratios as well as on R&D intensity. The coefficients for technology adoption measures are positive but small in magnitude. On the other hand, the results in the bottom half of the industries that face less import competition

⁴³ An alternative strategy is to include both final imports and offshoring as regressors in equations for the various outcome measures. However, the exchange rate constructs used as instruments for both of these endogenous regressors are very highly correlated with each other yielding a very noisy first stage.

from developing countries than the median industry show a similar pattern as for the full sample of industries. All the outcome variables (except the real price level) are impacted positively by increased offshoring. For all outcome variables, the coefficients on imports are also statistically significant. This pattern is inconsistent with the expected results if the final good imports were strongly influencing the main results. Thus, I conclude that my results are not being driven by movements in the final good imports.

A second concern is that the measure of offshoring used in this paper includes both related party and arm's length trade. It is likely that a substantial fraction of imported intermediates are from transactions between related parties, eg. multinational firms may shift some part of their production processes to foreign countries. A narrow measure of offshoring that includes intermediate imports belonging to the same two digit industry (suggested by Feenstra and Hanson (1999)) may be a closer proxy for related party trade. Related party trade data for 2002-2007 is also available. Multinational firm production data (available from BEA) may also be used for this purpose. Existing evidence shows that relatively more productive and capital intensive firms engage in greater levels of related party trade. Nonetheless, I expect the labor market implications of such trade to be qualitatively the same as the results obtained from the measure used in this paper. Using the framework of the model developed in the next section, I quantitatively analyze the predictions for industries that are relatively more capital intensive to shed light on the labor market impact of offshoring in these industries with higher levels of related party trade. Results are very similar to the baseline results.

Finally, the empirical estimates presented above could also be capturing other mechanisms in addition to the direct and indirect channels that the paper focuses on. This may particularly be the case for innovation. I suggest a few alternative mechanisms underlying the positive relationship between offshoring and innovation. With falling costs of transport and communication technologies, firms may find greater opportunities to offshore. This may lead them to invest in innovation to standardize production techniques and make organizational changes. Alternatively, firms may innovate to maintain their market shares. The subcontractor firms in the developing countries that perform the offshored tasks may eventually become competitors as they gain knowledge and expertise about the production of the final goods themselves. To secure themselves against such competition, firms in the advanced countries may defensively innovate to produce superior products with technologies that are not readily imitable. To my knowledge, these alternative mechanisms have not been examined before. Yet another possibility, offered by Glass and Saggi (2001), is that the higher profits caused by offshoring make it feasible for them to invest in innovation. All of these channels imply a positive relationship between offshoring and innovation and may be picked up by the estimated coefficient on offshoring in the equation for R&D expenditures. Nonetheless, regardless of which one is the strongest underlying mechanism, my results point towards a strong and robust positive impact of offshoring on innovation in the U.S. industries. In future, I plan to delve deeper into the relationship between offshoring and innovation.

Table 11: FE-IV Estimates for Sub-Samples of Industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Employment Ratio	Wage Bill Ratio	Production Wage Bill	Production Employment	R&D Intensity	Total Capital Equipment	Total Capital Equipment / Labor	Total Capital Equipment / Labor	Equipment / Labor	Price
Industries with Above Median Import Penetration from Developing Countries²										
Imported Intermediates ¹	-0.070** (0.035)	-0.081** (0.040)	0.065 (0.064)	0.047 (0.062)	-0.081 (0.129)	0.023 (0.052)	0.049 (0.059)	-0.017 (0.050)	0.009 (0.054)	-0.033 (0.040)
Observations	6,940	6,939	6,941	6,941	6,379	6,941	6,941	6,941	6,941	6,941
Number of 4 digit industries	225	225	225	225	224	225	225	225	225	225
Industries with Below Median Import Penetration from Developing Countries³										
Imported Intermediates ¹	0.133* (0.075)	0.163* (0.087)	0.124 (0.142)	0.189 (0.138)	0.705*** (0.261)	0.358** (0.162)	0.306* (0.166)	0.122 (0.111)	0.070 (0.112)	-0.034 (0.060)
Observations	7,145	7,145	7,145	7,145	6,907	7,145	7,145	7,145	7,145	7,145
Number of 4 digit industries	226	226	226	226	224	226	226	226	226	226

Notes:

*** p<0.01, ** p<0.05, * p<0.10

¹: As a proportion of total non-energy materials used in the industry.

