Accounting for Automation and Offshoring in International Macroeconomic and Employment Dynamics*

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Abstract

Employment in middle-skill occupations witnessed an outright decline in the US during the last three decades. Middle-skill workers specialize in routine labor tasks which are prone to be automated. In addition, these occupations do not usually require on-site interactions and thus may be offshored overseas. High-skill workers instead execute non-routine cognitive tasks while the low-skilled specialize in on-site service occupations that cannot be automated. Motivated by this evidence, I develop a stochastic growth model of international trade in tasks with the possibility of automation to account for the role of offshoring and computerization in the decline of middle-skill employment. A system-based estimation approach which uses disaggregated employment data, trade-weighted international macroeconomic indicators, as well as, alternative proxies for automation and offshoring costs is implemented.

JEL classification: F16, F41

Keywords: Offshoring, Automation, Computerization, Employment, International Business Cycles, Heterogeneous Agents, Stochastic Growth, Two-Country Models.

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1 Introduction

The recurring destruction of middle-skill jobs witnessed since the early 1980s is among the most debated topics. The literature attribute much of these job losses to the emergence of offshoring and automation. Middle-skill occupations typically consists of both blue collar manufacturing jobs associated with assembling and machine operations. They also involve white collar jobs involving office and administrative duties. These occupations mostly involve the execution of a daily routine which can be easily broken down into a set of smaller tasks. In turn, these tasks can be programmed into computer code and performed by computers or robots.

By easing offshoring, revolutionary advances in telecommunications also contributed to the demise of these middle-skill occupations. Nowadays a manager can give directions, provide feedback, and monitor workers in plants located in remote locations on real time. Not surprisingly, breakthroughs in communications combined with a drastic decline in transportation costs fundamentally altered the nature of international trade in recent times. Intermediate goods now accounts for about two thirds of global trade. As a result, trade is increasingly characterized by the traffic of value added at different locations of the firms' global supply chains rather than the traditional exchange of final goods across countries. While offshoring is usually associated with manufacturing jobs, white collar service jobs are also increasingly migrating overseas. These includes help desk services, telemarketing, administration, and code debugging, among many others.

Occupations located both at the bottom and the top of the skill distribution where instead sheltered from the emergence of automation and offshoring. Low-skill jobs are hard to be automated since they are characterized by the execution of non-routine labors tasks. For instance, baby-sitters, home-health aides, and restaurant bartenders are jobs that require dealing with unpredictable human behavior. Other low-skill jobs do not necessarily involve human interactions, but require detailed manual handling which also prevents automation. Examples include, home and office cleaners, gardeners and construction laborers. Interestingly, these low-skilled jobs not only are protected from automation but also from offshoring. By definition, jobs requiring human interactions cannot be executed remotely, while the manual jobs just described must be executed where the final consumer is physically located. Put it differently, low-skill labor tasks are typically non-tradable. High-skill jobs are not prone to be automated as they typically require creativity, managerial skills, and flexibility. However, in most cases, nothing prevents these jobs of being executed remotely. Take an extreme example, in principle, many R&D and high-tech design jobs in Silicon Valley could be easily reallocated overseas. However, workers from the U.S. and other developed countries have a comparative advantage in these high-skilled occupations. In sum, the evidence appears to indicate that both offshoring and automation negatively affected the stance of middle-skills workers, while the low- and high-skilled workers where sheltered from these developments.

The main objective of this paper is to separately identify job losses arising from automation from those most likely lost to offshoring. To address this issue, this paper develops a stochastic growth model that displays international trade in labor tasks (offshoring) between two countries at different stages of economic development. The model also allows for the possibility of automation of some of these tasks. The economy consists of two sectors. First, a non-tradable low-skilled service sector hires only domestic labor. These workers execute on-site manual tasks that cannot be substituted (or complemented) with capital equipment. A second sector produces goods and services hiring labor and capital equipment. In this case, labor tasks maybe offshored or substituted by capital. A decline in the cost of offshoring (measured by transportation and telecommunication costs) bolsters the outsourcing of less productive routine tasks to the less developed economy. Similarly, a decline in the (quality adjusted) price of capital equipment encourages firms to substitute away from routine labor tasks towards capital. These developments benefit the employment prospects and earnings of those in low- and high-skilled occupations. Automation and offshoring lowers the cost of routine tasks that complement the cognitive labor tasks provided by high-skill individuals, thus enhancing the employment and earnings prospects of this last skill group. These phenomena encourage task upgrading and training among households, thus boosting aggregate productivity. Finally, as the earnings of those located at the top of the skill distribution increase, so does their demand for non-tradable services that are provided by low-skill workers–who are also sheltered from automation and offshoring.

