Offshoring – Effects on Technology and Implications for the Labor Market

Manisha Goel*

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Abstract

I propose a "technology channel" through which imports of low-skilled intermediates (offshoring) benefit *both* high- and low-skilled workers by inducing capital deepening and innovation in developed countries. Data strongly support the presence of this channel. Offshoring is associated with large increases in technology variables – equipment-labor ratio and R&D intensity – and labor outcomes – employment and wage bills of high- and low-skilled workers. I formalize this channel in a structural model. Results show that it is the dominant mechanism through which offshoring affects labor outcomes, offsetting negative substitution effects on low-skilled wages, and generating a large welfare gain.

JEL Classifications: F16, J31, O33
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*Pomona College, Department of Economics. 425 N. College Avenue, Claremont, CA 91711, USA. Email: manisha.goel@pomona.edu.

1 Introduction

The share of imports from developing countries in intermediate goods used by U.S. manufacturing, or offshoring, grew tenfold from 1.8% to 19% over 1974-2005.[1] The conventional view on how offshoring impacts labor markets in developed countries is that greater imports of cheap low-skilled inputs substitute for domestic low-skilled workers leading to a decline in their wages and employment and increasing inequality between high- and low-skilled workers (substitution effect). Indeed, recent evidence shows that exposure to rising Chinese import competition led to declines in U.S. manufacturing employment.[2] Evidence also supports a positive association between wage inequality and offshoring; as Figure 1(a) shows, manufacturing industries that increased their offshoring levels the most over 1975-2005, also witnessed the largest increases in the relative wage bills of high-skilled workers.[3] However, low-skilled workers may not necessarily be worse off in absolute wage terms. As Figure 1(b) shows, real wage levels of low-skilled workers increased more in industries that offshored more over this time period.[4]

In this paper, I show that offshoring can generate wage and employment gains for both high- and low-skilled workers through a "technology channel" wherein it induces skill-complementary capital deepening and greater innovation in U.S. industries. This effect is triggered in addition to the previously examined substitution and scale effects. While the substitution channel reduces low-skilled wage and employment, the scale effect has positive impacts on both. Thus, the net effect of offshoring depends on the relative strength of these channels. I develop a model formalizing these channels of offshoring. Quantitative results from the model show that the technology channel is the dominant channel so that offshoring increases real wages for both high- and low-skilled workers, but more so for the former, increasing inequality. Low-skilled employment still falls, although this adverse effect is mitigated by the technology channel. This mechanism also demonstrates that skill-biased technology adoption, measured as skill-complementary capital deepening,[5] is endogenous to and reinforced by offshoring. Thus far, these two phenomena have largely been considered independent of each other.

The technology channel is motivated by the observation that the growth in offshoring

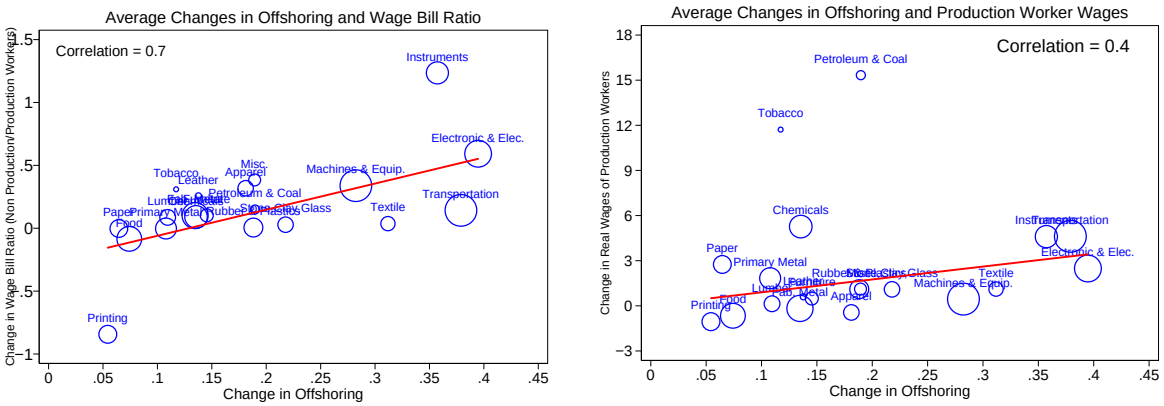
[1] See Figure 2(a).

[2] Acemoglu et al. (2016) and Autor et al. (2013).

[3] Figure 1(a) shows a scatter plot of the average changes in the wage-bill ratios of non-production (high-skilled) to production (low-skilled) workers against the average changes in offshoring levels in U.S. manufacturing industries over 1975-2005. See also, Burstein and Vogel (2016) and Feenstra and Hanson (1999), among others.

[4] The correlation of 0.4 in Figure 1(b) is robust to dropping outlier industries such as tobacco, and petroleum and coal.

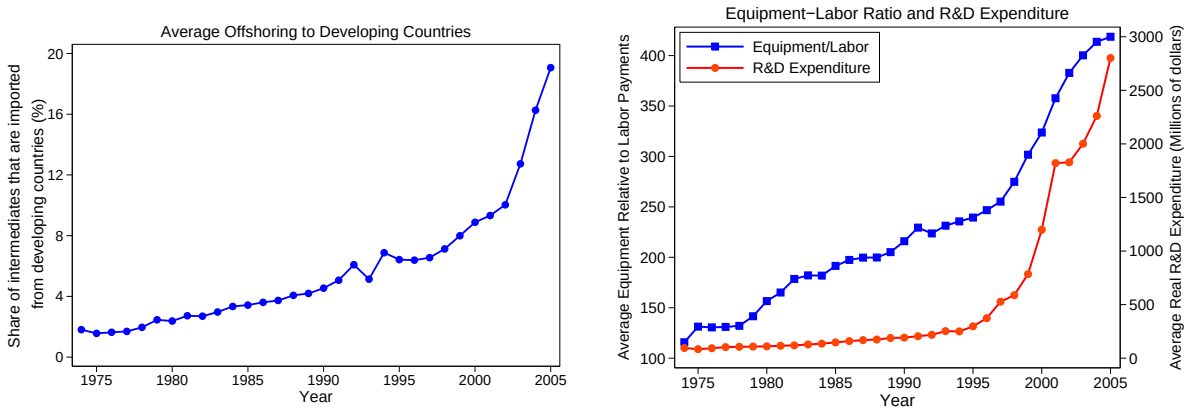
[5] Krusell et al. (2000) and Autor et al. (1998).



(a) (b)

Figure 1: Changes in Offshoring, Wage Bill Ratio, and Real Low-skilled Wage[a]

[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Industry database, Input-Output tables, World Bank Income Classification. The measure of offshoring is standard. See section 2 for details. Changes between 1975 and 2005 in offshoring, wage-bill ratios, and real production worker wages in all 4 digit industries are averaged over 2 digit industries. All 2 digit industries are weighted by size, measured as the share of each industry in total manufacturing wage-bill in 2005.



(a) (b)

Figure 2: Growth in Offshoring with Rise in Equipment & Innovation[a]

[a]Source: U.S. Imports and Exports data, NBER-CES Manufacturing Productivity database, Input-Output tables, Compustat. The measure of offshoring is standard. See section 2 for details. The payments to equipment capital are divided by the total payments to workers for each industry. R&D is measured as the total expenditures on product R&D of all publicly traded U.S. firms in an industry. Offshoring, equipment-labor ratio and R&D expenditure are averaged over 459 4-digit industries.

to developing countries is accompanied by capital deepening and increasing R&D expenditures, with all three accelerating after the mid-1990s. Figure 2(a) shows that imports from developing countries, as a share of intermediates used in U.S. manufacturing industries, consistently grew between 1974 and 2005, accelerating slightly after the mid-1990s,

following the Uruguay round of trade negotiations, and growing fast after China's entry into the WTO in 2001. Simultaneously, as Figure 2(b) shows, the average equipment-labor payments ratio rose from about 115 points to 420 points and the average product R&D-sales ratio grew from 1.5% to 2.4% (corresponding to a growth in average real product R&D expenditure from $95 million to $2,800 million), with both series also accelerating after the mid-1990s. I argue that the rise in equipment-labor ratio and R&D in U.S. industries is causally related to offshoring. Note, however, that factors other than offshoring must also have contributed to the rapid growth in equipment-labor payments ratio and R&D expenditure which began before 2002, when offshoring started increasing remarkably.

The intuition for the technology channel is as follows. Imports of low-skilled labor intensive intermediates reduce the marginal cost of production which, in turn, can trigger two effects that constitute the technology channel. First, firms are induced to expand their output, thus demanding more of both high- and low-skilled workers. This scale effect is accompanied by a greater demand for high- relative to low-skilled workers because of the substitution of some low-skilled tasks by imported intermediates. As firms hire more high-skilled workers, they also invest in skill-complementary equipment capital (technology adoption).[6] For example, if the firm hires an engineer, it also provides her with a computer – a skill-complementary equipment. Second, with lower production cost, and larger markets resulting from trade, firms find it more profitable to invest in innovation. This leads to higher R&D expenditures. Both effects increase the productivity of firms, generating increased demand and productivity for both high- and low-skilled workers. Thus, the technology channel and scale effects compete with the negative substitution effects for low-skilled workers, with the net effect depending on the relative strengths of these channels.[7]

I begin my analysis by documenting several empirical facts in support of the technology channel. I combine data for a panel of four-digit manufacturing industries for the period 1974-2005 with U.S. import and export data, and use input-output tables to construct a standard measure of offshoring. Industry-level regressions using these data[8]

[6] I use the term "technology adoption" to imply equipment capital deepening. In the skill-biased technological change (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.

[7] A few other effects can also be triggered. Grossman and Rossi-Hansberg (2008) classify labor effects of offshoring into the relative price effect, labor supply effect, and productivity effect. While the first two effects reduce the relative wages of low-skilled labor, the third increases low-skilled wages. Feenstra (2008) shows that offshoring can generate an increase in real wages of domestic low-skilled workers if it leads to a larger decline in final good prices than in nominal wages.

[8] More detail about data analysis is available in Appendix A.

show the following: (1) Technology adoption is endogenous to offshoring. Doubling intermediates increases the equipment-labor ratio by 38.5% and R&D intensity by 42%. (2) Offshoring is associated with greater inequality. Doubling offshoring in an industry leads to 11.1% and 13.2% increase in the relative employment and wage-bill of high-skilled workers, respectively. (3) Total employment and wage-bills of *both* groups of workers in the offshoring industry increase. In particular, low-skilled employment and wage-bill increase 24% and 25%, respectively, when offshoring doubles.

Motivated by these facts, I develop a structural model that formalizes the technology channel. In the model, monopolistically competitive firms in the North produce final goods using high- and low-skilled intermediates, and offshore the production of low-skilled intermediates to the South. While the North has both high- and low-skilled labor, the South has only low-skilled labor; both economies also have capital. The model has three key features. First, the offshored intermediates are highly, but not perfectly, substitutable for domestically produced low-skilled intermediates. The reason for introducing this feature is the empirical evidence that wages of low-skilled workers are positively correlated with offshoring by U.S. manufacturing industries – a pattern inconsistent with perfect substitution between imported and domestic intermediates, as explained in section 4.2. Second, the production function of the monopolistically competitive firms allows for capital-skill complementarity. This feature is consistent with previous empirical evidence (see Krusell et al. (2000)). I show that offshoring induces greater use of skill-complementary capital that increases high-skilled wages more than low-skilled wages. Third, production of new goods, or entry of new firms, requires innovation. Offshoring increases profit opportunities encouraging entry of new firms. Since new firm entry requires innovation, the model shows that innovation rises with offshoring, simultaneously increasing demand for both high- and low-skilled labor.

This model, calibrated to U.S. data, shows the net impact of offshoring in the aggregate economy, that combines the effects on firms that offshore and those that compete with these offshored intermediates.[9] I find that a tenfold growth in offshoring to developing countries, as that seen in U.S. manufacturing between 1974 and 2005, increases the skill premium by about 16%. Thus, the high-skilled wage increases relative to the low-skilled wage. But the low-skilled wage also increases by a remarkable 24%. Low-skilled employment, however, declines by 7.5%. Further, the technology channel is the dominant mechanism by which offshoring impacts labor outcomes and output, explaining half to two-thirds of the baseline changes.

[9]See Ebenstein et al. (2014) and also Autor et al. (2013), and Pierce and Schott (2016) who focus on exposure to competition from Chinese imports.

Next, I compare the effects of offshoring in the baseline model with its effects in an alternative model with no technology channel. Quantitative results from this model show that the same tenfold increase in offshoring generates smaller increases in output and wages for high- and low-skilled labor than in the model with the technology channel. The low-skilled wage is especially lower, and *falls* when imported and domestic intermediates are perfectly substitutable. The decline in low-skilled employment and rise in inequality are also larger. This indicates that through the technology channel, offshoring creates important quantitative gains for all workers in the North, including the low-skilled.

Finally, I examine the welfare implications of the technology channel. I find that increasing offshoring from 1.8% to 19% generates a 17% increase in welfare in the North. In comparison, the model without the technology channel yields a welfare increase of 3%.

This paper contributes to the large literature on the impacts of offshoring on labor markets in developed countries. Feenstra and Hanson (1996; 1999); Grossman and Rossi-Hansberg (2008); and Criscuolo and Garicano (2010), among others, show that offshoring increases the skill premia in advanced countries. While previous empirical studies find mixed results for employment effects of offshoring (Mann (2005), Amiti et al. (2005), Groshen et al. (2005), Landefeld and Mataloni (2004)), existing theoretical analysis also demonstrates that low-skilled employment can increase through scale and productivity effects but fall due to relative price and labor supply effects (see Amiti et al. (2005), Feenstra (2008), Grossman and Rossi-Hansberg (2008), Wright (2014), and Ottaviano et al. (2013)). The technology channel I present is a novel mechanism through which offshoring increases the skill premium, while also increasing the real wage level for low-skilled labor. I also show that offshoring industries increase their employment of low-skilled labor.

The increase in the wage-bill and employment of low-skilled workers in offshoring industries shows that the negative substitution effects are more than offset by the technology channel. It is also consistent with the effects described by Feenstra (2008); Grossman and Rossi-Hansberg (2008) and Wright (2014). Note further that these results are not in contradiction with the negative employment effects for low-skilled workers emphasized by Acemoglu et al. (2016), Ebenstein et al. (2014); Pierce and Schott (2016) and Autor et al. (2013). While my empirical results examine the outcomes for workers employed in industries that *use* the offshored goods, these studies focus on the effects of offshoring on workers employed in industries and occupations that *compete* with the offshored goods. The structural model presented later in the paper additionally incorporates the effect on low-skilled workers who compete with offshoring and shows that the net low-skilled employment is indeed negatively affected.

Few studies examine how offshoring impacts innovation. Glass and Saggi (2001) and Rodriguez-Clare (2010) argue theoretically and Boler et al. (2015) show for Norwegian firms, that innovation increases with offshoring. Naghavi and Ottaviano (2009) instead show that offshoring reduces innovation. I provide a new mechanism by which offshoring leads to greater firm entry resulting in more innovation. I also provide empirical evidence that R&D investment in U.S. manufacturing industries increases in response to a rise in offshoring.

This paper also relates to the large literature on SBTC. Many previous studies argue that SBTC is the primary cause of the rising skill premium and that trade plays a secondary role (see Katz and Murphy (1992), Berman et al. (1994), Lawrence and Slaughter (1993) and Berman et al. (1998), among others.) However, Feenstra and Hanson (1996, 1999) showed that offshoring does raise skill premium within industries. My paper contributes to this "trade versus SBTC" debate by showing that skill-biased technology adoption is endogenous to and reinforced by offshoring.[10] To my knowledge, this is the first study to show that offshoring induces capital deepening.[11]

The rest of the paper is organized as follows. Section 2 presents empirical evidence in support of the technology channel. Section 3 develops a general equilibrium model that captures the technology channel and other mechanisms through which offshoring affects labor outcomes. Section 4 presents the parameterization and provides intuition for how the model works. Section 5 discusses the quantitative predictions of the baseline model and its extension. Section 6 compares the baseline model to an alternative model without the technology channel. Section 7 examines sensitivity of baseline results to parameter values. Section 8 concludes.