²: Excluded instruments: Contemporaneous and one year lagged exchange rate (Kleibergen-Paap Walk rk F statistic = 13.69)

³: Excluded instruments: Contemporaneous exchange rate (Kleibergen-Paap Walk rk F statistic = 14.07)

All regressions include year fixed effects, 4-digit industry fixed effects and interactions of 2 digit industry dummies with an indicator for whether the year is post-1996.

Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.

All variables are in natural logs.

6 Model

To theoretically formalize how the direct and indirect channels operate and influence the labor markets in advanced countries, I now present a model of trade in intermediates between a developed and a developing country. In the model, the 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 indirect effects that are evident in the empirical results described above.

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 capital equipment - S , U , and K , respectively, while the South has only unskilled labor⁴⁴ 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 $t \in \{1, 2, \dots\}$.

6.1 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:

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

subject to

$$C_t + I_t + v_t N_t^E = W_{st} S_t + W_{ut} U_t + R_t K_t + \pi_t N_t \quad (6.1)$$

$$K_{t+1} = (1 - \delta^K) K_t + I_t \quad (6.2)$$

$$\text{and } N_t = (1 - \delta^N) N_{t-1} + N_t^E \quad (6.3)$$

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

⁴⁴This 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.

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.⁴⁵ Optimization yields the following Euler and asset-pricing conditions (in addition to two consumption-leisure conditions), respectively:

$$1 = \beta \left[\frac{C_t}{C_{t+1}} (R_{t+1} + 1 - \delta^K) \right] \quad (6.4)$$

$$v_t = \pi_t + \beta(1 - \delta^N) \left(\frac{C_t}{C_{t+1}} v_{t+1} \right) \quad (6.5)$$

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:

$$Y_t = \left[\int_0^1 Q_t(j)^\omega dj \right]^{\frac{1}{\omega}}, \omega < 1 \quad (6.6)$$

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, $Q_t(j)$. That is,

$$Q_t(j) = \left[\int_{i=0}^{N_t} g_t(j, i)^\tau di \right]^{\frac{1}{\tau}}, \tau < 1 \quad (6.7)$$

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 indirect 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.⁴⁶ 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 (ie, imported from the South). These imports, denoted by m_{ut} , are highly substitutable for domestically produced

⁴⁵This set-up is similar to Jaimovich and Floetotto (2008) in a few respects. Specifically, the utility function is similar in their model except that labor is homogeneous. The firm entry and exit process is the same.

⁴⁶Again, the set-up here draws upon Jaimovich and Floetotto (2008).

unskilled intermediates. This is the key assumption that triggers the direct and indirect effects of offshoring. Thus, the production function for the differentiated goods is:

$$g_t(j, i) = [\lambda[x_{ut}(j, i)^\sigma + m_{ut}(j, i)^\sigma]^{\frac{\gamma}{\sigma}} + (1 - \lambda)x_{st}(j, i)^\gamma]^{\frac{1}{\gamma}}, \lambda \in (0, 1), \gamma < 1, 0 < \sigma < 1 \quad (6.8)$$

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:

$$x_{st} = k_t^\mu s_t^{1-\mu}, \mu \in (0, 1), \quad (6.9)$$

$$x_{ut} = u_t \quad (6.10)$$

In this framework, capital is complementary to skilled labor. This is the key ingredient yielding the first indirect 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:

$$Q_t(j) = \left(\frac{p_t(j)}{P_t} \right)^{\frac{1}{\omega-1}} Y_t \quad (6.11)$$

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

$$P_t = \left[\int_0^1 p_t(j)^{\frac{\omega}{\omega-1}} dj \right]^{\frac{\omega-1}{\omega}} \quad (6.12)$$

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:

$$g_t(j, i) = \left[\frac{p_t(j, i)}{p_t(j)} \right]^{\frac{1}{\tau-1}} \left[\frac{p_t(j)}{P_t} \right]^{\frac{1}{\omega-1}} Y_t \quad (6.13)$$

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

$$p_t(j) = \left[\int_{i=0}^{N_t} p_t(j, i)^{\frac{\tau}{\tau-1}} di \right]^{\frac{\tau-1}{\tau}} \quad (6.14)$$

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:

$$\Psi_{nt} = [\varphi k_{nt}^\alpha + (1 - \varphi) s_{nt}^\alpha]^{\frac{1}{\alpha}}, \alpha < 1 \quad (6.15)$$

The innovation good firm faces the standard profit-maximization problem. These goods 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.