The structural estimation technique in this paper uses a general equilibrium approach that addresses the identification problems of reduced-form specifications. It proposes a system-based analysis that fits the solved model to a vector of aggregate time series. Several quarterly data series are used to estimate the model. These includes disaggregated employment data, international macroeconomic indicators and different proxies for the cost of offshoring and automation. Indicators measuring the changes in trade (transportation) costs and telecommunications are considered for offshoring. Quality adjusted price of capital equipment is used to measure the extent in automation. The structural approach not only allows to disentangle the employment effects of offshoring from those arising from automation, but it is also suitable to quantify the aggregate welfare effects of changes in trade policy within the estimated setup.

The existent literature uses off-the-shelf indicators to distinguish jobs that are offshorable from those subject to automation. Autor (2013) builds a Routine Task Intensity (RTI) to differentiate occupations that are subject to automation. While Blinder and Krueguer (2013) build measures of offshorability based on professional coders' assessment of the ease at which each occupation could potentially be offshored. The approach in these papers has the clear advantage of directly measuring the degree of potential automation and offshorability at the micro level, but it also has some potential drawbacks. First, these two indicators are highly correlated (See Goos et al, 2014). As explained above, the occupations that are prone to be automated are also subject to offshorability and vice versa. Second, the offshorability indicator is based on the perception of those surveyed which heavily relies on the current *status quo* observed in any particular occupation. For instance, office clerks are mostly regarded as non-offshorable in these surveys. But clearly, if some manufacturing moves to China, many office clerks providing administrative support for these production operations will move as well. Third, the extent of automation and offshorability is not predetermined but it evolves endogenously in practice. Manufacturing plants in the U.S. count with a higher degree of automation (robotization), than those in India because salaries are lower in the latter country. Even more, automation is enhanced as computers become cheaper and improve in quality. Same logic applies to offshoring. Lower communication costs reallocate labor, but the extent of such a reallocation is dampened by the resulting changes in country wages differentials triggered by this move. All said, the existing empirical work accounting for the role of offshorability vis-a-vis the one surging from automation relies on reduced form specifications that fail to capture general equilibrium effects which, as explained above, can be of great significance. In particular, when assessing policy changes like the imposition of tariffs in international trade.

2 The Model

The model consists of two countries, Home and Foreign. The former being more developed than the latter. The focus is in Home, with analogous equations holding for Foreign. I denote foreign variables with an asterisk. I start with a description of the productive sector and next characterize the household problem.

2.1 Firms

There are two sectors in this economy. The first sector comprises on-site services and goods which require only unskilled labor as a factor of production. As previously discussed, these services are non-tradable by definition and consists of manual labor tasks which cannot be automated. The output of the second sector is a composite of physical capital and a diverse number of skilled labor tasks that may be accomplished at home or overseas (subject to an offshoring cost). Workers who accomplish skilled tasks which require training, with each worker revealing an idiosyncratic productivity level on completion of this training. The skill distribution in the developed country stochastically dominates the one in the less developed one. Finally, the model allows for the presence of an investment specific technology shock (IST) that lowers the (quality-adjusted) relative price of capital equipment. A decrease in the relative price of equipment induces multinationals to substitute away from relatively less productive (routine) labor towards capital.