2 Facts Supporting Technology Channel

I present evidence in support of the technology channel using data from several sources. Imports and exports data are taken from the Center for International Data at the University of California, Davis. NBER-CES Manufacturing Industry database provides information on industrial characteristics. I take non-production workers as high-skilled

[10] Other mechanisms for endogenous SBTC have also been examined previously. See Acemoglu (1998, 2002a, 2002b) who shows that the skill-bias of technology responds to labor supply, and Thoenig and Verdier (2003) and Bloom et al. (2016) who analyze final goods-trade induced technical change. A related strand of literature analyzes consequences of trade for SBTC in *developing* countries. See, for example, Burstein et al. (2011), Parro (2013), Chamarbagwala (2006), Verhoogen (2008), and Zhu and Trefler (2005).

[11] Acemoglu et al. (2015) show that offshoring induced technical change can be both high- and low-skill biased.

and production workers as low-skilled labor. Data on firm R&D expenditures and R&D intensity (R&D/Sales) are taken from Compustat and aggregated to the industry level. I use input-output tables to construct the measure of offshoring. Finally, data on exchange rates and prices are obtained from Penn World tables and IMF International Financial Statistics. I describe these data sources in greater detail in Appendix A.

Measure of Offshoring: I use the standard measure of offshoring, M_{jt}^{low}, defined as all intermediate goods imported from developing countries[12] and used as inputs in industry j in year t, relative to all intermediates used in that industry and year. The imports data do not distinguish between final and intermediate good imports. So the offshoring measure is constructed by combining imports data with input-output tables and industry data, as follows: $M_{jt}^{\text{low}} = (1/X_{jt}) \sum_{k=1}^{n} r_{jkt} * Q_{jt} * (\text{Imp}_{kt}^{\text{low}}/(Q_{kt} + \text{Imp}_{kt} - \text{Exp}_{kt}))$. In this measure of offshoring, r_{jkt} denotes the direct requirement coefficient in year t for commodity k used as an input in industry j, Q_{jt} represents the output (value of shipments) of industry j, Imp_{kt} and Exp_{kt} are the total imports and exports belonging to industry k, respectively, $\text{Imp}_{kt}^{\text{low}}$ refers to imports belonging to industry k that are sourced from developing countries, 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"[13] developed by Feenstra and Hanson (1999).

This measure of offshoring includes imports of an intermediate input from a foreign country, regardless of whether the input is produced by a firm that is external or affiliated to the offshoring firm. Thus, this measure includes both related party and arm's length trade, and is consistent with the definitions adopted by Feenstra and Hanson (1996, 1999); Grossman and Rossi-Hansberg (2008); and Rodriguez-Clare (2010), among others.[14]

Estimation Strategy: For facts 2-5, I first discuss raw correlations of offshoring with various technology and labor variables in the data. I follow this with instrumental variable

[12] I use the World Bank Income Classification and categorize low income, lower and upper middle income countries as developing.

[13] The narrow measure of offshoring is obtained by considering only those inputs that belong to the same two digit industry as the one to which the output industry belongs.

[14] Note that offshoring is no longer limited to the intermediate stages of production; final goods assembly may also take place offshore. Thus, the extent of offshoring is not entirely captured by measuring imports of intermediate goods. Another limitation of this measure of offshoring is that it does not distinguish between imported inputs that are never also produced domestically within United States and those that are. Thus, this measure captures imports of inputs that represent a shift of production from U.S. to a developing country, but also of those that cannot or have not been produced domestically.

regressions to estimate the impact of offshoring on these outcomes. These reduced form regressions do not shed light on the mechanisms underlying the association of offshoring with technology and labor outcomes. Instead, the estimated coefficients on offshoring indicate the net impact of offshoring on these variables, resulting from the joint contribution of all the mechanisms through which offshoring affects these outcomes. Since, on net, this analysis shows that offshoring has a strong positive association with capital deepening, R&D intensity, and low-skilled employment and wage-bills, it lends support to the technology channel proposed in the paper.

I estimate reduced form regression equations using fixed effects and exchange-rates based instrumental variables to examine the effect of offshoring on technology variables. I estimate the following regression:

$$\ln Y_{jt} = \beta_1 \ln M_{jt}^{\text{low}} + D_t + I_j + \epsilon_{1jt} \tag{2.1}$$

Here, Y_{jt} represents the outcome variables of interest – technology outcomes (equipment-labor ratio and R&D intensity) and labor outcomes (employment and wage-bills of high- and low-skilled labor, ratios and levels) – in industry j in year t. The main regressor is offshoring, M_{jt}^{low}, constructed as described above. All variables are in natural logarithms.[15] Additionally, the regressors also include time and industry fixed effects, denoted by D_t and I_j, respectively.[16] Consistent with the technology channel, I expect the coefficients on offshoring to be positive. The standard errors are robust to arbitrary heteroskedasticity and clustered at the 4-digit industry level.

Since imports may be correlated with disturbances in the regressions described above, fixed effects (FE) estimates will be biased and inconsistent.[17] Both downward and upward biases are possible, but results show that the downward biases are stronger.[18]

[15] Specification tests reject a linear functional form in favor of the log-log specification.

[16] I also include interactions of 2-digit industry dummies with an indicator for whether the year is post-1996. The reason is that in 1997, industry classification changed from SIC (1987) to NAICS (1997) and this definitional change caused a break in the wage and employment series in the data, although the trends remained similar before and after the break.

[17] I present FE estimates in Table A.4 in Appendix A.

[18] Downward bias is likely for several reasons. Since the imported intermediate inputs measure is constructed from raw data, any resulting measurement error causes attenuation bias. Shocks or policies that affect technology or labor outcomes and offshoring in opposite directions can result in downward bias. For example, an increase in taxes can make domestic operations more expensive, resulting in more offshoring and reduced use of equipment and labor. Negative domestic supply shocks can also induce greater imports of inputs and lower employment of capital and labor, leading to downward biased estimates in the corresponding regressions. A financial or debt crisis in a major trading partner country, can also lead to reduced imports and their substitution with domestically produced inputs leading to greater employment of capital, workers, and more R&D, yet again causing a downward bias in all regressions. Upward bias is also possible. For instance, an unobserved technology shock may make some capital equipment that automates routine low-skilled tasks cheaper for an industry. This may reduce intermediate imports as well as domestic employment of low-skilled workers, leading to the corresponding estimates to be biased upwards.

To address endogeneity, I use fixed effects with instrumental variables (FE-IV).[19] Following Revenga (1992), I construct source-weighted industry level nominal exchange rates. The instruments 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 total U.S. imports in a given industry in a base year (1980).[20] 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. I also control for relative price levels in source countries (following Revenga (1992)) by including instruments using the ratio of consumer price indices of the U.S. relative to those of the developing countries it trades with.[21] The method used to construct these instruments is the same as that used for exchange rates.[22]

The validity of these instruments is plausible for two reasons. First, to the extent that exchange rates and aggregate price levels are influenced mainly by macroeconomic factors rather than by 4-digit industry-level shocks, they are likely to be independent of the unobservable industry-year variations in my dependent variables, especially since specifications include industry and year fixed effects. Second, by using static country-specific shares and direct requirement coefficients as weights, and weighting the observations by constant industry size, I avoid several possible factors leading to joint determination of import shares of countries and exchange rates in any given year. In Appendix A, I discuss in detail how this estimation strategy ensures the validity of instruments.[23]

There is substantial variation in the movements of the exchange rates of the U.S. dollar with the currencies of its trading partners (see Appendix Figure A.1). The dollar appreciated against the currencies of all major trading partners, except Taiwan, with

[19]The instrumental variable strategy also corrects for attenuation bias caused by measurement error in the constructed measure of offshoring if the errors are classical, i.e., errors are independent of the signal, and have a mean of zero and a constant variance.

[20]Results for other base years are similar.

[21]The producer price data are missing for several countries and years.

[22]Note that, ideally, I would use real exchange rates to construct instruments. However, it is hard to precisely measure real exchange rates of the U.S. dollar with developing countries' currencies. This is because price data for developing countries may not be reliable and several developing countries experienced episodes of hyperinflation over the sample period, making the real-exchange rate measure noisy. Indeed, results using real exchange rates based instruments have large standard errors.

[23]There may still be reasons why the exclusion restriction may be invalid. I address these remaining concerns in the robustness analysis included in Appendix A. In particular, I present results that control for NAFTA and the Uruguay round of trade negotiations in Table A.5, for pegged exchange rates in Table A.6, and for final goods exports and imports in Table A.7. In Table A.8, I control for interactions of two-digit industry dummies with years. In Table A.9, I define offshoring and the instruments by considering imports of inputs belonging to industries other than the output industry, i.e., industries off the diagonal in the input-output matrix. Results remain similar.

considerable variation across currencies – both in terms of year to year movements and in the extent of appreciation. Figure A.2 additionally shows that the instrument also varies considerably within each year, with this variation increasing over the sample period, suggesting that exchange rates are increasingly market determined. Finally, the instrument varies substantially across industries and is highly correlated with offshoring (see Appendix Table A.1).

Fact 1: Growing shares of U.S. imports come from developing countries. All major industries increasingly use these imports as intermediate goods.

Over the sample period, imports from China saw a meteoric rise. 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. Simultaneously, a number of other developing countries, including Mexico, Brazil, and Thailand, also increased their export shares considerably over time, albeit much less than China (see Appendix Table A.2).

Increase in offshoring is also widespread across all industries. In 2005, the electronics industry had the highest proportion of imported inputs. In 1975, it was second 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 least offshoring industry in 2005 (printing and publishing) had a higher proportion of imported inputs than the highest offshoring industry in 1975 (see Appendix Table A.3).

Fact 2: Offshoring is positively associated with capital deepening.

I start first by documenting raw correlation between average equipment-labor ratio and offshoring. In 1975, the correlation between equipment labor ratio and offshoring was -0.24, suggesting that more high-tech industries were less likely to offshore to developing countries. By 2005, however, this correlation fell to -0.08, indicating that over time increasingly more high-tech industries are engaging in offshoring (see Appendix Table A.3). Note that this negative correlation is driven by a handful of industries that are highly capital intensive but engage in low levels of offshoring – petroleum and coal products, tobacco products, paper and allied products, chemical and allied products, and primary metal industries. Barring these exceptions, we do see that industries that have higher equipment-labor ratio also offshore more, with a correlation of 0.5 in 2005. See Appendix

A.3 for a more detailed discussion.

Table 1: FE-IV Estimation - First Stage

Dependent Variable: Imported Intermediates			
Exchange Rate	-0.202***	-0.245***	-0.256***
	(0.039)	(0.040)	(0.052)
One Year Lagged Exchange Rate		0.069*	0.058**
		(0.039)	(0.027)
Two Years Lagged Exchange Rate			0.048
			(0.049)
Relative Price	-0.060**	-0.038**	-0.033**
	(0.024)	(0.015)	(0.015)
One Year Lagged Relative Price		-0.031*	-0.031***
		(0.017)	(0.010)
Two Years Lagged Relative Price			0.001
			(0.015)
Observations	14,564	14,095	13,626
F statistic	13.75	10.67	9.53
Shea's Partial R-squared	0.012	0.014	0.015

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 enodogenous 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.

I use contemporaneous and lagged exchange rate and relative price based instruments to identify the exogenous variation in imports.[24] Results for the first stage estimates from various specifications are presented in Table 1. In successive columns, I increase the number of lags of the exchange rates and relative price indices based instruments. All lags are statistically and economically significant for the exchange rate based instrument. For

[24]In other specifications (not reported), I use lagged tariffs as instruments, following Cunat and Guadalupe (2009). Data show that U.S. tariffs on imports from developing 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. Because of the small range over which these tariffs vary, there is not enough variation to identify exogenous changes in imported intermediates across industries and years.

Table 2: FE-IV Estimation Second Stage - Technology Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Excluded Instruments - Contemporaneous Exchange Rate and Relative Price						
	Equipment	Total Capital	Equipment / Labor	Total Capital / Labor	R&D	R&D Intensity
Imported Intermediates[1]	0.589***	0.536***	0.385***	0.238***	0.528**	0.399***
	(0.138)	(0.126)	(0.117)	(0.092)	(0.219)	(0.153)
Observations	14,566	14,566	14,097	14,566	13,743	13,743
F statistic	22.54	15.63	98	93.22	13.36	38.47
Panel B: Excluded Instruments - Contemporaneous and One Year Lagged Exchange Rate and Relative Price						
	Equipment	Total Capital	Equipment / Labor	Total Capital / Labor	R&D	R&D Intensity
Imported Intermediates[1]	0.683***	0.602***	0.385***	0.304***	0.620***	0.422***
	(0.160)	(0.142)	(0.117)	(0.100)	(0.232)	(0.155)
Observations	14,097	14,097	14,097	14,097	13,287	13,287
F statistic	19.98	14.36	78.16	80.84	12.43	35.72
Number of 4-digit industries	459	459	459	459	456	456

Notes:
*** p<0.01, ** p<0.05, * p<0.10

[1]: As a proportion of all non-energy materials used in the industry.

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. All observations are weighted by constant industry size.

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

the relative price based instrument the second lag is not statistically significant. The sign pattern of coefficients on the contemporaneous and lagged measures of both instruments reveal the familiar J-curve effect (see, for example, Cunat and Guadalupe (2009)). Immediately after an appreciation of the U.S. dollar vis-a-vis another currency (i.e., an increase in the exchange rate), imports become cheaper. But the quantity of imports demanded rises only after some time has elapsed.[25] Thus, we see that the total dollar value of imports falls in the first year, but rises thereafter. Analogous intuition applies to the ratio of U.S. price index vis-a-vis that of other countries.[26] In the specifications in the first and second columns, the F statistic is above ten, indicating a strong first stage. However, when I include two years lagged measures of the instruments, the F statistic falls to 9.53. Below, I present the second stage results for the specifications that include either only the contemporaneous, or contemporaneous and one year lagged measures of

[25]This may be because import contracts may take some time to be re-written.

[26]While the coefficient on nominal exchange rate instrument turns positive with one year lag, that on relative price instrument turns positive only with two years lag. However, since we want to see variation in imports due to movements in real exchange rates, we should consider the joint contribution of nominal exchange rate and relative price. Since the coefficient on the first lag of relative price is smaller in absolute value than that on the first lag of nominal exchange rate, jointly they indicate that with one year lag real exchange rates are positively associated with imports of intermediate inputs.

the instruments.

Table 2, columns 1 through 4, show the second stage results for how offshoring is associated with capital deepening. Panel A identifies the exogenous variation in imports using only the contemporaneous exchange rate and relative price based instruments. Panel B presents results for specifications that additionally include one lag of the instruments.[27] The effect of offshoring on capital deepening is large and statistically significant. Results in Panel B, column (3) show that doubling the imports of inputs from developing countries leads to 38.5% increase in equipment-labor ratio. These estimates imply that a one standard deviation change in imported intermediates leads to a 0.48 standard deviation change in log of equipment-labor ratio. Note that equipment-labor ratio could simply rise mechanically if offshoring is associated with a decline in employment of labor domestically. However, estimates in columns (1) and (2) show that offshoring industries use more equipment and total capital, in levels, and not just relative to labor.

Fact 3: Offshoring is positively associated with innovation.

Both at the beginning and end of the sample period, industries that spent more on R&D activities were also more likely to offshore more. In 1975, the correlation between offshoring and R&D was 0.058 but it rose to 0.531 by 2005 (Appendix Table A.3). Further, industries that saw the largest increases in offshoring also increased their R&D intensity the most – the correlation between changes in offshoring and changes in R&D intensity over 1975-2005 across two-digit industries is 0.5.