6.2 The South

Households

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

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

subject to

$$P_t^* C_t^* + C_{mt}^* + P_t^* I_t^* = W_{ut}^* U_t^* + R_t^* K_t^* \quad (6.16)$$

$$\text{and } K_{t+1}^* = (1 - \delta) K_t^* + I_t^* \quad (6.17)$$

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:

$$P_t^* = \left(\frac{C_t^*}{C_{mt}^*} \right)^{\rho-1} \quad (6.18)$$

$$1 = \beta^* \left[\frac{C_t^{*\rho} + C_{mt}^{*\rho}}{C_{t+1}^{*\rho} + C_{mt+1}^{*\rho}} \frac{C_{t+1}^{*\rho-1}}{C_t^{*\rho-1}} \right] \left[\frac{R_{t+1}^*}{P_{t+1}^*} + 1 - \delta \right] \quad (6.19)$$

Firms

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

$$Y_t^* = [X_{hut}^{*\zeta} + K_t^{*\zeta}]^{\frac{1}{\zeta}}, \zeta < 1 \quad (6.20)$$

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.

6.3 Equilibrium

I set Y_t as the numeraire good. 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

$$Y_t = Q_t = N_t^{\frac{1-\tau}{\tau}} g_t \quad (6.21)$$

$$\pi_t = \left(\frac{z-1}{z} \right) g_t \quad (6.22)$$

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. Defining ψ_t as the fixed average quantity of innovation goods required for each firm to enter, we have:

$$v_t = p_{nt}\psi_t \tag{6.23}$$

The market clearing conditions in the North are as follows:

$$K_t = N_t k_t + k_{nt} \tag{6.24}$$

$$U_t = N_t u_t \tag{6.25}$$

$$S_t = N_t s_t + s_{nt} \tag{6.26}$$

$$X_{st} = N_t x_{st} \tag{6.27}$$

$$X_{ut} = N_t x_{ut} \tag{6.28}$$

$$M_{ut} = N_t m_{ut} \tag{6.29}$$

The market clearing condition in the South is:

$$X_{ut}^* = M_{ut} + X_{hut}^* \tag{6.30}$$

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

$$C_{mt}^* = p_{ut}^* M_{ut} \tag{6.31}$$

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.

6.4 Calibration of Structural Parameters

The parameter values in the baseline calibration are listed in Table 12. 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.⁴⁷ 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.⁴⁸

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 (ie, $\sigma = 0.6$) in the baseline specification. I vary this parameter in the sensitivity analysis. The results from this analysis are presented later in section 4.

⁴⁷See Jaimovich and Floetotto (2008).

⁴⁸Thus, 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 12: 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

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 , is set at 0.4 so that the elasticity of substitution between consumption of home produced and imported goods is 1.67.⁴⁹

7 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 direct and indirect 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 direct channel. Lastly I discuss the sensitivity of my results.

7.1 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, $\frac{(1+d)p_{ut}^*M_{ut}}{(1+d)p_{ut}^*M_{ut}+p_{st}X_{st}+p_{ut}X_{ut}}$)⁵⁰ in 1974 was a negligible 0.018. By 2005, this figure had grown to 0.19. I approximate the economy in 1974 with autarky (offshoring = 0) and reduce d until offshoring increases to 0.19, which requires a value of $d = 3.8$.

The steady state values (corresponding to $d = 0$ and $d = 3.8$) for the outcomes of interest in the North are presented in Table 13.⁵¹ 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 the direct and indirect channels play a role in moving from autarky to trade. 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

⁴⁹The 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.