2.1.1 Personal Services (Non-Tradable) Sector

The output of the service sector, $Y_{N,t}$, is a linear function of unskilled labor: $Y_{N,t} = \mathbb{X}_t L_{N,t}$, where $L_{N,t}$ is an homogenous aggregate of raw (unskilled) labor units that households supply to the service sector. The price for unskilled services, $P_{N,t}$, is: $P_{N,t} = \frac{w_{\mathbf{u},t}}{\mathbb{X}_t}$, where $w_{\mathbf{u},t}$ is the real wage paid for each unit of raw labor.

2.1.2 Tradable Sector

Firms in the tradable sector combine capital and labor in a CES fashion to produce output as follows:

$$Y_t^T = \left\{ \alpha \left(K_{t-1}\right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left(\mathbb{N}_t\right)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}},$$

where K_t is the capital stock and $\mathbb{N}_t$ is a composite of tradable tasks which is further described below.

Capital accumulation is subject to the following law of motion:

$$K_t = (1-\delta^k)K_{t-1} + \varepsilon_t^V \left\{ I_t - \frac{\phi^k}{2} I_{t-1} \frac{\varepsilon_{t-1}^V}{\varepsilon_t^V} \left[\frac{I_t \varepsilon_t^V}{I_{t-1}\varepsilon_{t-1}^V} - \Lambda_X \right]^2 \right\} \tag{1}$$

where I_t is investment, δ^k is the depreciation rate, ϕ^kcharacterizes the elasticity of the adjustment cost in the capital stock with respect to changes in investment. ε_{t-1}^V is an investment specific technology (IST) shock which alters the relative cost of quality-adjusted capital with respect to labor. This enhances automation in equilibrium.

Every period, households may invest in training, thus creating a diversity of tasks (occupations). Training requires an irreversible investment (sunk cost). At the completion of training, the idiosyncratic productivity $\mathbf{z}$ is revealed. This productivity level remains fixed thereafter until an exogenous job destruction shock makes the specific skilled obtained in the training obsolete. Households draw this productivity from a common distribution $\mathcal{F}(\mathbf{z})$ with support on $[1, \infty)$. Labor provided by each occupation is measured in efficiency units, $l_{\mathbf{z},t}$, which are the product of raw hours, l_t, and the idiosyncratic productivity index, $\mathbf{z} : l_{\mathbf{z},t} = \mathbf{z} l_t$. The efficiency unit is transformed back into a raw labor unit if the job destruction shock hits.

The job destruction shock is independent of the worker's idiosyncratic productivity level, so $\mathcal{F}(\mathbf{z})$ also represents the efficiency distribution for all workers in any point in time. By assumption, the distribution of idiosyncratic productivity in Home may stochastically dominate the one characterizing Foreign –i.e. $\mathcal{F}(\mathbf{z}) > \mathcal{F}^*(\mathbf{z})$.

I assume that technology is labor-augmenting. Each efficiency unit, $l_{\mathbf{z},t}$, used in production benefits from two technological innovations. The first one, $\mathbb{X}_t$, is a permanent world technology shock, which affects all productive sectors in both countries. This global shock has a unit-root, as in Lubik and Schorfheide (2006), and it warrants a balanced growth for the economy. In addition, a temporary country-specific technology, ε_t^Z, exists, which affects the tradable sector and evolves as an AR(1) process. Each efficiency unit provided by each occupation can thus be transformed in a productive task, $n_t(\mathbf{z})$, as follows:

$$n_t(\mathbf{z}) = (\varepsilon_t^Z \mathbb{X}_t) l_{\mathbf{z},t} = (\varepsilon_t^Z \mathbb{X}_t) \mathbf{z} l_t. \tag{2}$$