Table 2, columns 5 and 6, show how offshoring affects R&D and R&D intensity. We see that an industry that doubles its offshoring witnesses about 42% increase in its R&D intensity. In terms of standard deviations, these estimates imply that a one standard deviation change in imported intermediates leads to a 0.32 standard deviation change in the log of R&D intensity.

Note that innovation, as measured in the data, reflects product innovation. According to Compustat data documentation, these R&D expenditures include all costs incurred to develop new products and services. Thus, this measure includes all expenditures made to develop new products that may be both horizontally and vertically differentiated.

The estimates do seem large, but, nonetheless, demonstrate strong technology effects of offshoring in U.S. manufacturing industries. Further, the positive response of equipment-labor ratio and R&D intensity do not simply reflect the scale effect of off-

[27] All variables are in logs. Both specifications fail to reject the joint null hypothesis of instrument validity, and have a strong first stage.

shoring. I estimate regressions of these technology variables on imported intermediates, including industrial output as an additional control. When controlling for output (see Appendix Table A.11), the estimated coefficients on imported intermediates are 0.38 and 0.4 in the regressions for equipment-labor ratio and R&D intensity, respectively. Thus, controlling for output does not reduce the estimates significantly, indicating that although scale effect exists, it does not explain the majority of the effect.

Fact 4: Offshoring is positively associated with employment and wage-bills of high- relative to low-skilled workers.

Over the sample period, more skill intensive industries offshore more. Data show that offshoring is positively correlated with the wage-bill and employment ratios of non-production relative to production workers across industries. In 1975, the correlation between offshoring and employment (wage-bill) ratio was 0.05 (0.16) but rose to 0.61 (0.62) by 2005 (Appendix Table A.3). Figure 1(a) in the introduction also showed that average changes in offshoring across industries over 1975-2005 are positively correlated with changes in the relative wage-bills of high-skilled workers.

Next, let us examine the instrumental variable estimates examining the effect of offshoring on these relative labor outcomes. Columns 1 and 2 of Table 3 show that offshoring leads to substantial increases in the relative wage-bill and employment of high-skilled workers. Results in Panel B show that doubling offshoring within a year and industry leads to 11% increase in the employment ratio and 13.2% increase in the wage-bill ratio of non-production workers relative to production workers.

Non-production workers' levels of employment and wage-bills increase substantially with offshoring. Note, however, that most of the increase in wage-bills at the industry level is likely driven by the increase in employment. Indeed, the coefficient estimate on wage-bill for non-production workers (0.36) is numerically close to that on employment (0.34), indicating that the wage level increased only slightly. This is borne out in the regression for real wage level in column 5, which shows that doubling offshoring in an industry is associated with 1.5% increase in non-production wages, and this estimate is statistically indistinguishable from zero. These results indicate that wages are closely aligned across 4-digit industries, as is likely due to worker mobility across these narrowly defined industries. Thus, industry level data are not ideal to examine the effects of offshoring on wage levels. However, we can examine the wage effects in general equilibrium

Table 3: FE-IV Estimation Second Stage - Labor Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Excluded Instruments - Contemporaneous Exchange Rate and Relative Price									
	Employment Ratio	Wage Bill Ratio	Non-Production Wage Bill	Non - Production Employment	Non - Production Wages	Production Wage Bill	Production Employment	Production Wages	Gross Output
Imported Intermediates[2]	0.087*	0.110**	0.356***	0.341***	0.015	0.245**	0.254**	-0.009	0.372***
	(0.049)	(0.051)	(0.118)	(0.114)	(0.023)	(0.105)	(0.104)	(0.024)	(0.116)
Observations	14,565	14,564	14,564	14,565	14,563	14,566	14,566	14,566	14,566
F statistic	35.68	26.11	18.21	16.48	63.19	44.14	43.52	72.29	24.87
Hansen's J statistic (p-value)[1]	0.69 (.41)	1.13 (0.29)	1.31 (.25)	0.01 (.91)	21.39 (.00)	0.55 (.46)	0.06 (.81)	18.01 (.00)	8.22 (.00)
Panel B: Excluded Instruments - Contemporaneous and One Year Lagged Exchange Rate and Relative Price									
	Employment Ratio	Wage Bill Ratio	Non-Production Wage Bill	Non - Production Employment	Non - Production Wages	Production Wage Bill	Production Employment	Production Wages	Gross Output
Imported Intermediates[2]	0.111**	0.132**	0.381***	0.352***	0.030	0.249**	0.240**	0.009	0.418***
	(0.049)	(0.051)	(0.122)	(0.115)	(0.023)	(0.106)	(0.103)	(0.022)	(0.119)
Observations	14,096	14,095	14,095	14,096	14,094	14,097	14,097	14,097	14,097
F statistic	33.69	20.68	16.48	15.42	58.32	42.52	44.28	70.82	22.32
Hansen's J statistic (p-value)[1]	2.46 (.48)	4.28 (.23)	6.04 (.11)	4.72 (.19)	23.93 (.00)	3.21 (.36)	3.43 (.33)	16.77 (.00)	18.11 (.00)
Number of 4-digit industries	459	459	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 we are unable to reject the null hypothesis that the instruments are valid.

[2]: 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 2 digit industry dummies with an indicator for whether the year is post 1996. All observations are weighted by constant industry size.

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

using the quantitative model of the aggregate economy later in the paper.[28]

Fact 5: Offshoring is positively associated with employment and wage-bills of low-skilled workers.

Raw correlations in the data show that while the low-skilled wage-bill was negatively correlated with offshoring in 1975, it rose to 0.55 by 2005, suggesting that industries that offshore more also have higher low-skilled wage-bills. Figure 1(b) also showed a correlation of 0.4 between average industry-level changes in offshoring and low-skilled wages over 1975-2005.

Next, consider the instrumental variable estimates in columns 3-4 and 6-7 in Table 3. These results show that although inequality increases between non-production and production workers, both groups benefit in terms of absolute wage-bills and employment. According to results in Panel B, doubling offshoring leads to 25% increase in the wage-bill and 24% increase in the employment of production workers. Estimates imply that a one standard deviation change in imported intermediates (=1.22) leads to 0.34 and 0.38 standard deviation changes in the relative employment and wage-bills of non-production workers. However, for the same change in imported intermediates, production workers' employment and wage-bills also rise by 0.24 and 0.25 standard deviations. Estimates in panel A are similar to those in panel B, though slightly smaller in magnitude. Finally, as in the case of non-production workers, the estimated coefficient on imported intermediates is small and statistically insignificant in regressions for production worker wages.

The gains for low-skilled workers seen in Table 3 may also be driven by imperfect substitution between imported and domestic intermediates. If imported intermediates perfectly substitute for low-skilled workers, wage-bills and employment could increase only through expansion in output, i.e. the scale effect. In that case, if we controlled for the scale effect, we should see that offshoring has a negative effect on low-skilled wage-bill and employment. Data suggest, however, that low-skilled wage-bills and employment are positively associated with offshoring even when output is held constant. I find that the aggregate time series correlation between offshoring and production workers' wages, weighted by constant industry size, is 0.08. Additionally, regressions presented in Appendix Table A.11 show that while the positive scale effect is strong, controlling for it does not lead to a negative effect of offshoring on low-skilled employment. Including output as

[28] Another reason why wage regressions may not be informative is that wages can potentially increase if the least productive among the non-production (or production) workers are displaced by offshoring. This potential pitfall is also overcome in the quantitative model since it considers only two types of workers with no skill heterogeneity within types.

a regressor, offshoring continues to have a positive, albeit statistically insignificant, effect on the wage-bill and employment of low-skilled workers. However, these coefficients are sensitive to the set of excluded instruments. They are larger (0.132 and 0.167, respectively) and statistically significant at the 10% and 5% levels, respectively, if the excluded instruments are contemporaneous and one year lagged exchange rates only. Further, output is an endogenous regressor in these regressions. Nonetheless, these regressions suggest that offshoring has a non-negative effect on low-skilled worker outcomes even when the scale effect is accounted for.[29] These results suggest that imported intermediates may not be perfect substitutes for domestically produced low-skilled intermediates. In section 4.2, I also explain theoretically why imperfect substitution between imported intermediates and domestic low-skilled labor is a necessary condition for a non-negative association between low-skilled wages and offshoring.

3 Model

The evidence presented in section 2 lends support to the technology channel by showing that industries that offshore witness (1) skill-complementary capital deepening and greater innovation, (2) an increase in wage-bill and employment gaps between high- and low-skilled workers and (3) a rise in wage-bill and employment of low-skilled workers. I now develop a general equilibrium model that formalizes the mechanisms underlying these technology and labor impacts of offshoring in the aggregate economy.

I present a model of trade in intermediates between a developed (North) and a developing (South) country. Final goods in both countries are produced using intermediate inputs. The North imports low-skilled intermediates from the South (offshoring) as the latter has a comparative advantage in producing these goods. These imports serve as

[29]The finding of a strong positive scale effect of offshoring on low-skilled employment is consistent with the conclusion of Wright (2014) who also found this effect to be large. However, Wright (2014) also finds that this effect is not strong enough to reverse the negative substitution effect of offshoring, so that, in the aggregate, low-skilled employment does fall. This difference in results may be driven by several factors besides the limitations of the regression described above. While Wright focuses solely on imports from China in the post 2001 period, I consider imports from all developing countries and for a much longer time period (1974-2005). China became an important trading partner only in the second half of this sample period, and saw a meteoric rise after its WTO entry in 2001. Second, the instrumental variable used to identify exogenous variation in offshoring is different. Third, while Wright (2014) uses the "narrow" measure of offshoring, restricting to imports of inputs that come from the same 3-digit NAICS industry as the output industry, I use the "broad" definition (Feenstra and Hanson (1999)) that includes imports of inputs from all industries. This difference may be particularly important since restricting to the narrow definition may mean that imported inputs substitute more highly (than in the broader definition) for low-skilled workers in the output industry, leading to a larger negative effect on their employment.

substitutes for domestically produced low-skilled intermediates in the North. This substitution triggers indirect technology effects. The model also allows for other effects of offshoring suggested in previous literature that I refer to simply as "other" effects.

The North has three factors of production: high-skilled labor, low-skilled labor, and capital equipment – H, L, and K, respectively, while the South has only low-skilled labor and capital, denoted by L^*, and K^*, respectively. The respective factor payments are denoted by W_h, W_l (W_l^* in the South), and R (R^* in the South). Time periods (years) are indexed by $t \in \{1, 2, ..., \}$.

3.1 The North

Households

A representative household owns firms and supplies capital, high-, and low-skilled labor to these firms. It uses the composite good of the economy for consumption, investment, and the purchase of new firms. Letting the composite good be the numeraire and assuming perfect foresight, the household faces the following optimization problem:

$$\begin{aligned}
&\underset{C_t, H_t, L_t, K_{t+1}, N_t}{\text{Max}} \mathcal{U} = \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \theta_h \frac{H_t^{1+\chi_h}}{1+\chi_h} - \theta_l \frac{L_t^{1+\chi_l}}{1+\chi_l} \right) \\
&\text{subject to} \\
&C_t + I_t + v_t N_t^E = W_{ht} H_t + W_{lt} L_t + R_t K_t + \pi_t N_t \\
&K_{t+1} = (1 - \delta^K) K_t + I_t \\
&\text{and } N_t = (1 - \delta^N) N_{t-1} + N_t^E
\end{aligned} \tag{3.1}$$

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 new firms, π_t denotes the profits of each firm that accrue to the households, and $\delta^K, \delta^N \in (0, 1)$ are the depreciation rate of capital and the exit rate of firms, respectively. The discount factor is given by $\beta \in (0, 1)$, $\theta_h, \theta_l > 0$ are the disutility weights on high- and low-skilled labor supply, and $\chi_h, \chi_l \geq 0$ are the inverse Frisch elasticities of high- and low-skilled labor supply, respectively. [30] While making its decisions, the household takes W_h, W_l, and R as given.

[30] This set-up draws on Jaimovich and Floetotto (2008). Specifically, the utility function is similar in their model except that labor is homogeneous.

Industries and Firms

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

$$Y_t = \left[\int_0^1 Q_t(j)^{\omega}\, dj\right]^{\frac{1}{\omega}} \quad , \omega < 1 \tag{3.2}$$

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

$$Q_t(j) = \left[\int_{i=0}^{N_t} q_t(j,i)^{\eta}\, di\right]^{\frac{1}{\eta}} \quad , \eta < 1 \tag{3.3}$$

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.[31] The differentiated goods are produced with a CES technology using high- and low-skilled intermediate goods, denoted x_{ht} and x_{lt}, respectively. The low-skilled intermediate goods can also be offshored (i.e., imported from the South). These imports, denoted by m_{lt}, are highly substitutable for domestically produced low-skilled intermediates. Thus, the production function for differentiated goods is:

$$q_t(j,i) = [\lambda[x_{lt}(j,i)^{\sigma} + m_{lt}(j,i)^{\sigma}]^{\frac{\gamma}{\sigma}} + (1-\lambda)x_{ht}(j,i)^{\gamma}]^{\frac{1}{\gamma}} \ , \lambda \in (0,1)\,, \gamma < 1, 0 < \sigma < 1 \tag{3.4}$$

In this production function, the elasticity of substitution between x_{lt} and m_{lt} is $1/(1-\sigma)$ and that between low- and high-skilled intermediates is $1/(1-\gamma)$. 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. In the second stage, they maximize profits, taking the prices of intermediate goods as given.

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

The intermediate good producing firms are perfectly competitive and face the stan-

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

dard profit maximization. High-skilled intermediates are produced using equipment capital and high-skilled labor, while low-skilled intermediate goods are produced using only low-skilled labor:

$$x_{ht} = k_t^{\mu} h_t^{1-\mu} \ , \mu \in (0,1) \, , \tag{3.5}$$

$$x_{lt} = l_t \tag{3.6}$$

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

$$Q_t(j) = \left(\frac{p_t(j)}{P_t} \right)^{\frac{1}{\omega-1}} Y_t \tag{3.7}$$

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

$$P_t = \left[\int_0^1 p_t(j)^{\frac{\omega}{\omega-1}} \, dj \right]^{\frac{\omega-1}{\omega}} \tag{3.8}$$

The industrial demand for the differentiated goods produced by firms is given by:

$$q_t(j,i) = \left[\frac{p_t(j,i)}{p_t(j)} \right]^{\frac{1}{\eta-1}} \left[\frac{p_t(j)}{P_t} \right]^{\frac{1}{\omega-1}} Y_t \tag{3.9}$$

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

$$p_t(j) = \left[\int_{i=0}^{N_t} p_t(j,i)^{\frac{\eta}{\eta-1}} di \right]^{\frac{\eta-1}{\eta}} \tag{3.10}$$

Letting the composite good of North be the numeraire, $P_t = 1$.

Innovation and Entry

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

$$\Psi_{nt} = [\varphi k_{nt}^{\alpha} + (1-\varphi) h_{nt}^{\alpha}]^{\frac{1}{\alpha}} \ , \alpha < 1 \tag{3.11}$$

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

3.2 The South

Households

A representative household faces the following optimization problem:

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

$$\text{subject to}$$

$$P_t^* C_t^* + C_{mt}^* + P_t^* I_t^* = W_{lt}^* L_t^* + R_t^* K_t^*$$

$$\text{and } K_{t+1}^* = (1-\delta) K_t^* + I_t^* \tag{3.12}$$

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. The household is endowed with one unit of labor in every period. P_t^* is the price of final goods produced in the South and δ is the rate of depreciation of capital.

Firms

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

$$Y_t^* = [X_{slt}^{*\zeta} + K_t^{*\zeta}]^{\frac{1}{\zeta}} \ , \zeta < 1 \tag{3.13}$$

where X_{slt}^* 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 low-skilled labor. Firms face the standard profit maximization problem.