⁵⁰This measure closely corresponds to the measure of offshoring in the empirical analysis

⁵¹Since 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 13: Quantitative Results

	Autarky (Corresponds to 1974)	Steady state with trade cost=3.8 (Corresponds to 2005)	% change relative to autarky	% 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 Unemployment	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
Direct Channel				
Skilled Intermediates/ Unskilled Intermediates	0.93	1.19	27.72	n.a.
Indirect 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)

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 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 direct and indirect channels. In the direct 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 direct channel

is evident from a comparison of the steady states under autarky and with trade. The skilled intermediates relative to unskilled intermediates used in the industry increase by 27.7% when we move from autarky to trade. This variable does not have an empirical counterpart.

Now, consider the indirect channel. Recall that the indirect 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 indirect 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 indirect 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 indirect 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 described in section five show that innovation responds much more strongly to offshoring. In that section, I briefly dwell on these alternative mechanisms.

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 direct channel, we observe (1) a higher relative production of skilled intermediates. Via the indirect 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.

7.2 Counterfactuals

The model can be used to quantify the distinct contributions of the direct and indirect channels to relative and absolute wages of skilled and unskilled labor. I present two counterfactual experiments to quantify the contributions of the two parts of the indirect channel.

The experiment to assess the contribution of induced innovation is straightforward and so I describe that first. 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 autarky steady state. 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 autarky. This, in turn, keeps the level of innovation constant at its autarky level.

Assessing the contribution of technology adoption is relatively more involved. Offshoring leads to increased production of skilled intermediates. This leads to increased demand for skilled workers and skill-complementary capital, accentuating the wages of skilled workers. In order to study the effects of this channel, one option is to shut off any increase in equipment capital. However, in this experiment capital is still complementary to skilled labor. To eliminate capital-skill complementarity in production, I require that skilled labor is as easily substituted for by capital as unskilled labor. This can be achieved in multiple ways. I present one such alternative here and describe others in Appendix B. I rewrite the production function of skilled intermediates as a CES function with the curvature parameter equal to 0.001, yielding an elasticity of substitution equal to 1.001.⁵² Thus, this function is close to the Cobb Douglas case. Starting with this level of elasticity, I solve for the steady states in autarky and full trade. This yields results very close to the baseline specification. Next, to eliminate capital-skill complementarity, I increase the elasticity of substitution between capital and skilled labor to 1.67 - the same as the substitution elasticity between skilled and unskilled intermediates.

The results of these counterfactual simulations are summarized in Table 14. The table presents baseline and counterfactual steady state results when the economy moves from an autarky steady state (where trade cost is ∞) to a steady state with trade cost of 3.8. This change in trade cost generates an increase in offshoring that is close to the change in offshoring observed in the data.

In Panel A, I report the results of the baseline model for the employment and wage ratios (skilled relative to unskilled) under autarky and free trade. In the baseline specification, moving from autarky to trade is associated with 14.4% increase in the relative employment of skilled labor and 14.5% increase in the skill premium. Holding constant the amount of capital used in production of skilled intermediates (Panel B), I find, of the total increase in the skill premium, technology adoption explains 14.5%.⁵³ Eliminating capital-skill complementarity in the production of skilled intermediates (Panel C) leads to substantially less growth in the relative employment and wages of skilled workers from autarky to trade. The results from this experiment suggest that 80.9% and 81.7% of the total increase in both skill upgrading and skill premia are attributable to capital-skill complementarity. In the third counterfactual simulation,

⁵²The shares of capital and skilled labor are set equal those in the baseline specification.

⁵³This experiment is the theoretical counterpart of the empirical decomposition of the direct and indirect channels in which I held equipment-labor ratio constant on the RHS of the regression equations.