I assume that each occupation can perform a given set of tasks, ξ, which are defined over a continuum of tasks Ξ (i.e. $\xi \in \Xi$). At any given time, only a subset of these tasks, Ξ_t ($\Xi_t \subset \Xi$), may be demanded by firms in the global labor market and effectively used in production.[1] The labor input of the tradable sector consists of a compilation of productive tasks, $n_t(\mathbf{z}, \xi)$, which, as in Ottaviano et al (2013), are imperfectly substitutable[2]: $\mathbb{N}_t = \left[\int_{\xi \epsilon \Xi_t} n_t(\mathbf{z}, \xi)^{\frac{\theta-1}{\theta}} d\xi\right]^{\frac{\theta}{\theta-1}}$, where $\theta > 1$ is the elasticity of substitution across tasks. Some of these tasks can be executed in the foreign country. The wage bill is $\mathbb{W}_t = \left[\int_{\xi \epsilon \Xi_t} w_t(\mathbf{z}, \xi)^{1-\theta} d\xi\right]^{\frac{1}{1-\theta}}$, where $w_t(\mathbf{z}, \xi)$ is the corresponding wage paid to each efficiency unit labor used in production.

The firms' optimization problem deliver the following optimality characterizing the evolution of capital:

[1]The subset of tasks demanded by foreign companies is $\Xi_t^* \subset \Xi$, and may differ from Ξ_t.

[2]This may capture some local specialization in each specific task (see Grossman and Rossi-Hansberg, 2012). Notice that tasks are not substitutable in Grossman and Rossi-Hansberg (2008). Instead, I take the model approach in Ottaviano et al (2013), which assumes a CES specification.

$$P_t\zeta_t{=}\lambda_t\varepsilon_t^V\left(1-\phi^k\Omega_t\right)+\beta\mathbb{E}_t\left\{\lambda_{t+1}\varepsilon_{t+1}^V\left[\phi^k\Omega_{t+1}\frac{I_{t+1}}{I_t}-\frac{\phi^k}{2}\frac{\varepsilon_t^V}{\varepsilon_{t+1}^V}\left(\Omega_{t+1}\right)^2\right]\right\} \tag{3}$$

$$\text{where } \Omega_t=\frac{I_t\varepsilon_t^V}{I_{t-1}\varepsilon_{t-1}^V}-\Lambda_X$$

$$\text{and } \lambda_t=\beta\mathbb{E}_t\left\{(1+r_{t+1}^k)\zeta_{t+1}+\lambda_{t+1}\left(1-\delta\right)\right\} \tag{4}$$

This model characterizes a real economy with no role for nominal variables. The equilibrium conditions for the choice of labor and capital equipment are as follows: $(1-\alpha)\left(\frac{Y_t^T}{\mathbb{N}_t}\right)^{\frac{1}{\sigma}}=\frac{1}{P_t^T}, \alpha\left(\frac{Y_t^T}{K_{t-1}}\right)^{\frac{1}{\sigma}}=\frac{(1+r_t^k)}{P_t^T}$. For analytical convenience, I take a use the wage bill as the numeraire $\mathbb{X}_t\equiv 1$, hence serving as a unit of account.

2.1.3 Trade in Tasks and Skill Income Premia

In a symmetric equilibrium, $w_t(\mathbf{z},\xi)=w_t(\mathbf{z},.)$, stands for every task $\xi\in\Xi$. Therefore, the skill premium gap for a unit of labor employed in the domestic tradable sector with respect to a unit of of raw labor in the nontradable service sector, $\pi_{D,t}$, is defined as:

$$\pi_{D,t}(\mathbf{z},.)=w_{D,t}(\mathbf{z},.)n_{D,t}(\mathbf{z},.)-w_{\mathbf{u},t}l_t, \tag{5}$$

where the subscript D denotes a task executed for the domestic based firm. Some labor tasks can be accomplished in Foreign. These tasks are subject to a melting-iceberg trade cost, $\tau\geqslant 1$, as well as a fixed outsourcing cost, $f_{o,t}$. The fixed outsourcing costs is paid on a period-by-period basis. For consistency with the economy-wide balanced growth path, these costs are expressed in units of effective raw labor as follows: $f_{o,t}=\frac{w_{\mathbf{u},t}}{(\varepsilon_t^Z\mathbb{X}_t)}(\mathbb{X}_t f_o)$. Notice that these outsourcing costs must grow at a rate of $\mathbb{X}_t$ along this path (as all real variables do in this model). The premium gap for a unit of efficient labor that is demanded overseas (denoted with a X subscript) is:

$$\pi_{X,t}(\mathbf{z},.) = \left(\mathbb{Q}_t w_{X,t}(\mathbf{z},.)\frac{n_{X,t}(\mathbf{z},.)}{\varepsilon_t^{\tau}\tau} - f_{o,t}\right) - w_{\mathbf{u},t} l_t, \tag{6}$$