Finally, we have the balanced trade condition such that exports from the North are equal to the exports from the South: $C_{mt}^* = p_{lt}^* M_{lt}$, where M_{lt} is the total quantity of intermediates exported from the South to the North.[32]

3.3 Equilibrium

Since all households and firms are symmetric in their utility functions and technologies, respectively, I focus on symmetric equilibria. Given this normalization and symmetry, I solve for an equilibrium, which consists of: prices of intermediate goods, $(p_{lt}, p_{ht}, p_{lt}^*)$,

[32] Note that the trade cost does not appear in the trade balance equation since it is not modeled as the standard iceberg cost where the South exports a higher quantity of goods than would ultimately reach the North. Instead, I model it as a cost incurred by the North but not paid to the South. This trade cost incurred by the North is, therefore, accounted for in its aggregate resource constraint.

prices of final goods, $(P_t, p_t(j), p_t(j,i), P_t^*)$, factor prices, $(W_{lt}, W_{ht}, R_t, W_{lt}^*, R_t^*)$, price of innovation goods, p_{nt}, and price of firms, v_t; allocations of labor, (l_t, h_t, h_{nt}), and capital, (k_t, k_{nt}); the total supplies of labor, (L_t, H_t, L_t^*), and capital, (K_t, K_t^*); quantities of intermediates, $(x_{ht}, x_{lt}, X_{ht}, X_{lt}, X_{lt}^*, X_{slt}^*)$; imports of intermediate goods by the North, (m_{lt}, M_{lt}), exports to the South, C_{mt}^*, final goods, (Y_t, Q_t, q_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 following:

- Consumers in the North and South maximize their lifetime utility following the optimization problems 3.1 and 3.12.
- Final and intermediate good firms in the North and South and innovation good producing firms in the North maximize profits subject to their production functions.
- New firm entry is such that the cost of innovation is equal to the present discounted value of future profits, i.e., $v_t = \frac{\pi_t}{1-\beta(1-\delta^N)} = p_{nt}\psi$.
- Trade is balanced.
- Markets for all goods and factors of production clear and the aggregate resource conditions are met in the North and South, as described below.

The market clearing conditions in the North are as follows:

$$K_t = N_t k_t + k_{nt} \tag{3.14}$$

$$L_t = N_t l_t \tag{3.15}$$

$$H_t = N_t h_t + h_{nt} \tag{3.16}$$

$$X_{ht} = N_t x_{ht} \tag{3.17}$$

$$X_{lt} = N_t x_{lt} \tag{3.18}$$

$$M_{lt} = N_t m_{lt} \tag{3.19}$$

$$\Psi_{nt} = \psi N_t^E \tag{3.20}$$

The market clearing condition in the South is:

$$X_{lt}^* = M_{lt} + X_{slt}^* \tag{3.21}$$

Aggregate resource constraint in the North is[33]:

$$Y_t = C_t + I_t + vN_t^E + (1+\tau)p_{lt}^* M_{lt} \tag{3.22}$$

Aggregate resource constraint in the South is:

$$P_t^* Y_t^* = P_t^* C_t^* + P_t^* I_t^* + C_{mt}^* \tag{3.23}$$

[33]The last term in equation 3.22 can alternatively be written as: $C_{mt}^* + \tau p_{lt}^* M_{lt}$

Symmetry over firms and industries[34] implies

$$Y_t = Q_t = N_t^{\frac{1-\eta}{\eta}} q_t \tag{3.24}$$

$$\pi_t = \left(\frac{z-1}{z}\right) q_t \tag{3.25}$$

4 Parameterization and Intuition for Key Model Features

4.1 Parameterization

The parameter values in the baseline specification are listed in Table 4. I focus first on 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 $q_t(j,i)$, such that the elasticity of substitution between low-skilled and high-skilled intermediates is 1.67. By construction, the substitution elasticity between capital and high-skilled labor in the production of high-skilled intermediates is 1. In the production function for innovation goods, I set α such that the elasticity of substitution between high-skilled labor and capital is 0.67, following Krusell et. al. (2000).

I fix η to yield a markup of 1.225 – the average of the range of values (1.05 to 1.4) estimated in the literature (see Jaimovich and Floetotto (2008)). In the sensitivity analysis, I vary the value of η 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 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 parameterization, I set the elasticities of both kinds of labor at 1. Later, I examine sensitivity of results to these elasticities.

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,

[34] An equivalent model can be written that aggregates firms' outputs to the composite final good, Y, and does not include industries. However, since the data used in the paper are at the industry level, I aggregate firms' output to industries first so as to make the model results conceptually comparable to the data.

Table 4: Parameterization

Parameter	Description	Value	Target
	North		
	Parameter Values Taken from Literature		
ω	Governs elasticity of substitution between industrial goods	0.001	Jaimovich and Floetotto (2008)
η	Governs elasticity of substitution between firm level goods, and markup	0.8163	Markup=1.225
α	Governs elasticity of substitution between high-skilled labor and capital in production of innovation goods	-0.495	Krusell et. al. (2000)
χ_l	Frisch elasticity of low-skilled labor supply	1	Kimball and Shapiro (2008)
χ_h	Frisch elasticity of high-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
γ	Governs the elasticity of substitution between high- and low-skilled intermediates	0.401	Krusell et. al. (2000)
ψ	Fixed cost of entry	0.6	Baseline assumption
β	Time discount factor	0.96	Standard for annual data
δ^K	Depreciation rate for capital	0.08	Standard
δ^N	Exit rate of firms	0.10	Standard
	Parameter Values Calibrated to Data		
λ	Share of low-skilled intermediates in production of differentiated goods	0.486	Average skill premium=1.6
μ	Share of capital in total output of high-skilled intermediates	0.63	Overall share in production=0.3
φ	Share of capital in the production of innovation goods	0.3	Overall share in total output = 0.3
θ_l	Disutility weight on low-skilled labor	1.155	Share of low-skilled labor=0.7
θ_h	Disutility weight on high-skilled labor	4.295	Share of high-skilled labor=0.3
	South		
ρ^*	Governs the elasticity of substitution between home produced and imported final goods	0.4	(Close to) Armington elasticity=1.5
ζ	Governs elasticity of substitution between low-skilled intermediates and capital	0.5	Close to North
β^*	Time discount factor	0.96	Standard
δ	Depreciation rate for capital	0.08	Standard

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 the sample period (1974-2005), about 70% of the employed workers are production workers and 30% are non-production workers. Normalizing the total amount of labor supply in initial steady state to 1, the disutility weights on the high- and low-skilled 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 low-skilled intermediates, λ, in the production of $q_t(j,i)$ is set at 0.486, and the share of high-skilled workers, $(1-\mu)$, in the production of high-skilled intermediates is set at 0.37 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 0.3 (Krusell et. al. (2000)), respectively. I set the weight, φ, on capital in the technology for innovation also at 0.3.

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

For the parameters in the South, I keep the parameterization close to the North. 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. Finally, ρ, is set at 0.4 so that the elasticity of substitution between consumption of home produced and imported goods is 1.67.[35]

4.2 Intuition for Key Model Features

I describe the role played by three features of the model: (1) imperfect substitution between imported and domestic low-skilled intermediates, (2) capital-skill complementarity in the production of differentiated goods, and (3) entry of new firms requires purchase of innovation goods.

Imperfect Substitution Between Imported Intermediates and Low-Skilled Labor: I show that for greater offshoring to result in higher wages for low-skilled workers,

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

imported intermediates must be imperfectly substitutable for domestic low-skilled labor. Substituting equations 3.5 and 3.6 into equation 3.4, we get:

$$q_t(j,i) = [\lambda(l_t(j,i)^{\sigma} + m_{lt}(j,i)^{\sigma})^{\frac{\gamma}{\sigma}} + (1-\lambda)(k_t(j,i)^{\mu} h_t(j,i)^{1-\mu})^{\gamma}]^{\frac{1}{\gamma}} \tag{4.1}$$

In the above equation, the elasticity of substitution between m_l and l is $1/(1-\sigma)$. Using the first order conditions from profit maximization, we have:

$$\frac{w_{lt}}{(1+\tau)p^*_{lt}} = \left(\frac{l_t(j,i)}{m_{lt}(j,i)}\right)^{\sigma-1} \tag{4.2}$$

Perfect substitution or infinite elasticity of substitution between imported and domestic substitutes occurs when $\sigma = 1$. If $\sigma = 1$, equation 4.2 would be: $w_{lt} = (1+\tau)p^*_{lt}$. From this equation, we can see that a decline in the effective price of imported intermediates will necessarily lead to a decline in low-skilled wages. However, if $m_{lt}(j,i)$ and $l_t(j,i)$ are imperfectly substitutable, with $\sigma < 1$, then domestic low-skilled wage may not fall in response to imports becoming cheaper; if this elasticity is sufficiently small, low-skilled wage may in fact rise.

In the baseline specification, 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 low-skilled 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. As Figure 3 shows, the gain in low-skilled wage as a result of greater offshoring declines as this elasticity increases. At $\sigma = 0.967$, i.e., when elasticity of substitution between imported and domestic low-skilled intermediates equals 30, low-skilled wage falls in response to greater offshoring. This fall grows in magnitude as the elasticity increases further.

Capital Deepening: Next, I describe how offshoring can induce skill-complementary capital deepening and its implications for high- and low-skilled labor. In equation 3.5, the elasticity of substitution between $k_t(j,i)$ and $h_t(j,i)$ is 1, by construction. Restricting γ to be strictly positive, we have $1/(1-\gamma) > 1$. Hence, the elasticity of substitution between $k_t(j,i)$ and $l_t(j,i)$ (or $m_{lt}(j,i)$) is greater than the elasticity of substitution between $k_t(j,i)$ and $h_t(j,i)$. Thus, with the parameter restriction on γ we have built capital-skill complementarity (i.e., capital is less substitutable with high- than with low-skilled labor) into the production function. Further, I restrict γ to be less than 1 so that the elasticity of substitution between $k_t(j,i)$ and $l_t(j,i)$ (or $m_{lt}(j,i)$) is finite. In other words, $k_t(j,i)$ and $l_t(j,i)$ (or $m_{lt}(j,i)$) are imperfect substitutes, i.e., there is some

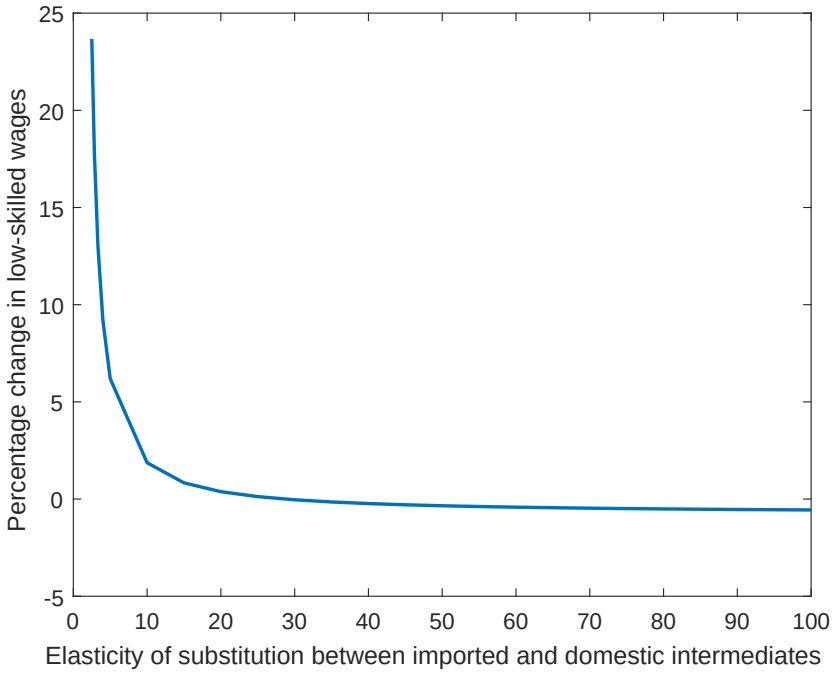
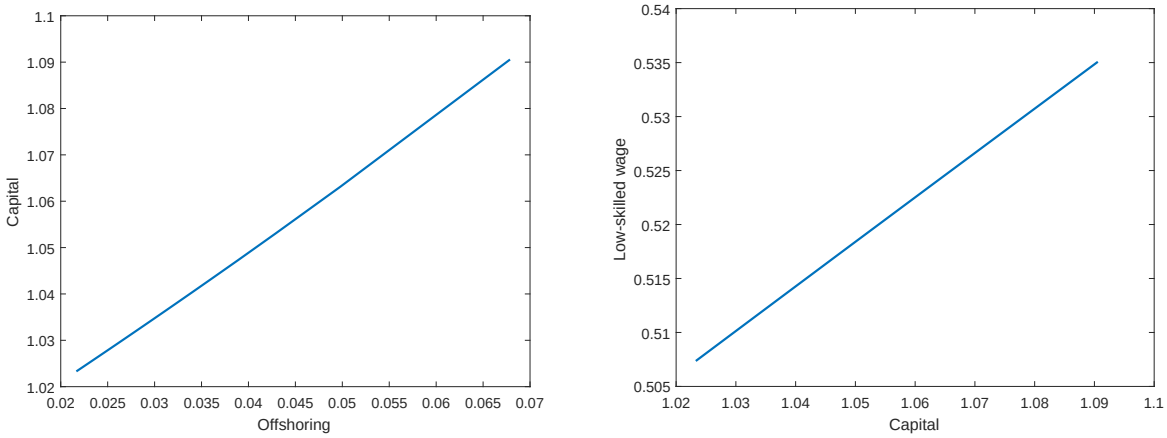


Figure 3: Low-Skilled Wage Change Sensitivity to Substitution Elasticity[a]

[a]The figure shows how the percentage changes in low-skilled wage between the low and high offshoring steady states vary as the elasticity of substitution between imported and domestic intermediate goods increases.



(a) (b)

Figure 4: Capital Deepening and Low-Skilled Wage[a]

[a]Figures 4(a) and 4(b) plot numerical values for offshoring, capital, and low-skilled wage as obtained from the model using the baseline parameterization described in Section 4.1.

complementarity between them.

Now, if there is an exogenous decline in the price of imported intermediates, the

firm will import more. This will increase the marginal return to using capital since it is imperfectly substitutable with imported intermediates. The firm will be induced to use more capital. Thus, greater offshoring leads to skill-complementary capital deepening. Figure 4(a) plots levels of capital stock in the North as it imports increasingly higher levels of low-skilled intermediates due to lower trade costs. The figure shows that as North offshores more, it also uses greater capital. Further, since capital is imperfectly substitutable with low-skilled labor, the firm will also expand its demand for low-skilled labor, leading to an increase in the low-skilled wage. Indeed, Figure 4(b) shows that as the economy uses more capital, the low-skilled wage also increases.

R&D: Imperfect substitution between imported intermediates and domestic low-skilled labor, scale effect, and capital deepening are all channels through which offshoring affects firm activity along the intensive margin. But offshoring can also affect firms along the extensive margin by inducing net firm entry. I capture this effect in the model by allowing for endogenous firm entry that requires innovation.[36] I provide intuition for how this feature works in the model.

In the symmetric equilibrium of model described in Section 3.3, we found that $\pi_t = ((z-1)/z)q_t$ (equation 3.25). Using this, we can find the present discounted value of future stream of profits (same as the marginal benefit of entry) as:

$$v_t = \frac{\pi_t}{1-\beta(1-\delta^N)} \tag{4.3}$$

Now, if there is an exogenous decline in the price of imported intermediates, the firm imports more, and the scale effect leads to greater output, q_t (see Figure 5). From the expression for π_t, one can see that that an increase in q_t leads to higher π_t, and hence, higher present discounted value of future stream of profits, v_t. Thus, entry becomes more attractive, leading more new firms to enter. But entry requires innovation. Thus, greater offshoring induces an increase in net entry of firms and, hence, more R&D. Indeed, Figure 5 shows that as trade costs fall in the model (leading to greater offshoring), the mass of firms, N_t, increases.[37]

[36]This set up is motivated by the definition of innovation in the data – expenditures incurred to produce new products. Since I model a firm as a single product firm, producing a new product is the same as new firm entry. Thus, innovation in the model is associated with the extensive margin (firm entry), although in the data it is an intensive margin activity of multi-product firms.