Table 14: Contribution of the Indirect Channel

Panel A: Baseline model				
	(A1)	(A2)	(A3)	(A4)
	Autarky (Corresponds to 1974)	Trade with trade cost=3.8 (Corresponds to 2005)	Change relative to autarky (A2-A1)	Total percentage change (100*A3/A1)
Employment Ratio	0.43	0.49	0.06	14
Wage Ratio	1.68	1.92	0.24	15
Panel B: Counterfactual 1a (No increase in capital used to produce skilled intermediates)				
	(B1)	(B2)	(B3)	(B4)
	Autarky	Trade with skill- complementary capital constant at autarky level	Change relative to autarky (B2-B1)	% change explained by increase in skill- complementary capital (100*(A3-B3)/A3)
Employment Ratio	0.43	0.48	0.05	13
Wage Ratio	1.68	1.89	0.21	14
Panel C: Counterfactual 1b (No capital skill complementarity)				
	(C1)	(C2)	(C3)	(C4)
	Autarky	Trade with no capital skill complementarity	Change relative to autarky (C2-C1)	% change explained by capital skill complementarity (100*(A3-C3)/A3)
Employment Ratio	0.43	0.44	0.01	81
Wage Ratio	1.68	1.72	0.05	82
Panel D: Counterfactual 2 (No increase in innovation relative to autarky)				
	(D1)	(D2)	(D3)	(D4)
	Autarky	Trade with innovation constant at autarky level	Change relative to autarky (D2-D1)	% change explained by increase in innovation (100*(A3-D3)/A3)
Employment Ratio	0.43	0.48	0.05	23
Wage Ratio	1.68	1.87	0.19	22
Panel E: Counterfactual 3 (Indirect channel shut off; retaining capital-skill complementarity)				
	(E1)	(E2)	(E3)	(E4)
	Autarky	Trade with indirect channel shut off	Change relative to autarky (E2-E1)	% change explained by indirect channel (100*(A3-E3)/A3)
Employment Ratio	0.43	0.47	0.04	42
Wage Ratio	1.68	1.82	0.14	44
Panel F: Counterfactual 4 (Indirect channel shut off)				
	(F1)	(F2)	(F3)	(F4)
	Autarky	Trade with indirect channel shut off	Change relative to autarky (F2-F1)	% change explained by indirect channel (100*(A3-F3)/A3)
Employment Ratio	0.43	0.40	-0.02	139
Wage Ratio	1.68	1.59	-0.09	138

I hold the number of firms constant at the baseline autarky level. The results (Panel D) suggest that 22.5% of the total baseline increase in the employment ratio is attributable to the increase in innovation required to produce a larger mass of varieties. Similarly, 22.1% of the increase in the skill premium is because of the increase in innovation in response to offshoring.

Panel E shows the results when I simultaneously hold capital and innovation constant at their autarky levels. This eliminates the indirect channel partly, although retains capital-skill complementarity in the production function. This experiment shows that 43.5% of the increase in skill premium can be explained by increase in innovation and equipment capital when offshoring is increased to match the change in the data between 1974 and 2005. Panel F shows the results from the model when all components of the indirect channel are shut off so that only the direct channel operates. The results show that in the absence of the indirect channel, offshoring reduces the employment and wage ratios (skilled relative to unskilled), i.e., if only the direct channel operates, the skill premium falls. This result suggests that the productivity effect described by Grossman and Rossi-Hansberg (2008) dominates the substitution and relative price effects so that in net terms there is a decline in the employment and wage ratios. These counterfactual results suggest that the indirect channel is a significantly more important mechanism underlying the relationship between offshoring and the skill premium than the direct channel thus far considered.

As mentioned before, capital-skill complementarity can be eliminated in several ways. Results are sensitive to the method adopted. Thus, I interpret the results from holding innovation and equipment constant as the lower bounds on the impact of the indirect channel on the relative employment and wages of skilled workers. Once we shut off capital-skill complementarity, the indirect channel can explain almost the entire impact of offshoring on skill-upgrading and the skill premium.

Table B.2 in appendix B presents the counterfactual results when I reduce the trade cost further to zero, so that the North trades freely with the South. It is noteworthy that while the increase in skill-upgrading and the skill premium attributable to the increase in innovation is of a similar order of magnitude as in Table 14, the contribution of capital-skill complementarity is smaller. In particular, the percentage of the total changes in the employment and wage ratios attributable to capital-skill complementarity are 66.5% and 65.2%, respectively. This suggests that as an advanced country offshores more unskilled intermediates to a developing country, capital-skill complementarity plays a relatively smaller role in the magnification of the skill premium.