Where $\mathbb{Q}_t$ the factor-based real exchange rate (or terms of labor) and ε_t^{τ} is a shock that affects the trade (offshoring) costs.[3] Here, the wage for outsourced factors is denoted in terms of the foreign numeraire. Due to these outsourcing and melting-iceberg costs, only the most efficient workers have their tasks demanded in Foreign. In other words, a worker's tasks will take part in multinational production as long as productivity $\mathbf{z}$ is above the threshold $\mathbf{z}_{X,t} = \inf\{\mathbf{z} : \pi_{X,t}(\mathbf{z},.) > 0\}$. Workers with productivity above this threshold are regarded as high-skill. Workers with productivity below $\mathbf{z}_{X,t}$ accomplish tasks only for the domestic market and are middle-skill. From a different angle, foreigners will not execute some of these lower productivity tasks because the outsourcing costs fail to justify that execution. Aggregate shocks to productivity, demand or the cost of trade will result in changes to this threshold level.

Idiosyncratic Productivity Averages Melitz (2003) shows that these productivity weighted averages summarize the productivity distributions relevant for all macroeconomic aggregates. The average productivity of each worker is: $\tilde{\mathbf{z}}_{D,t} \equiv \left[\int_{\mathbf{1}}^{\infty} \mathbf{z}^{\theta-1} d\mathcal{F}(\mathbf{z})\right]^{\frac{1}{\theta-1}}$. The average efficiency of a worker whose tasks are used globally is: $\tilde{\mathbf{z}}_{X,t} \equiv \left[\frac{1}{1-\mathcal{F}(\mathbf{z}_{X,t})}\int_{\mathbf{z}_{X,t}}^{\infty} \mathbf{z}^{\theta-1} d\mathcal{F}(\mathbf{z})\right]^{\frac{1}{\theta-1}}$. This setup is isomorphic to one where a mass of workers, $N_{D,t}$, with productivity $\tilde{\mathbf{z}}_{D,t}$ executes tasks in the domestic market, and a mass of workers, $N_{X,t}$, with productivity $\tilde{\mathbf{z}}_{X,t}$ also accomplish tasks that serve as an input for foreign firms. We can define average wages for each of these skill groups as follows: $\tilde{w}_{D,t} = w_{D,t}(\tilde{\mathbf{z}}_{D,t},.)$ and $\tilde{w}_{X,t} = w_{X,t}(\tilde{\mathbf{z}}_{X,t},.)$. Similarly, the average skill-income gap for labor employed domestically is $\tilde{\pi}_{D,t} = \pi_{D,t}(\tilde{\mathbf{z}}_{D,t},.)$ while the corresponding outsource skill premia is $\tilde{\pi}_{X,t} = \pi_{X,t}(\tilde{\mathbf{z}}_{X,t},.)$. Taking these factors into account, the wage bill of the tradable sector, $\mathbb{W}_t$, can be redefined as: $\mathbb{W}_t = \left[N_{D,t}\left(\tilde{w}_{D,t}\right)^{1-\theta} + N_{X,t}^{*}\left(\tilde{w}_{X,t}^{*}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}$, where asterisks identify foreign variables.

[3]That is, $\mathbb{Q}_t = \frac{\varepsilon \mathbb{W}_t^{*}}{\mathbb{W}_t}$ (ε is the nominal exchange rate, units of the home numeraire per units of the foreign one). In the baseline specification, $P_{T,t} = \mathbb{W}_t$; therefore $\mathbb{Q}_t$ also may be interpreted as the terms of trade. The empirically relevant consumption-based real exchange rate measure is defined in the next section. Regarding the nominal exchange rate, ε, note that money must solely be interpreted as a unit of account. Prices are flexible, and money plays no other role in the economy.