[37]Note that offshoring can also potentially generate firm exit. This can happen for two reasons. First, a firm may be exposed to competition from imported goods and be forced to exit. Second, if firms are heterogeneous in their productivity, some may offshore their intermediate goods, while others do not. While the former group of firms would reduce their costs through offshoring, the latter may not succeed in achieving a similar cost reduction. If so, non-offshoring firms would be unable to compete with offshoring firms, and, hence, be forced to exit. The model presented in the paper allows for the

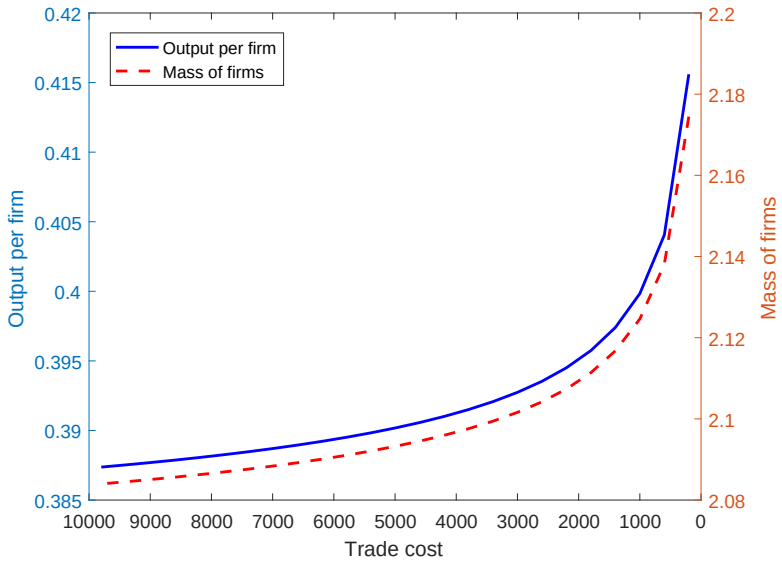


Figure 5: Mass of Firms and Their Output Increases With Offshoring[a]

[a]Figure 5 plots the equilibrium numerical values for the mass of firms and output per firm corresponding to different values of the trade cost, as obtained from the model using the baseline parameterization described in Section 4.1.

Finally, since R&D is a skill-intensive activity, this leads to greater demand for high-skilled labor and capital. And, as more firms enter and start producing, the demand for low-skilled workers also increases.[38]

In summary, the above production function, with parameter restrictions on σ and γ, and assuming a monopolistically competitive market structure in which entry requires innovation, gives the three predictions of the technology channel: 1. greater offshoring leads to capital deepening and more innovation, 2. offshoring induced capital deepening and innovation lead to greater demand (and hence higher employment and wages) for both high- and low-skilled workers, although more so for high-skilled workers, and 3. for greater offshoring to lead to higher domestic low-skilled wages, imported intermediates must substitute imperfectly for domestic low-skilled workers.

first possibility, in principle. In response to competition from low-skilled intermediates imported from the South, the production of domestic low-skilled intermediates falls. Currently, these firms are modeled as perfectly competitive. If the intermediates good firms were modeled as monopolistically competitive, this mechanism would entail firm exit in response to offshoring. The model does not incorporate the second possibility, however, since firms are considered to be homogeneous in their productivity, so that they all operate symmetrically.

[38]In the absence of capital accumulation, the mass of firms increases only by a small percentage. In particular, fixing capital at its level in the initial steady state (corresponding to the 1974 offshoring level of 1.8%) and reducing trade cost such that offshoring reaches its 2005 level of 19% in the new steady state, shows that the mass of firms increases only by 1.4%, instead of 17% as in the baseline with capital accumulation.

5 Quantitative Results

This section discusses the effects of an increase in offshoring using the experiment of an exogenous reduction in trade costs. It also discusses an extension of the baseline model.

5.1 Comparison of Steady States

I numerically solve for steady states for various levels of the trade cost, τ. 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 τ leading to higher levels of offshoring. In 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, $\frac{(1+\tau)p^*_{lt}M_{lt}}{(1+\tau)p^*_{lt}M_{lt}+p_{ht}X_{ht}+p_{lt}X_{lt}}$[39] in 1974 was 0.018. By 2005, this figure had grown to 0.19. I start with a high trade cost of 17,800 so as to match the 1974 level of offshoring (1.8%) and reduce the trade cost to 1.132 which matches the 2005 level of offshoring (19%).

The steady state values (corresponding to $\tau = 17,800$ and $\tau = 1.132$) for the outcomes of interest in the North are presented in Table 5.[40] The table also shows how the empirical counterparts of these key outcomes changed in U.S. data between 1974 and 2005.[41] Of course, several factors besides offshoring influenced these variables in the data. Since the objective of the baseline model is to understand how offshoring impacts labor outcomes, I do not include factors other than offshoring in this section. Hence, it is no surprise that the results from the model are not quantitatively close to the data. Instead, what the table can tell us is the contribution of offshoring to the overall changes in these outcomes in the data.

Consider first the effect of an increase in offshoring on skill upgrading and the skill premium. The model predicts that in response to an increase in offshoring from 1.8% to 19%, the skill premium, or the wage of high-skilled relative to low-skilled labor, rises by 16.4% from 1.6 to 1.8. Also, the relative employment (and supply) of high-skilled labor rises by 16.4% from 0.4 to 0.5. Although the high-skilled wage rises more than the low-skilled wage, the low-skilled wage also rises by a substantial 23.7%. In terms of

[39] This measure corresponds to the measure of offshoring used in section 2.

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

[41] For ease of comparison with the data, I report values (prices multiplied by quantities) of the outcomes of interest from the model, wherever applicable, since I generally observe only the dollar values of the various variables in the data.

Table 5: Quantitative Results

	Steady state with offshoring=1.8% (corresponding to 1974)	Steady state with offshoring=19% (corresponding to 2005)	% change in model	% change in data
	(1)	(2)	(3)	(4)
Relative Employment of High-Skilled Labor	0.4	0.5	16.4	30
Relative Wage of High-Skilled Labor	1.6	1.8	16.4	2
High-Skilled Employment	0.3	0.32	7.7	-17
Low-Skilled Employment	0.7	0.64	-7.5	-34
High-Skilled Wage	0.8	1.2	44.0	9
Low-Skilled Wage	0.5	0.6	23.7	5
Output	0.9	1.5	62.2	300
High-Skilled Intermediates/ Low-Skilled Intermediates	1.2	1.6	32.8	n.a.
Equipment capital in production of high-skilled intermediates	0.1	0.2	30.0	n.a.
Equipment Capital	0.3	0.4	51.1	163
Equipment Capital/ Labor	0.3	0.5	55.7	304
Innovation	0.1	0.2	56.4	2842
Firms	2.1	2.5	17.8	14 (1989-2005)

employment, while the high-skilled workers' employment rises by 7.7%, that of low-skilled workers falls by 7.5%. The increased output per firm combined with a greater number of firms yields a higher value of the aggregate 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 55% of the skill upgrading, and 21% of the expansion in manufacturing output. The change predicted by the model in wages of high-skilled labor is larger than that in the NBER manufacturing industry data for non-production workers. However, the wages for college (high-skilled) workers increased about 50% according to the Current Population Survey data. Wage increase for low-skilled labor predicted by the model is also higher than in the data. This suggests that there may be other forces that exert a downward pressure on low-skilled wages such as routinization, decline of unions, and erosion of real minimum wage. As for employment of both high- and low-skilled workers, the NBER manufacturing data show a decline.

This may be driven by the general shrinking of the manufacturing sector in the United States over the years, as well as other factors, two of which I consider in the extension presented in section 5.3.

Now, let us consider the technology variables. Between columns (1) and (2), the skill-complementary capital employed to produce high-skilled intermediates rises by 30%. The total mass of firms rises by 17.8%, while innovation increases by 56.4%. We also see substantial technology adoption resulting from offshoring; the total value of equipment capital in the North rises from 0.283 to 0.427 – an increase of nearly 51.1%. Relative to labor, equipment capital grows 55.7%. Comparing these changes to the total changes in the data shows offshoring can explain 31% of the growth in equipment capital stock and 18% of the increase in equipment-labor ratio. The offshoring increase in the model can explain 2% of the total increase in innovation expenditures in the data. This is likely 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.

Finally, I examine the welfare implications of greater offshoring in the baseline model. For this purpose, I use the dynamic equations of the model to calculate the transition paths.[42] The welfare metric that I use is the equivalent variation in consumption from a change in trade costs, i.e. the extra consumption needed by households for them to be indifferent between the old steady state with low offshoring and transition to the new steady state with high offshoring. Using this metric, the baseline model shows a substantial 17% increase in welfare.

To summarize, a comparison of steady states with low and high offshoring shows the following. As offshoring increases, we observe (1) a higher relative production of high-skilled intermediates, (2) a higher level of skill-complementary capital employed to produce high-skilled intermediates, and (3) an increase in innovation. These effects of offshoring lead to an increase in both high- and low-skilled wages (with high-skilled wage rising more), an increase in high-skilled employment and a decline in low-skilled employment, and a rise in the total output in the North.

5.2 Decomposition

Next, I assess the importance of the technology channel and its two components – capital deepening and increased innovation induced by offshoring – for the overall labor outcomes in the model economy. For this purpose, I shut off capital-skill complementarity and

[42] The transition paths for key variables of interest are presented in Appendix B.

offshoring induced innovation, first separately and then together.

With capital-skill complementarity, increased accumulation of capital results in an increase in the relative marginal product of high- relative to low-skilled workers. On the other hand, with neutral capital, increase in capital increases the marginal products of high- and low-skilled workers equally. This has implications for the wages and employment of high- and low-skilled workers. To quantify the effect of capital-skill complementarity on wages and employment, I eliminate capital-skill complementarity by making capital equally substitutable for high- and low-skilled workers. In particular, I rewrite the production function of the monopolistically competitive firms such that capital has an elasticity of substitution equal to one with high- and low-skilled intermediates (which, in turn, are produced with linear technologies using high- and low-skilled labor, respectively).[43] The resulting percentage changes between steady states are presented in Table 6, column 2.

Offshoring creates an incentive for new firms to innovate and produce differentiated products. I can quantify the effect of this channel on wages and employment by shutting off any offshoring induced increase in innovation. I hold the mass of firms constant at its level in the steady state corresponding to 1974. This implies that in response to the greater profit opportunity resulting from offshoring, no larger net entry of firms occurs than did in the initial steady state. This, in turn, keeps the level of innovation constant at its initial level. Results are presented in column 3 of Table 6.

Finally, I simultaneously eliminate capital-skill complementarity and hold innovation constant. These results are presented in the last column of Table 6. Comparing results in the first and last columns enables us to quantify the contribution of the technology channel.

Comparing baseline results with results from the decomposition simulations suggest that both capital-skill complementarity and innovation contribute substantially to the total changes in the baseline model, although capital-skill complementarity contributes more. With neutral capital (i.e., with no capital-skill complementarity), low- (high-) skilled wage increases 16.4% (25%), while holding innovation constant yields an 18.2% (33.1%) increase. Skill premium and employment ratio also increase similarly by 7.3% and

[43]There are multiple ways of eliminating capital-skill complementarity, i.e., making capital equally substitutable for high- and low-skilled labor. The method that I follow is the closest counterpart to the alternative model in section 6. The method also requires re-calibrating λ, μ, θ_l, and θ_h to achieve the initial steady state targets for skill premium, capital share in output, supply of low-skilled labor, and supply of high-skilled labor, respectively. Decomposition results presented in Table 6 use this alternative calibration. Results using baseline calibration remain close.

Table 6: Contribution of the Technology Channel

	Baseline	No Capital-Skill Complementarity	No Increase in Innovation	Technology Channel Shut Off
	Percentage Change Between Steady States			
Low-Skilled Employment	-7.5	-4.2	-8.8	-5.6
High-Skilled Employment	7.7	2.8	2.7	-0.5
Employment Ratio	16.5	7.3	12.6	5.4
Low-Skilled Wage	23.7	16.4	18.2	11.9
High-Skilled Wage	44	25.0	33.1	17.9
Skill Premium	16.5	7.3	12.6	5.4
Output	62.2	39.3	52.1	32.2
Consumption	33.7	21.5	29.6	18.5

12.6%, respectively in the two experiments. Shutting off capital-skill complementarity and innovation simultaneously shows that the technology channel accounts for half to two-thirds of the baseline changes. While in the baseline model skill premium increases by 16.5%, with the technology channel shut off, skill premium increases only by 5.4%. Similarly, while there is a 23.7% increase in the low-skilled wage in the baseline model, it increases only by 11.9% when the technology channel is shut off. The changes in output and consumption when the technology channel is shut off are also nearly half of those in the baseline. These results indicate that the technology channel is the dominant mechanism through which offshoring impacts key economic outcomes in the North.

Note that low-skilled employment in the baseline falls by 7.5%, but when the technology channel is shut off, it falls by two percentage points less. This is because capital-skill complementarity and innovation affect low-skilled employment in opposite directions. When capital is skill-complementary, it is relatively more substitutable for low-skilled than for high-skilled intermediates. So, when the marginal cost of production falls with a decline in trade cost, the firms expand output and can easily substitute capital for low-skilled intermediates. However, when capital is equally substitutable with both types of intermediates then the firms use more low-skilled intermediates and cannot as easily substitute for them using capital. Thus, low-skilled employment falls by less than in the baseline where capital is skill-complementary. On the other hand, innovation works to increase the employment of low-skilled labor. Hence, when innovation is held constant, employment of low-skilled labor declines more between steady states than in the baseline model. The effect of capital-skill complementarity is stronger than the effect of innovation so that when the two are simultaneously shut off, the total decline in low-skilled

employment is less than in the baseline.

5.3 Extension

The baseline model focuses on quantifying the labor market effects of offshoring and does not allow for any other changes. However, as mentioned earlier, several other factors impacted the U.S. economy during 1974-2005, including erosion of the real minimum wage, decline of unions, automation that replaced low-skilled routine workers, skill-biased technological change, greater imports of final goods, etc. In this section, I extend the model to allow for two of the major changes that occurred over this time period: skill-biased technological change and competition from final good imports.

Skill biased technological change can be incorporated in the model by allowing for technological change that makes investment in skill-complementary capital more efficient. This is described as investment specific technological change (ISTC) in previous literature. I follow Greenwood et al. (1997) to incorporate ISTC. The stock of equipment capital evolves as follows:

$$K_{t+1} = (1 - \delta^K)K_t + g_t I_t \tag{5.1}$$

where g_t denotes the state of technology in period t. Changes in g represent ISTC, such that higher g makes investment more efficient. Defining $\tilde{K}_t = \frac{K_t}{g_{t-1}}$, the capital accumulation process can be re-written as:

$$\tilde{K_{t+1}} = (1 - \tilde{\delta^K})\tilde{K}_t + I_t \tag{5.2}$$

where $(1 - \tilde{\delta^K}) = (1 - \delta^K)\frac{g_{t-1}}{g_t}$. Further, defining $B_t = g_{t-1}$, the production functions for high-skilled intermediate and innovation goods change to:

$$x_{ht} = (B_t \tilde{k}_t)^{\mu} h_t^{1-\mu} \tag{5.3}$$

$$\Psi_{nt} = \left[\varphi(B_t \tilde{k_{nt}})^{\alpha} + (1 - \varphi)h_{nt}^{\alpha}\right]^{\frac{1}{\alpha}} \tag{5.4}$$

This transformation was proposed by Greenwood et al. (1997) and maps ISTC to changes in B_t, which represents the level of capital productivity.