7.3 Welfare Analysis

So far, I have presented results that suggest that the indirect channel is the dominant mechanism underlying the positive relationship between offshoring and the skill premium. Next, I examine the relative welfare implications of the direct and indirect channels. For this purpose, I write an alternative model to only capture the features of the direct 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 direct 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 15, 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 indirect 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 direct channel but the same elasticity of substitution between domestic and imported intermediates as in the baseline model. In the third model, I present the results from the model with direct channel considering imported and domestic inputs as perfect substitutes in production.

Comparing columns 1 and 2, 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 indirect mechanisms 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 direct 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.

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

Table 15: Welfare Comparison (Change in Offshoring from 0 (1974) to 0.19 (2005))

	Full model	Model with only direct channel	Model with only direct channel 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

employment and wages. Finally, an increase in offshoring is akin to a productivity increase leading to growth in output (and, hence, consumption of households). These welfare improving implications are much stronger with the baseline model that captures both the direct and indirect channels.

7.4 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.

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 0.12. 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 1.⁵⁴ 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).

8 Conclusion

This paper develops a new mechanism by which a rise in offshoring to developing countries induces the adoption of skill-complementary technology and innovation, impacting labor markets in advanced countries. Empirical results lend strong support to the presence of this indirect channel in the U.S. manufacturing industries. Results show that this channel is the primary mechanism underlying the effect of offshoring on the relative wage-bills and employment of skilled labor. Although it increases inequality, offshoring does not hurt unskilled workers - the absolute wage-bills and employment of unskilled workers increases with offshoring. Decomposition results from the model confirm the importance of this mechanism. Normative analysis suggests that without the indirect 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.

⁵⁴This 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.

Future work will extend the analysis theoretically, by allowing for heterogeneity between firms, and empirically, by analyzing firm level data. Firms with different skill intensities, different costs of innovation and different levels of technology use may respond to different degrees to similar increases in offshoring. This research agenda will help examine two questions: What are the characteristics of firms that offshore? And, amongst the firms that offshore, what is the extent of heterogeneity in their responses to offshoring with regard to their total employment, skill mix, output, technology adoption and innovation?

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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 imports 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 database 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:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$W_u = p_u \quad (\text{B.16})$$

$$W_s = p_s(1 - \mu)k^\mu s^{-\mu} \quad (\text{B.17})$$

$$R = p_s \mu k^{\mu-1} s^{1-\mu} \quad (\text{B.18})$$

$$\Psi_n = [\varphi k_n^\alpha + (1 - \varphi)s^\alpha]^{\frac{1}{\alpha}} \quad (\text{B.19})$$

$$\Psi_n = \psi N^E \quad (\text{B.20})$$

$$W_s = p_n(1 - \varphi)s^{\alpha-1}[\varphi k_n^\alpha + (1 - \varphi)s^\alpha]^{\frac{1}{\alpha}-1} \quad (\text{B.21})$$

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

$$v = p_n \psi \quad (\text{B.23})$$

$$\pi = \left(\frac{z-1}{z}\right)g \quad (\text{B.24})$$

$$X_u = Nx_u \quad (\text{B.25})$$

$$X_s = Nx_s \quad (\text{B.26})$$

$$K = Nk + k_n \quad (\text{B.27})$$

$$S = Ns + s_n \quad (\text{B.28})$$

$$U = Nu \quad (\text{B.29})$$

$$Y = C + I + vN^E + C_m^* \quad (\text{B.30})$$

The equations for the South are as follows:

$$K^* = (1 - \delta)K^* + I^* \quad (\text{B.31})$$

$$P^* = \left[\frac{C^*}{C_m^*}\right]^{\rho-1} \quad (\text{B.32})$$

$$\Delta U^{*\xi} = \frac{C_m^{\rho-1} W_u^*}{C^{*\rho} + C_m^\rho} \quad (\text{B.33})$$