2.2 Households

I do not address distributional issues in this model. As common in the literature, I assume that household members perfectly insure each other against fluctuations in labor income resulting from changes in employment status, thus eliminating any type of ex-post heterogeneity across individuals. Following the seminal works of Andolfatto (1996) and Merz (1995), households form an extended family that pools all its income and chooses aggregate variables to maximize expected lifetime utility.

Demand Composites Consumption and investment demand is composite of tradable and non-tradable output:

$$C_t + I_t = \left[(\gamma_c)^{\frac{1}{\rho_c}} \left(Y_{T,t}\right)^{\frac{\rho_c - 1}{\rho_c}} + (1-\gamma_c)^{\frac{1}{\rho_c}} \left(Y_{N,t}\right)^{\frac{\rho_c - 1}{\rho_c}} \right]^{\frac{\rho_c}{\rho_c - 1}}.$$

The associated price index is: $P_t = \left[\gamma_c \left(P_{N,t}\right)^{1-\rho_c} + (1-\gamma_c) \left(P_{N,t}\right)^{1-\rho_c} \right]$.

Household's Decision Problem Households have standard additive separable utility over real consumption, C_t, and leisure, $1 - L_t$, where L_t is the labor supply. They maximize a standard utility kernel, which is modified to be consistent with a balanced growth-path[4]:

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \varepsilon_t^b \left[\frac{1}{1-\gamma} C_t^{1-\gamma} - a_n \mathbb{X}_t^{1-\gamma} \frac{L_t^{1+\gamma_n}}{1+\gamma_n} \right], \tag{7}$$

where $\gamma, a_n, \gamma_n > 0$. ε_t^b is an AR(1) shock to the intertemporal rate of substitution, which may be interpreted as a demand shock.

The period budget constraint is expressed in terms of the numeraire, or indistinctly, in units of the wage bill, $\mathbb{W}_t$:

$$w_{\mathbf{u},t} L_t + N_{D,t} \tilde{\pi}_t + (1 + r_t^k) K_{t-1} + B_{t-1} = P_t C_t + P_t I_t + q_t B_t + \Phi(B_t) + f_{e,t} N_{e,t}, \tag{8}$$

where $\tilde{\pi}_t = (N_{D,t} \tilde{\pi}_{D,t} + N_{X,t} \tilde{\pi}_{X,t}) / N_{D,t}$ is defined as the average skill income premium for all the skilled

[4]See, for instance, Rudebusch and Swanson (2012).

tasks executed by all workers in Home. Households' total labor income is: $w_{\mathbf{u},t}L_t + N_{D,t}\tilde{\pi}_t$. The first term of this expression captures the remuneration from all "raw" units of labor that households supply to the non-tradable service sector as well as the domestic- and foreign- based tradable sectors. The second term adds the average skill income premium for all the skilled tasks performed both domestically and outsourced to Foreign. International financial transactions are restricted to one period, risk-free bonds. The level of debt due is B_{t-1}, q_t is the price of new debt, its inverse is the implicit interest rate. To induce model stationarity, I introduce an arbitrarily small cost of holding these bonds, $\Phi(.)$, which takes the following functional form: $\Phi(B_t) = \mathbb{X}_t \frac{\phi}{2}\left(\frac{B_t}{\mathbb{X}_t}\right)^2$. It is necessary to include the level of world technology both in the numerator and denominator of this functional specification to guarantee stationary along the balanced growth path.[5] $N_{e,t}$ represents the new skilled occupations created in period t. $f_{e,t}$ is the cost of creating these occupations. Mimicking outsourcing costs, $f_{e,t}$ is expressed in units of effective raw labor and follows a path consistent with balanced-growth: $f_{e,t} = \frac{w_{\mathbf{u},t}}{(\varepsilon_t^Z \mathbb{X}_t)}(\mathbb{X}_t f_e)$.