Additionally allowing for imports of final goods, the household's optimization problem is:

$$\underset{C_t, C_{st}, H_t, L_t, \tilde{K_{t+1}}, N_t}{\text{Max}} \mathcal{U} = \sum_{t=0}^{\infty} \beta^t \left(\log \left(C_t^{\rho} + C_{st}^{\rho}\right)^{\frac{1}{\rho}} - \theta_h \frac{H_t^{1+\chi_h}}{1+\chi_h} - \theta_l \frac{L_t^{1+\chi_l}}{1+\chi_l} \right)$$

subject to

$$C_t + (1+\phi) P_t^* C_{st} + I_t + v_t N_t^E = W_{ht} H_t + W_{lt} L_t + R_t B_t \tilde{K}_t + \pi_t N_t$$

$$\tilde{K_{t+1}} = (1 - \delta^{\tilde{K}}) \tilde{K}_t + I_t$$

$$\text{and } N_t = (1 - \delta^N) N_{t-1} + N_t^E \tag{5.5}$$

where C_{st} represents the quantity of final goods imported from the South, ϕ denotes the ad valorem cost incurred by the North to import these goods, and $1(1-\rho)$ is the elasticity of substitution between imported and domestically produced final goods. The aggregate resource constraints for the North and South and the trade balance equation change to reflect the imports of final goods. The rest of the model remains the same as in the baseline.

To calibrate B_t (and g_t), I follow He (2012). In the presence of ISTC, the relative price of capital equals the inverse of g. Taking data from Cummins and Violante (2002) and following He (2012), I measure g for the period 1973-2000 as the NIPA price index of personal consumption expenditure divided by the quality-adjusted price index of total investment. Since $B_t = g_{t-1}$, this gives me a time series for B_t for the period 1974-2001.[44] Normalizing the 1974 (initial steady state) level of B to 1, the value for B in 2001 equals 2.6. I use this value of B as the capital productivity level in the second steady state.

The calibration remains the same for all parameters as in the baseline. We have one new parameter, ρ, which I set at 0.77. We have three exogenous variables that change between the initial and final steady states – τ, ϕ, and B. The values of τ, the cost associated with imports of intermediate goods, are set such that we achieve a tenfold increase in offshoring witnessed during 1974-2005.[45] The values for final goods trade cost, ϕ, are set such that the final goods share in total imports matches the 1974 level of 53% in the initial steady state and the 2005 level of 21% in the second steady state. Finally, as mentioned earlier, the values of B are 1 and 2.6 in the initial and second steady states, respectively.

I again compare the percentage changes in variables between the two steady states corresponding to 1974 and 2005. In this extension, I find that several key variables of interest change by percentages close to data. Most importantly, the extended model

[44] The estimates of quality-adjusted price index of total investment are available only up to year 2000. So I use the data for 2000 to approximate the level of g in 2004 (or B in 2005). This is likely an underestimate of its actual 2004 level.

[45] Given the calibration, the levels of offshoring in the initial and second steady state are 1.6% and 16.4%, respectively.

predicts that low-skilled employment falls by 23.3%, a significantly larger decline than in the baseline model, and closer to the 34% decline in the data. While in the data, skill premium rose 50% during 1974-2005, the model predicts a 54.7% increase. Output also rises 248%, closer to the 300% increase in the data. Change in equipment capital relative to labor also increases comparably to the data (334.5% and 304%, respectively). However, wages of high- and low-skilled labor increase significantly more than in the data (231% and 114%, respectively), suggesting that other factors that are still not incorporated in the model (such as decline of unions, automation of routine tasks, erosion of the minimum wage, greater skill acquisition in the labor force, etc.) are important forces putting a downward pressure on wages.

6 Alternative Model

How does offshoring impact the economy if it does not generate technology effects? To examine this, I consider a model economy without the technology channel. In particular, I write an alternative model in which there is a fixed mass of perfectly competitive firms in the North that produce identical final products using a Cobb Douglas technology that combines capital with high- and low-skilled intermediates. The high (low)-skilled intermediates are produced with linear technologies using only high (low)-skilled labor. This framework eliminates capital-skill complementarity and any role for innovation – two key features of the baseline model. However, this alternative model, continues to allow for other mechanisms through which offshoring affects high- and low-skilled labor outcomes. Specifically, the model allows for the scale and productivity effects that increase wages and employment of both types of labor, and substitution, relative price, and labor supply effects that work to reduce low-skilled wage and employment. Further, I consider two variants of the alternative model: in the first variant I keep the elasticity of substitution between domestic and imported low-skilled intermediates the same as that in the baseline model; in the second variant I allow for perfect substitution between them. The model and parameterization are described in Appendix B.

In Table 7, I compare results of both variants of the alternative model with the baseline model. In the first column, I present the percentage changes in the baseline model for a few variables of interest when the economy moves from the initial to the second steady state. In the second column, I present the analogous percentage changes in the alternative model with no technology channel but the same elasticity of substitution between domestic and imported intermediates as in the baseline model. In the third column, I present the results from the alternative model taking imported and domestic

Table 7: Comparison of Baseline and Alternative Models

	Baseline	Model Without Technology Channel	Model Without Technology Channel and Perfect Substitution Between High-Skilled and Low-skilled Intermediates
	Percentage Change Between Steady States		
Low-Skilled Employment	-8	-10	-10
High-Skilled Employment	8	9	9
Total Employment	-3	-4	-4
Low-Skilled Wage	24	7	-8
High-Skilled Wage	44	31	12
Skill Premium	16	22	22
Output	62	44	23
Consumption	34	20	2

inputs as perfect substitutes in production.

Comparing across columns, the baseline model predicts a smaller decline in the employment of low-skilled labor than both variants of the alternative model. This result suggests that a model with the technology channel predicts fewer job losses for low-skilled workers than a model without. 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 without the technology channel (second column) imply an increase in both low- and high-skilled wages, but the baseline implies substantially larger increases (24% and 44%, respectively) than the latter model. However, these results stand in sharp contrast to those from the variant with perfect substitution between imported and domestic low-skilled intermediates, which implies a 12% increase in high-skilled wages but a *decline* of 8% in low-skilled wages. Further, the increase in skill premium is *lower* in the baseline than in the alternative models. Finally, the baseline model also implies substantially larger growth in output and consumption than the alternative models, especially the variant with perfect substitution between imported and domestic low-skilled intermediates.

These results suggest that although the distributional and employment consequences of offshoring are unfavorable to low-skilled workers in the North, offshoring increases their real wages as long as offshored inputs do not substitute perfectly for domestic inputs, as supported by Figure 1(b). With perfect substitution, this favorable result for low-skilled labor is reversed with its wage declining as offshoring increases. The analysis also shows

that high-skilled labor gains both in terms of employment and wage. Finally, an increase in offshoring is akin to a productivity increase leading to growth in output (and, hence, consumption of households). The increases in output and consumption are much larger in the baseline model that captures the technology channel.

Finally, I compare the welfare implications of the baseline model with those of the alternative model without the technology channel and with perfect substitution between imported and domestic intermediates. While there is a 17% increase in welfare in the baseline, the alternative model yields a 3% increase in welfare.

7 Sensitivity Analysis

I examine sensitivity of the baseline results to values of several parameters.

Consider the depreciation rate for equipment capital. Krusell et. al. (2000) set this 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 the low to high offshoring steady state, this model results in similar increases in the wages of low- and high-skilled labor (44.6% and 24.6%) and the skill premium (16%) as in the baseline model. Also similar to baseline results, employment of high-skilled labor increases by 8.5% and that of low-skilled labor falls by 6.5%.

In the baseline calibration, I set the exogenous exit rate of firms at 10%. The model results are not sensitive to the value of the exit rate of firms. For example, increasing the exit rate to 12%, the employment and wage ratios increase by similar amounts as with the baseline (16%), when moving from the low to high offshoring steady state. Other key variables also change by similar amounts as in the baseline. The results are also not very sensitive to the cost of entry. For example, increasing ψ to 0.8 (i.e., higher cost of entry), results in 8% increase in high-skilled employment and 7% decline in low-skilled employment and their respective wages increase by 44% and 24% as we move from the low to high offshoring steady state.

For the baseline calibration, I set the markup at 1.225 – the average of the range of 1.05 to 1.4 found in the literature. To examine sensitivity to this value, I vary the value of η to yield a markup ($= 1/\eta$) over this range. Results remain qualitatively similar for different values of the markup. In particular, moving from the low to high offshoring steady state, as the markup increases, the gains in low- and high-skilled wages increase by small amounts, increase in high-skilled employment reduces slightly and the fall in low-skilled employment rises a little.

Finally, I examine sensitivity to the Frisch elasticities of low- and high-skilled labor supply, both set at 1 in the baseline calibration. Kimball and Shapiro (2008) noted that high-skilled labor supply may be somewhat less elastic than low-skilled labor supply. Following this observation, I set χ_l at 0.9091 and χ_h at 1.3044 so that the implied supply elasticities are 1.1 and 0.77, respectively for low- and high-skilled labor, and the linear combination of these elasticities, with weights of 0.7 and 0.3 (shares of low- and high-skilled labor in the data), respectively, is 1; this matches the Kimball and Shapiro (2008) estimate of aggregate labor supply elasticity of 1. The results from the model remain qualitatively similar. In particular, moving from the low to high offshoring steady state, the employment ratio increases by 16% and the skill premium increases by 17%. Low skilled employment falls by 8.3% and wage increases by 23.5%.

8 Conclusion

This paper proposes and evaluates a mechanism by which a rise in offshoring to developing countries induces the adoption of skill-complementary technology and innovation, benefitting both high- and low-skilled workers in advanced countries. Facts from the data lend strong support to the presence of this technology channel in U.S. manufacturing industries that engage in offshoring. Results from the model show that this channel is the dominant mechanism underlying the effect of offshoring on labor outcomes in the aggregate economy. Without the technology channel, the wages and employment of both types of labor are lower, and the inequality between them is significantly greater. Thus, offshoring induced capital deepening and innovation generate quantitatively important gains for all workers.

The findings presented in this paper have important policy implications. The positive effects of offshoring on the technology variables suggest that policies designed to limit offshoring can potentially have the unintended consequence of impeding investments in capital and innovation. Moreover, restricting offshoring, and with it the investments in technology, may also entail much smaller gains in total output and welfare, as also in high-skilled wages and employment. Finally, policies should take into account that while offshoring may reduce the overall employment of low-skilled workers, it can result in higher wages for them. Thus, instead of aiming to reduce offshoring, policies should be designed to aid skill-acquisition for those low-skilled workers who are hurt by offshoring.

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Online Appendix

Manisha Goel

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Appendix A Empirical Appendix

Appendix A.1 Data Sources

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 et al. (2002).

NBER-CES Manufacturing Productivity Database

Data on 459 four digit manufacturing industries in the United States are available from NBER. 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 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 are not provided. I construct 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 concord 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 obtain 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.

CPI: The U.S. consumer price index data are obtained from the Bureau of Labor Statistics. The CPI data for developing countries are taken from IMF's International Financial Statistics (IMF-IFS). CPI data series for China was not available at IMF-IFS for the full sample period, and is taken from https://measuringworth.com/chinadata/. These data are used to construct the price-based instrumental variable.

World Bank Income Classification: The World Bank classifies all countries into five categories: High Income: OECD, High Income: non-OECD, Upper Middle Income, Lower Middle Income and Low Income. I obtain these classifications from the World Bank. For the empirical analysis in this paper, I group upper middle income, lower middle income and low income countries together as "developing" countries. High income OECD and non-OECD countries are grouped together as "advanced," or "developed," 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. 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

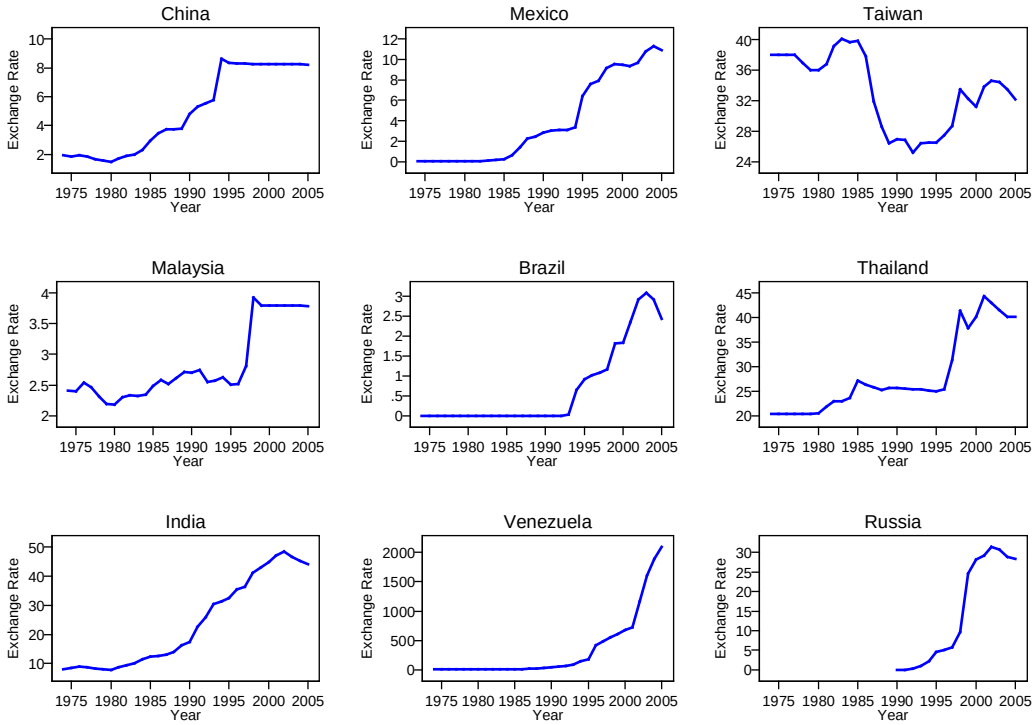
SIC 1987 classifications to domestic SIC 1987 classification. This provides me with the average tariff rates imposed on imports belonging to all 4-digit SIC 1987 industries. To get a measure of tariffs imposed on imported intermediates, I follow the same procedure as that used for exchange rates.

Appendix A.2 Exchange Rates Based Instruments

I discuss the validity and relevance of the exchange rate based instruments. As explained in the paper, to the extent that exchange rates are influenced mainly by macroeconomic factors rather than by 4-digit industry-level shocks, they are likely to be independent of the unobservable industry-year variations in the dependent variables, especially since specifications include industry and year fixed effects. Further, by using static country-specific shares and direct requirement coefficients as weights, and weighting the observations by constant industry size, I avoid several possible factors leading to joint determination of import shares of countries and exchange rates in any given year. For example, as China increases its presence in the world market, if it begins to export large shares of intermediates to a major manufacturing industry in the U.S., then the exchange rates of the U.S. dollar with Chinese yuan could be impacted. Static country shares throughout the sample period avoid this possibility. Moreover, as technological and production processes evolve, firms may change the quantities of various inputs they use to produce their final products. If some input quantities increase substantially and begin to be imported in large amounts, then the exchange rate of the U.S. dollar with the exporting countries' currencies could be affected. Using constant direct requirement coefficients as weights also avoids this possibility. Further, with structural changes in the economy, some manufacturing industries have grown larger over time. If these industries import substantial shares of their inputs from a few developing countries, then U.S. dollar's exchange rate with those countries' currencies could be impacted. Keeping industry shares constant[1] throughout the sample period also avoids this source of joint determination of exchange rates and outcome variables.

Next, I show that there is considerable variation in exchange rates both within and across years and that changes in exchange rates are highly correlated with changes in imported intermediates in all industries.