$$1 = \beta^* \left[\frac{R^*}{P^*} + 1 - \delta^*\right] \quad (\text{B.34})$$

$$Y^* = [X_{hu}^{*\zeta} + K^*\zeta]^{\frac{1}{\zeta}} \quad (\text{B.35})$$

$$p_u^* = P^* [X_{hu}^{*\zeta} + K^*\zeta]^{\frac{1}{\zeta}-1} X_{hu}^{*\zeta-1} \quad (\text{B.36})$$

$$R^* = P^* [X_{hu}^{*\zeta} + K^*\zeta]^{\frac{1}{\zeta}-1} K^{*\zeta-1} \quad (\text{B.37})$$

$$X_u^* = U^* \quad (\text{B.38})$$

$$W_u^* = p_u^* \quad (\text{B.39})$$

$$X_u^* = X_{hu}^* + M_u \quad (\text{B.40})$$

$$P_* Y^* = P^* C^* + P^* I^* + C_m^* \quad (\text{B.41})$$

$$C_m^* = p_u^* M_u \quad (\text{B.42})$$

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 intermediates exported from the South to the North, M_L . 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 iceberg cost, d and import price, p_S^L , I provide the system with guesses for three more variables - capital used in innovation, k_n , skilled labor used in innovation, h_n , and the imported intermediates used per firm, m_L . 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_L 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 iceberg cost - $(1 + d) * p_S^L$, 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 indirect 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 indirect channel entirely shows that the direct 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.

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

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 Unemployment	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
	Direct Channel		
Skilled Intermediates/ Unskilled Intermediates	0.929	1.280	38
	Indirect 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	77.00
Varieties	1.518	1.915	26

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

Panel A: Baseline Model				
	(A1)	(A2)	(A3)	(A4)
	Autarky	Free Trade (Trade cost=0)	Change relative to autarky (A2-A1)	Total percentage change (100*A3/A1)
Employment Ratio	0.429	0.511	0.083	19.33
Wage Ratio	1.678	2.005	0.327	19.49
Panel B: Counterfactual 1 (No capital skill complementarity)				
	(B1)	(B2)	(B3)	(B4)
	Autarky	Trade with no capital skill complementarity	Change relative to autarky (B3-B1)	% change explained by capital skill complementarity (100*(A3-B3)/A3)
Employment Ratio	0.429	0.457	0.028	66.46
Wage Ratio	1.678	1.791	0.113	65.17
Panel C: Counterfactual 2 (No increase in innovation relative to autarky)				
	(C1)	(C2)	(C3)	(C4)
	Autarky	Trade with innovation constant at autarky level	Change relative to autarky (C3-C1)	% change explained by increase in innovation (100*(A3-C3)/A3)
Employment Ratio	0.429	0.492	0.064	23.29
Wage Ratio	1.678	1.933	0.255	21.89
Panel D: Counterfactual 3 (Indirect Channel Shut Off)				
	(D1)	(D2)	(D3)	(D4)
	Autarky	Trade with indirect channel shut off	Change relative to autarky (D3-D1)	% change explained by indirect channel (100*(A3-D3)/A3)
Employment Ratio	0.429	0.414	-0.015	117.60
Wage Ratio	1.678	1.627	-0.051	115.47

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 substitutable 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

($\frac{1}{1-\sigma} = 7.69$), 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 indirect 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 the Direct Channel

To compare the relative welfare implications of the models with and without the indirect channels, I write an alternative model that captures only the direct 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:

$$g_t(i) = K_t(i)^\mu (I_{ut}(i)^\sigma + M_{ut}(i)^\sigma)^{\frac{\gamma}{\sigma}} I_{st}(i)^{1-\mu-\gamma} \quad (\text{B.43})$$

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 aggregate is given by:

$$Y_t = \left[\int_0^1 g_t(i)^\omega di \right]^{\frac{1}{\omega}}, \omega < 1 \quad (\text{B.44})$$

The households solve the following problem:

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

subject to

$$C_t + I_t = W_{st}S_t + W_{ut}U_t + R_tK_t \tag{B.45}$$

$$K_{t+1} = (1 - \delta^K)K_t + I_t \tag{B.46}$$

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:

$$Y_t = C_t + I_t + C_{mt}^* \tag{B.47}$$

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.