[1] 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 over the sample period.



Source: Penn World Tables and World Bank Income Classification. Exchange rate is defined as foreign currency relative to U.S. dollar. The figure shows evolution of exchange rates for all developing countries that appear among the top twenty trading partners of the U.S. in 2005. Data for Russia were only available after 1989.

Figure Appendix A.1: Exchange Rates of U.S. Dollar with Top Trading Partner Currencies

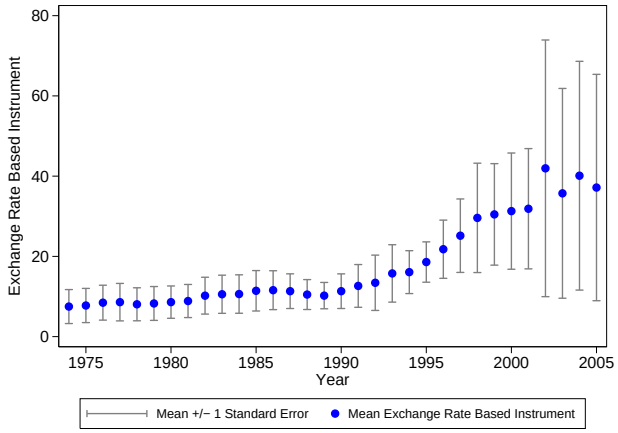


Figure Appendix A.2: Variation in Exchange Rate Based Instrument[a]

[a]The figure shows the mean +/- 1 standard deviation of the exchange rate based instrumental variable for each year in the sample period. 1993 exchange rates for three industries (3292, 3341, and 3915) were outliers and were dropped from the analysis.

Table Appendix A.1: Changes in Offshoring and Industry Exchange Rates

Industry Code	Description	Change in Offshoring	Change in Exchange Rate	Time Series Correlation Between Offshoring and Exchange Rate
		1974-2005		
20	Food and Kindred Products	0.07	22.21	0.84
21	Tobacco Products	0.12	120.19	0.88
22	Textile Mill Products	0.31	18.46	0.65
23	Apparel and Other Textile Products	0.17	21.04	0.48
24	Lumber and Wood Products	0.09	27.80	0.54
25	Furniture and Fixtures	0.14	14.86	0.84
26	Paper and Allied Products	0.06	27.15	0.94
27	Printing and Publishing	0.05	25.05	0.90
28	Chemicals and Allied Products	0.13	48.73	0.91
29	Petroleum and Coal Products	0.19	104.60	0.96
30	Rubber and Miscellaneous Plastics Products	0.19	23.76	0.93
31	Leather and Leather Products	0.13	26.27	0.85
32	Stone, Clay, and Glass Products	0.21	40.25	0.96
33	Primary Metal Industries	0.11	45.30	0.89
34	Fabricated Metal Products	0.13	30.40	0.78
35	Industrial Machinery and Equipment	0.28	19.61	0.87
36	Electronic and Other Electric Equipment	0.40	18.89	0.76
37	Transportation Equipment	0.37	17.42	0.85
38	Instruments and Related Products	0.36	18.74	0.73
39	Miscellaneous Manufacturing Industries	0.19	20.73	0.66

Changes are averages over all 4 digit industries within each 2 digit industry.

Appendix A.3 Offshoring Descriptive Statistics

Table Appendix A.2: 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

Table Appendix A.3: Average Offshoring by Industries and Their Characteristics

		1975							2005						
Industry Code	Description	Rank	Offshoring**	Employment Ratio*	Wage Bill Ratio*	Production Workers Wage Bill***	Equipment/ Labor	R&D***	Rank	Offshoring**	Employment Ratio*	Wage Bill Ratio*	Production Workers Wage Bill***	Equipment/ Labor	R&D***
39	Miscellaneous Manufacturing Industries	1	0.027	0.313	0.612	454.504	10.889	11.178	7	0.216	0.539	0.996	476.796	41.459	82.260
36	Electronic and Other Electric Equipment	2	0.026	0.524	0.923	757.355	18.721	261.780	1	0.421	0.823	1.515	697.647	147.257	12564.700
20	Food and Kindred Products	3	0.026	0.526	0.703	1005.170	35.933	34.561	18	0.100	0.427	0.619	937.449	105.670	63.110
38	Instruments and Related Products	4	0.022	0.789	1.250	1270.843	11.526	323.590	3	0.379	1.453	2.486	794.693	59.252	1161.296
25	Furniture and Fixtures	5	0.022	0.252	0.439	627.374	8.411	6.530	11	0.168	0.313	0.542	610.365	28.288	54.666
31	Leather and Leather Products	6	0.019	0.159	0.340	374.217	5.841	0.560	12	0.156	0.295	0.599	51.102	26.216	6.960
28	Chemicals and Allied Products	7	0.018	0.712	1.036	933.303	65.684	761.459	13	0.153	0.752	1.126	974.888	220.471	3644.444
33	Primary Metal Industries	8	0.017	0.282	0.380	4694.232	64.594	125.505	15	0.125	0.270	0.377	1395.793	221.256	27.356
37	Transportation Equipment	9	0.015	0.519	0.710	4460.612	26.909	2063.363	2	0.394	0.657	0.852	4118.491	97.797	6564.820
23	Apparel and Other Textile Products	10	0.014	0.161	0.349	724.737	5.085	2.703	9	0.195	0.326	0.667	192.797	23.747	0.798
22	Textile Mill Products	11	0.013	0.166	0.330	826.519	22.742	9.735	4	0.325	0.204	0.366	252.130	89.472	9.657
24	Lumber and Wood Products	12	0.010	0.181	0.327	1004.426	22.731	31.399	16	0.120	0.250	0.414	1039.375	39.223	33.580
32	Stone, Clay, and Glass Products	13	0.008	0.294	0.413	685.631	36.895	17.471	6	0.226	0.285	0.442	718.814	125.268	11.065
34	Fabricated Metal Products	14	0.008	0.329	0.501	1063.771	22.328	17.744	14	0.143	0.368	0.602	920.393	72.703	22.744
29	Petroleum and Coal Products	15	0.008	0.442	0.592	1522.310	151.425	758.420	8	0.197	0.619	0.742	1459.754	651.776	377.665
35	Industrial Machinery and Equipment	16	0.007	0.558	0.857	1226.434	18.493	93.849	5	0.290	0.757	1.196	1027.952	84.300	18132.040
26	Paper and Allied Products	17	0.007	0.308	0.453	1261.191	57.051	79.485	19	0.072	0.283	0.451	1108.512	220.512	207.160
27	Printing and Publishing	18	0.005	1.091	1.457	2190.654	13.795	4.214	20	0.059	0.403	0.614	3075.353	51.368	8.599
30	Rubber and Miscellaneous Plastics Products	19	0.005	0.304	0.513	1581.401	29.893	80.364	10	0.193	0.299	0.519	2859.820	76.973	173.268
21	Tobacco Products	20	0.003	0.184	0.275	653.400	28.268	55.919	17	0.120	0.337	0.585	294.028	194.832	260.351
	Correlation with Offshoring			0.053	0.163	-0.175	-0.240	0.058			0.608	0.621	0.547	-0.079	0.531

Notes: All numbers are averages over all 4 digit industries within each 2 digit industry.
*: Ratios are for non-production workers relative to production workers.
**: Sum of imported inputs as a proportion of non-energy materials.
***: Millions of dollars (1987=1)

Comment on the negative correlation between equipment-labor ratio and offshoring: Table A.3 shows that while offshoring is positively correlated to R&D intensity, it is negatively correlated to equipment-labor ratio. This indicates that R&D intensity and equipment-labor ratio are negatively correlated to each other. But investigating the underlying patterns more closely shows that, in general, more capital-intensive industries are also more R&D intensive, and offshore more. However, a few industries are highly capital-intensive but engage in relatively low levels of R&D and offshoring. These are the ones driving the negative correlation of equipment-labor ratio to R&D intensity and offshoring.

Looking at the data in 2005, the raw correlation between average R&D intensity and offshoring across two digit manufacturing industries is indeed negative, although small in magnitude: -0.03. However, this is driven entirely by petroleum and coal products, a two-digit industry that had the highest level of equipment-labor ratio among all industries but low levels of R&D intensity. Dropping this industry yields a large positive correlation of 0.19 between R&D intensity and equipment-labor ratio, indicating that, in general, more capital-intensive industries are also more R&D intensive.

We also know that more R&D intensive industries offshore more, with the correlation between the two at 0.53. Thus, the negative correlation of -0.08 between equipment-labor ratio and offshoring as of 2005 seems puzzling. However, looking into this more closely shows that this negative correlation is also driven by a handful of industries – petroleum and coal products, tobacco products, paper and allied products, chemical and allied products, and primary metal industries – all of which have high equipment-labor ratios but relatively low offshoring levels. Dropping these industries yields a large, positive correlation of 0.5, indicating that more capital-intensive industries also offshore more, barring a few exceptions. These industries also have low R&D intensities. Dropping all of them makes the correlation between R&D intensity and equipment-labor ratio even higher: 0.32 (compared to 0.19 when we only drop petroleum and coal products).

Appendix A.4 Fixed Effects Estimates

Table A.4 presents the fixed effects estimates of the relationship between offshoring and several outcome variables. For the sake of uniformity of presentation, the results in this table are categorized on the basis of whether I expect the dependent variables to be influenced via the technology channel only (columns 1 to 2(b)) or also through other mechanisms (columns 3 to 11). The coefficients on offshoring in these regressions are within industry within year correlations, and do not have a causal interpretation.

The negative, albeit small, coefficient in column 2(b) is consistent with the negative correlation of offshoring with equipment/labor presented in Table A.3. The negative coefficient on R&D intensity in column 1 is not consistent with the positive correlation in Table A.3, but may reflect the fact that more high-tech industries offshore less. The labor market outcomes, on the other hand, are affected via both technology and other channels. Consistent with both channels, columns 3 and 4, show that offshoring is positively associated with employment and wage ratios. Next consider the absolute outcomes, i.e., the levels of employment, wage-bills, and wages of both groups of workers. Both channels predict positive effects of offshoring on the levels of non-production employment and wage-bills. The positive coefficients on imports in columns 5 and 6 are consistent with this prediction. As for the levels of production workers' employment and wage-bills, the substitution channel implies a negative effect and the technology channel implies a positive effect. The positive coefficients on imports in columns 8 and 9, may suggest that the positive influence of the technology channel more than offsets the negative substitution effect. However, the estimated coefficient on offshoring is negative, although small, in regressions for both non-production and production wages. Gross output is also affected by both channels. The positive coefficient on imports in column 11 is consistent with this intuition.

These fixed effects estimates are small and statistically insignificant, and indicate that the sources of downward bias discussed in section 2 are strong.

Table Appendix A.4: Fixed Effects Estimates for Various Outcome Variables

	Technology Channel			Both Channels								
	(1)	(2a)	(2b)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	R&D Intensity[1]	Equipment	Equipment / Labor	Employment Ratio[2]	Wage Bill Ratio[2]	Non-Production Wage Bill	Non - Production Employment	Non - Production Wages	Production Wage Bill	Production Employment	Production Wages	Gross Output
Imported Intermediates[3]	-0.085***	0.007	-0.003	0.009	0.010	0.013	0.015	-0.002	0.003	0.005	-0.003	0.004
	(0.030)	(0.015)	(0.012)	(0.007)	(0.008)	(0.013)	(0.013)	(0.003)	(0.013)	(0.013)	(0.004)	(0.025)
Observations	13,746	14,570	14,570	14,569	14,568	14,568	14,569	14,570	14,570	14,570	14,570	14,570
R-squared	0.124	0.587	0.762	0.259	0.326	0.122	0.162	0.1	0.272	0.302	0.015	0.260
Number of 4 digit industries	456	459	459	459	459	459	459	459	459	459	459	459

Notes:

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

[1]: Real R&D Expenditure/Total Sales for the firms for which data on R&D expenditures and sales are available.

[2]: Ratios are for non-production workers relative to production workers.

[3] 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. All observations are weighted by constant indsutry size.

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

All variables are in natural logs.

Appendix A.5 Robustness

The construction of the exchange rates based instrument takes into consideration several potential factors that could lead to a violation of the exclusion restriction. I examine robustness of results to accounting for other factors that can still render the instrument invalid.

It is possible that some sources of variation in the exchange rates (besides those already accounted for in the baseline results) also directly impact the outcome variables. For example, a trade agreement like NAFTA impacts exchange rates of the U.S. dollar with the Mexican Peso, and also directly impacts wage-bills and employment of high- and low-skilled workers in U.S. industries that directly compete with imports from Mexico. Three major trade agreements took place over the sample period – NAFTA, the Uruguay round, and the multi-fiber trade agreement. To the extent that these trade agreements affected industries similarly, their effects are already captured in year fixed effects. But, we do expect that their effects are heterogeneous across industries. Thus, not controlling for these trade agreements may cause an omitted variable bias in the estimates. To address this possibility, I include a vector of pre- and post-NAFTA (or Uruguay rounds) indicator variables with two digit industry fixed effects. While the NAFTA came into effect in 1994 and continued through 2005, the Uruguay round of trade agreements stayed in effect between 1995 and 2004. The multi-fiber agreement was in place throughout my sample period and, hence, does not need to be controlled for in addition to the year and industry fixed effects.

Second stage results from regressions that control for NAFTA and the Uruguay round are presented in Table A.5.[2] The estimates of the coefficients on offshoring in regressions for both technology and labor market outcomes remain similar to the baseline results. Results that control for NAFTA indicate that doubling offshoring in an industry leads to 29% increase in equipment-labor ratio and 31% increase in the R&D intensity. Production workers' employment and wage-bills also increase by 26.2% and 28.3% when offshoring increases by 100% in an industry. Similarly, regressions that control for the Uruguay round show that doubling offshoring in an industry is associated with 13.3% increase in capital-embodied technology adoption (smaller than the baseline results but still large and statistically significant) and about 40% increase in R&D intensity. The labor market effects of offshoring also remain similar.

Another factor that I consider is pegging of exchange rates. Policies to peg currencies

[2]Excluded instruments include contemporaneous and one year lagged exchange rate and relative price constructs. The first stage F statistic is 15.35 and 13.71 for the regressions controlling for NAFTA and the Uruguay round, respectively.

Table Appendix A.5: FE-IV Estimates for Regressions Controlling for NAFTA and Uruguay Trade Agreements

	Technology Outcomes		Labor Outcomes			
	(1)	(2)	(3)	(4)	(5)	(6)
	Equipment/ Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
	Results from regressions including interactions of NAFTA indicator with 2-digit industry fixed effects					
Imported Intermediates[1]	0.294***	0.310***	0.072*	0.081**	0.262***	0.283***
	(0.079)	(0.117)	(0.037)	(0.037)	(0.085)	(0.089)
Observations	14,097	13,287	14,096	14,095	14,097	14,097
Number of industries	459	456	459	459	459	459
	Results from regressions including interactions of Uruguay round indicator with 2-digit industry fixed effects					
Imported Intermediates[1]	0.133*	0.402**	0.095**	0.110***	0.218***	0.233***
	(0.070)	(0.161)	(0.040)	(0.041)	(0.084)	(0.088)
Observations	14,097	13,287	14,096	14,095	14,097	14,097
Number of industries	459	456	459	459	459	459

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of total non-energy materials used in the industry.
Excluded instruments: Contemporaneous and one year lagged exchange rates and relative prices.
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. All observations are weighted by constant industry size.
Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.
All variables are in natural logs.

to the U.S. dollar or other major currencies impact exchange rates as well as outcome variables through channels other than offshoring. Over the sample period, several developing countries followed policies to peg their currencies according to a fixed or crawling regime. But many of them accounted for a negligible share of U.S. imports over the entire time period. I consider countries that accounted for at least 0.5% of total U.S. imports in any year during the sample period. For each of these countries, I include indicators for the years during which they managed the values of their currencies according to fixed or crawling exchange rate pegging regimes. Results from these regressions are presented in Table A.6. Controlling for fixed and crawling exchange rate pegging regimes followed by a subset of developing countries does not affect results. Offshoring continues to have economic and statistically significant positive technology effects. Similarly, the impacts of offshoring on low-skilled workers' employment and wage-bills remain close to the baseline results.

The exclusion restriction for the exchange rates based instrument could also be rendered invalid if exchange rates impact the outcome variables through mechanisms other than offshoring. Examples for these mechanisms include final good imports and exports.

Table Appendix A.6: FE-IV Estimates for Regressions Controlling for Pegged Exchange Rates

	Technology Outcomes		Labor Outcomes			
	Equipment/ Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
Imported Intermediates[1]	0.385***	0.422***	0.111**	0.132**	0.240**	0.249**
	(0.117)	(0.155)	(0.049)	(0.051)	(0.103)	(0.106)
Observations	14,105	13,287	14,096	14,095	14,097	14,097
Number of industries	459	456	459	459	459	459
R-squared	0.534	0.047	0.139	0.170	0.133	0.084
Hansen's J statistic (p-value)	14.64 (0.00)	10.69 (0.01)	2.46 (0.48)	4.28 (0.23)	3.43 (0.33)	3.21 (0.36)

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of total non-energy materials used in the industry.
Excluded instruments: Contemporaneous and one year lagged exchange rates and relative prices.
All regressions include year fixed effects, 4-digit industry fixed effects, interactions of 2 digit industry dummies with an indicator for whether the year is post-1996, and country-specific indicators that equal 1 for the years that a country pegged its exchange rate. All observations are weighted by constant industry size.
Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.
All variables are in natural logs.

Not controlling for these possible channels would again cause an omitted variable bias in the estimates. To address this concern, I consider two specifications. In the first specification, I include the natural log of industry-year specific import penetration ratio as a control variable. In the second specification, I include the natural log of real dollar values of exports and imports in each industry as additional controls. Table A.7 presents the results. In both specifications, results remain qualitatively similar to the baseline results. While controlling for import penetration ratios does not affect the estimates much, controlling separately for imports and exports slightly reduces the magnitudes of estimates.

Note, however, that in these regressions exports and imports (or import penetration) are also endogenous regressors. To overcome this problem, I run another robustness check. 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. If the final good imports and exports 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. This is not what the results show, however, further confirming the main results. The results in the bottom half of the industries that face less import competition

from developing countries than the median industry still show a similar pattern as for the full sample of industries, as in the baseline results. All the outcome variables are impacted positively and significantly by increased offshoring.[3]

Table Appendix A.7: FE-IV Estimates for Regressions Controlling for Exports and Imports

	Technology Outcomes		Labor Outcomes			
	(1)	(2)	(3)	(4)	(5)	(6)
	Equipment/ Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
	Results from regressions including import penetration					
Imported Intermediates[1]	0.437***	0.430***	0.125**	0.145**	0.293**	0.314***
	(0.131)	(0.162)	(0.054)	(0.057)	(0.116)	(0.119)
Observations	13,568	12,823	13,567	13,566	13,568	13,568
Number of industries	451	446	451	451	451	451
	Results from regressions including exports and imports					
Imported Intermediates[1]	0.423***	0.354**	0.115**	0.139***	0.172*	0.175*
	(0.126)	(0.148)	(0.052)	(0.054)	(0.099)	(0.101)
Observations	13,568	12,823	13,567	13,566	13,568	13,568
Number of industries	451	446	451	451	451	451

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of total non-energy materials used in the industry.
Excluded instruments: Contemporaneous and one year lagged exchange rates and relative prices.
All regressions include year fixed effects, 4-digit industry fixed effects, interactions of 2 digit industry dummies with an indicator for whether the year is post-1996. All observations are weighted by constant industry size.
Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.
All variables are in natural logs.

In Table A.8, I include interactions of two-digit industry dummies with years so as to control for any unobservable time varying factors influencing broad industry groups. Results remain qualitatively similar to baseline estimates. However, estimates for offshoring effects on technology variables, albeit large, are not statistically significant. Employment and wage-bill ratios are also not statistically significantly associated with offshoring.

In Table A.9, I use alternative measures for offshoring and the instruments. In the baseline measures, I include imports belonging to all industries that provide inputs to an industry, including the one that is the same as the output industry. Thus, if the output industry is j, the input industries are $k = 1, .., j, ., n$. However, one concern with this approach may be that movements in exchange rates that affect imports of inputs belonging to an industry can also impact that industry's final good production and exports, and, hence, bias the FE-IV estimates when exports are not controlled for. To address this pos-

[3]Results are available upon request.

Table Appendix A.8: FE-IV Estimates for Regressions Controlling for Industry-Year Interactions

	Technology Outcomes		Labor Outcomes			
	(1)	(2)	(3)	(4)	(5)	(6)
	Equipment / Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
Imported Intermediates[1]	0.146	0.166	0.025	0.045	0.346***	0.352***
	(0.091)	(0.168)	(0.046)	(0.044)	(0.121)	(0.126)
Observations	14,097	13,287	14,096	14,095	14,097	14,097
Number of 4-digit industries	459	456	459	459	459	459
R-squared	0.776	0.419	0.302	0.352	0.154	0.115

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of all non-energy materials used in the industry.
Excluded Instruments: Contemporaneous and one year lagged exchange rate and relative price
All regressions include year fixed effects, 4-digit industry fixed effects, interactions of 2 digit industry dummies and years, and interactions of 2 digit industry dummies with an indicator for whether the year is post 1996. All observations are weighted by constant industry size.

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

sibility, I construct offshoring, and exchange rates and relative price based instruments by considering imports belonging to industries other than the output industry itself, i.e. industries off the diagonal in the input-output matrix. Results are presented in Table A.9 and are qualitatively similar to the baseline, and remain statistically significant for equipment-labor ratio, and employment and wage-bill ratios. Although, coefficient estimates on offshoring are not statistically significant in regressions for R&D intensity and production worker employment and wage-bill, they continue to show that these outcomes are positively associated with offshoring.

I also examine robustness to sample period, set of exporting countries, choice of base year for weights used in construction of instruments, and time trends. In particular, I estimate regressions for the period 1974-1997 (before the acceleration in offshoring), as well as 1974-2001 (before China's entry into WTO). Results remain similar to those for the period 1974-2005. I also estimate results considering imports from all countries except China, and find that results remain qualitatively similar to the baseline results. Results are also robust to controlling for hyperinflation episodes in various countries over the sample period. Results remain similar when I change the base year for weights that are used in the construction of instrumental variables. I also estimate results including flexible time trends. In addition to the year and industry fixed effects, I include a quadratic in time, fully interacted with two-digit industry dummies. This allows industries to have different time trends. Results remain similar.

In Table A.10, I present results for estimations in which current values of various

Table Appendix A.9: FE-IV Estimates Using Alternative Measures of Offshoring and Instruments

	Technology Outcomes		Labor Outcomes			
	(1)	(2)	(3)	(4)	(5)	(6)
	Equipment / Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
Imported Intermediates[1]	0.166**	0.167	0.089**	0.096**	0.054	0.020
	(0.077)	(0.145)	(0.044)	(0.047)	(0.085)	(0.090)
Observations	14,097	13,287	14,096	14,095	14,097	14,097
Number of 4-digit industries	458	455	458	458	458	458
R-squared	0.715	0.165	0.187	0.244	0.301	0.275

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of all non-energy materials used in the industry.
Excluded Instruments: Contemporaneous and one year lagged exchange rate and relative price
Offshoring measure (imported intermediates) and the instruments are constructed by removing the diagonal in the input-output matrix.
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. All observations are weighted by constant industry size.
Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.
All variables are in natural logs.

Table Appendix A.10: Dynamic Effects of Offshoring

	Total Capital / Labor	Equipment / Labor	R&D Intensity	Non Production Wage Bill	Non Production Employment	Production Wage Bill	Production Employment
				One Year Lag			
Imported Intermediates[1]	0.282***	0.354***	0.517***	0.323***	0.282***	0.204**	0.193**
	(0.086)	(0.098)	(0.149)	(0.099)	(0.092)	(0.090)	(0.087)
				Two Years Lag			
Imported Intermediates	0.260***	0.326***	0.373***	0.270***	0.229***	0.172**	0.165**
	(0.071)	(0.081)	(0.131)	(0.079)	(0.073)	(0.076)	(0.072)
				Three Years Lag			
Imported Intermediates	0.279***	0.330***	0.392***	0.207***	0.162***	0.110*	0.095
	(0.064)	(0.071)	(0.129)	(0.066)	(0.061)	(0.067)	(0.063)

Notes:
*** p<0.01, ** p<0.05, * p<0.10
Excluded instruments: Current and lagged exchange rates and relative prices.
[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.

outcome variables are regressed on lagged values (1-3 years) of offshoring.[4] Results are qualitatively similar to the baseline results. As expected, innovation is more responsive

[4]Results for 5 or 10 year changes are estimated imprecisely due to the reduced sample size.

Table Appendix A.11: Effects of Offshoring Controlling for Output

	Technology Outcomes		Labor Outcomes			
	(1)	(2)	(3)	(4)	(5)	(6)
	Equipment / Labor	R&D Intensity	Employment Ratio	Wage Bill Ratio	Production Employment	Production Wage Bill
Imported Intermediates[1]	0.381***	0.397***	0.113**	0.141***	0.072	0.061
	(0.119)	(0.152)	(0.048)	(0.051)	(0.078)	(0.078)
Real Output	0.015	0.061	-0.003	-0.021	0.401***	0.449***
	(0.063)	(0.065)	(0.015)	(0.013)	(0.105)	(0.103)
Observations	14,097	13,287	14,096	14,095	14,097	14,097
Number of 4-digit industries	459	456	459	459	459	459

Notes:
*** p<0.01, ** p<0.05, * p<0.10
[1]: As a proportion of all non-energy materials used in the industry.
Excluded Instruments: Contemporaneous and one year lagged exchange rate and relative price
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. All observations are weighted by constant industry size.
Heteroskedasticity-robust standard errors are in parentheses. Standard errors are clustered at the level of 4-digit industries.
All variables are in natural logs.

to lagged than to contemporaneous offshoring. The magnitudes for capital deepening are close to those obtained from contemporaneous regressions. Offshoring also impacts the future non-production and production workers' wage bills. The falling coefficient magnitudes, show, as expected, that workers' employment and wage-bills adjust to changes in offshoring faster than capital and innovation, and more so for production than for non-production workers.

In Table A.11, I control for industry output (real shipments) in all regressions. The objective is to examine how offshoring impacts the technology and labor outcomes when the scale effect is controlled for. We see that offshoring continues to impact technology and labor outcomes positively, although the coefficients on offshoring in regressions for production employment and wage-bills are statistically insignificant.

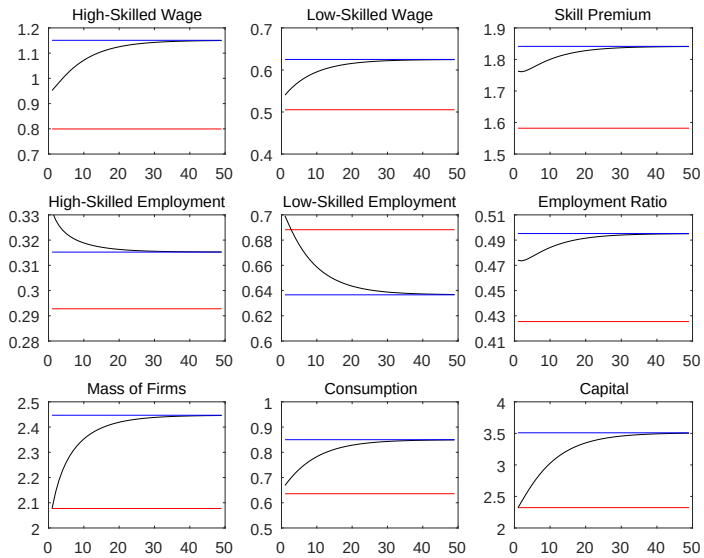


Figure B.1: Transition Paths of Key Variables[a]

[a]The red line in all graphs in the figure represents the initial steady state corresponding to an offshoring level of 1.8%. The blue line represents the new steady state in which offshoring is 19%. The curves show how various variables in the model transition from the old steady state to the new.

Appendix B Model Appendix

Appendix B.1 Transition Dynamics

Figure B.1 presents the transition dynamics for a few key outcomes of interest in the baseline model. In each graph, the red line represents the initial steady state in the North that corresponds to the low offshoring level of 1.8%. The blue line represents the new steady state that the variables converge to when trade cost declines enough to induce an increase in offshoring to 19%. The figure shows that high-skilled wage increases more than the low-skilled wage leading to an increase in the skill premium. High-skilled employment increases substantially at first but then slowly declines to settle at a higher level than at the initial steady state. Low-skilled employment falls after initially jumping up to settle below the initial steady state level. As a result, employment of high- relative to low-skilled labor increases. The mass of firms in the economy, consumption, and capital also increase gradually to settle at their higher steady state values.

Appendix B.2 Alternative Model

I write an alternative model that does not include the technology channel and allows for perfect substitution between imported and domestically produced low-skilled intermedi-

ates. I briefly describe the model and its parameterization below.

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

$$q_t(i) = K_t(i)^{\mu}(I_{lt}(i)^{\sigma} + M_{lt}(i)^{\sigma})^{\frac{\gamma}{\sigma}} I_{ht}(i)^{1-\mu-\gamma} \qquad \text{(Appendix B.1)}$$

where K_t is capital, and I_{lt} and I_{ht} denote low- and high-skilled intermediates that are produced by perfectly competitive firms with linear technologies using low- and high-skilled labor, respectively. The final good producing firms take the rental rate on capital, R_t, and the prices, p_{lt} and p_{ht}, of low- and high-skilled intermediates, as given. The low-skilled intermediates can also be offshored to the South for a price, p^*_{lt}. These imports are denoted by M_{lt}. The North incurs a trade cost, τ, such that the effective price of imported intermediates for the North is $(1+\tau)p^*_{lt}$. 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:

$$Y_t = \left[\int_0^1 q_t(i)^{\omega}\, di\right]^{\frac{1}{\omega}}, \omega < 1 \qquad \text{(Appendix B.2)}$$

The households solve the following problem:

$$\underset{C_t, H_t, L_t, K_{t+1}}{\text{Max}} \mathcal{U} = \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \theta_h \frac{H_t^{1+\chi_h}}{1+\chi_h} - \theta_l \frac{L_t^{1+\chi_l}}{1+\chi_l}\right)$$

subject to

$$C_t + I_t = W_{ht}H_t + W_{lt}L_t + R_tK_t \qquad \text{(Appendix B.3)}$$

$$K_{t+1} = (1-\delta^K)K_t + I_t \qquad \text{(Appendix B.4)}$$

While taking their decisions, households take the rental rate on capital, R_t, and the high- and low-skilled wages, W_{ht} and W_{lt}, as given.

The economy for the South remains the same as in the baseline, and imports final goods from the North, denoted by C^*_{mt}. Trade is balanced. The overall resource constraint in the North is:

$$Y_t = C_t + I_t + (1+\tau)p^*_{lt}M_{lt} \qquad \text{(Appendix B.5)}$$

I calibrate the share, μ, of capital in the production of firms' output so as to match the data value of 0.3 and the share of low-skilled labor, γ, at 0.408 to match the skill premium of 1.6 in the data in 1974. The disutility weights, θ_l and θ_h, on low- and high-skilled labor are set at 1.039 and 4.026, respectively, to match their respective empirical shares of 0.7 and 0.3 in total manufacturing employment. The rest of the parameter values are the same as in the baseline model. Between the two steady states, the trade cost is changed so as to yield a tenfold increase in offshoring as witnessed during 1974-2005.