The mass of workers executing tasks for the tradable sector, $N_{D,t}$, evolves according to the following law of motion:

$$N_{D,t} = (1-\delta)(N_{D,t-1} + N_{e,t-1}). \tag{9}$$

Where δ captures the job destruction that renders the acquired skills obsolete. The mass of middle-skill workers, $N_{M,t}$, executing tasks exclusively for the domestic firms, is: $N_{M,t} = N_{D,t} - N_{X,t}$.

Optimality Conditions Households maximize utility subject to its budget constraint and the law of motion above. The optimality conditions for labor effort and the consumption/saving are reasonably conventional:

$$a_n \mathbb{X}_t^{1-\gamma} L_t (C_t)^{\gamma} = \frac{w_{\mathbf{u},t}}{P_t}, \tag{10}$$

[5] In the balanced growth path, debt, B_t, grows in sync with technology, $\mathbb{X}_t$, making the ratio stationary. In addition, since all real variables grow at the rate $\mathbb{X}_t$, I also need to make the adjustment cost grow at the same rate. See Rabanal et al (2011) for further details.

$$q_t = \beta \mathbb{E}_t \left\{ \frac{\zeta_{t+1}}{\zeta_t} \right\} - \Phi'(B_t), \tag{11}$$

where $\zeta_t = \varepsilon_t^b (C_t)^{\gamma} / P_t$, characterizes the marginal utility of the consumption index. The optimality condition governing the choice of bonds for foreign households in conjunction with the Euler equation in (11) yields the following risk-sharing condition:

$$\mathbb{E}_t \left\{ \frac{\zeta_{t+1}^*}{\zeta_t^*} \frac{\mathbb{Q}_t}{\mathbb{Q}_{t+1}} \right\} = \mathbb{E}_t \left\{ \frac{\zeta_{t+1}}{\zeta_t} \right\} - \frac{\Phi'(B_t)}{\beta}. \tag{12}$$

The training optimality condition is pinned down by the following condition:

$$f_{e,t} = \mathbb{E}_t \sum_{s=t+1}^{\infty} \left[\beta \left(1 - \delta \right) \right]^{s-t} \left(\frac{\zeta_s}{\zeta_t} \right) \tilde{\pi}_s. \tag{13}$$

That is, the training cost incurred to create an occupation in period t, $f_{e,t}$, is evaluated against the present discounted value of the average skill income premium accounted for all the skilled tasks $\{\tilde{\pi}_s\}_{s=t+1}^{\infty}$. Households adjust the discount factor, β, for the possibility of job destruction, δ.

2.3 Aggregate Accounting and Balanced Trade

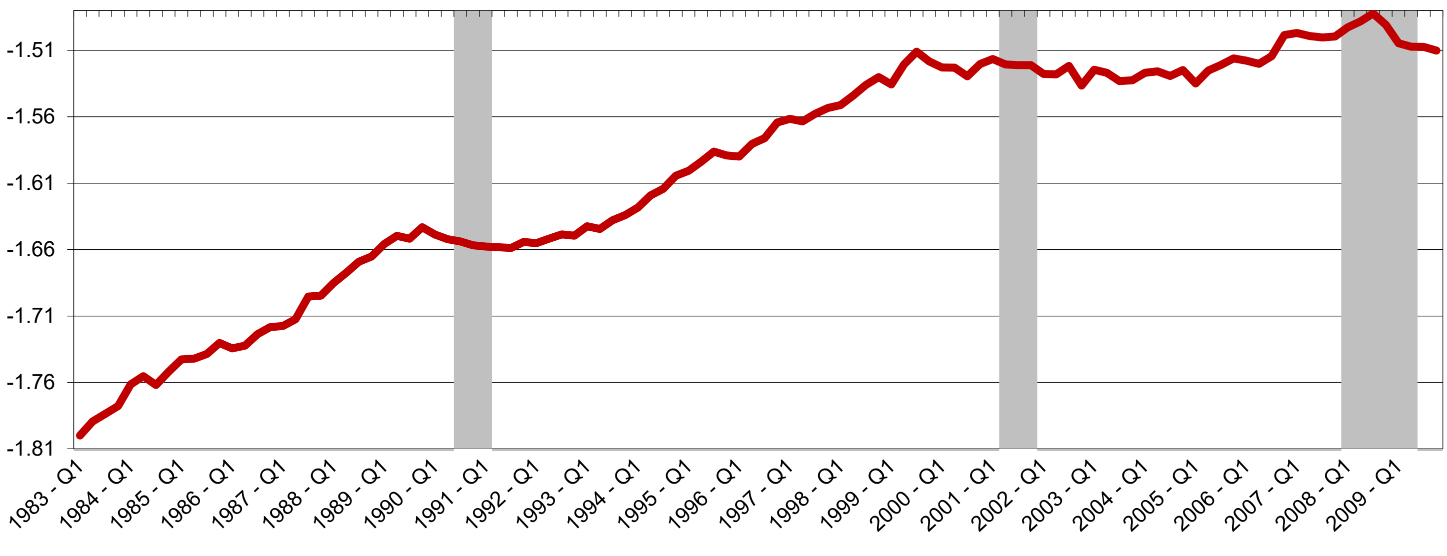
The evolution of the net foreign asset position of this economy is characterized as follows:

$$q_t B_t - B_{t-1} = \mathbb{Q}_t N_{X,t} \left(\tilde{w}_{X,t} \right)^{1-\theta} \mathbb{N}_t^* - N_{X,t}^* \left(\tilde{w}_{X,t}^* \right)^{1-\theta} \mathbb{N}_t. \tag{14}$$

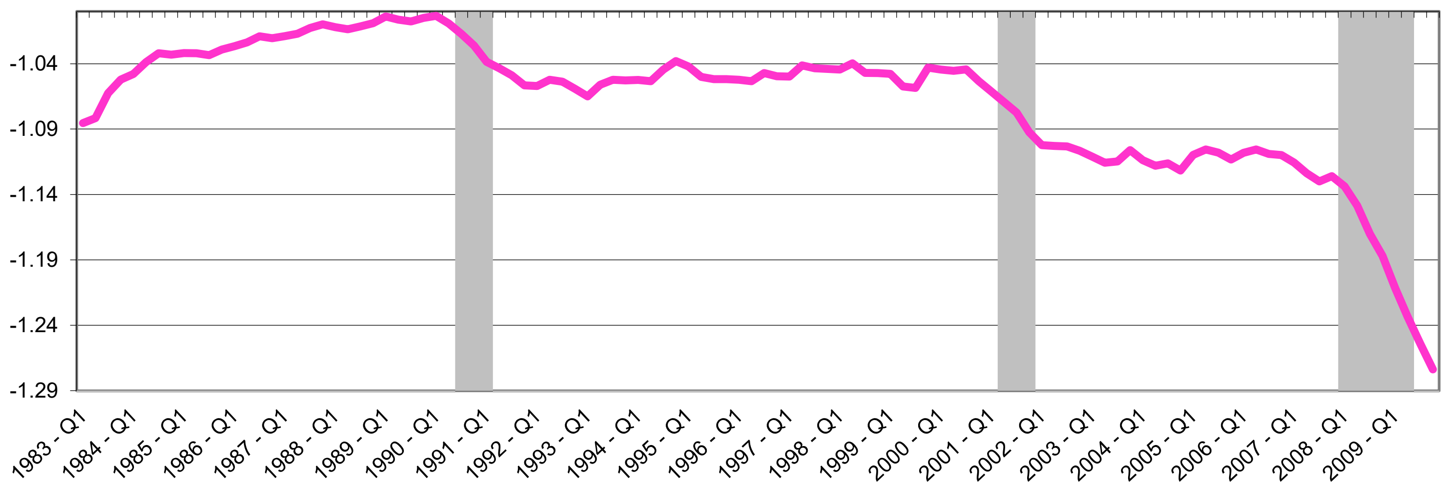
The first term on the right-hand side is the sum of all tasks executed in Home and outsourced to Foreign. The second term reflects the opposite. Finally, home and foreign holdings of risk-free bonds are zero in net supply worldwide: $B_t + B_t^* = 0$.

Employment over Population (in logs) by occupation groups

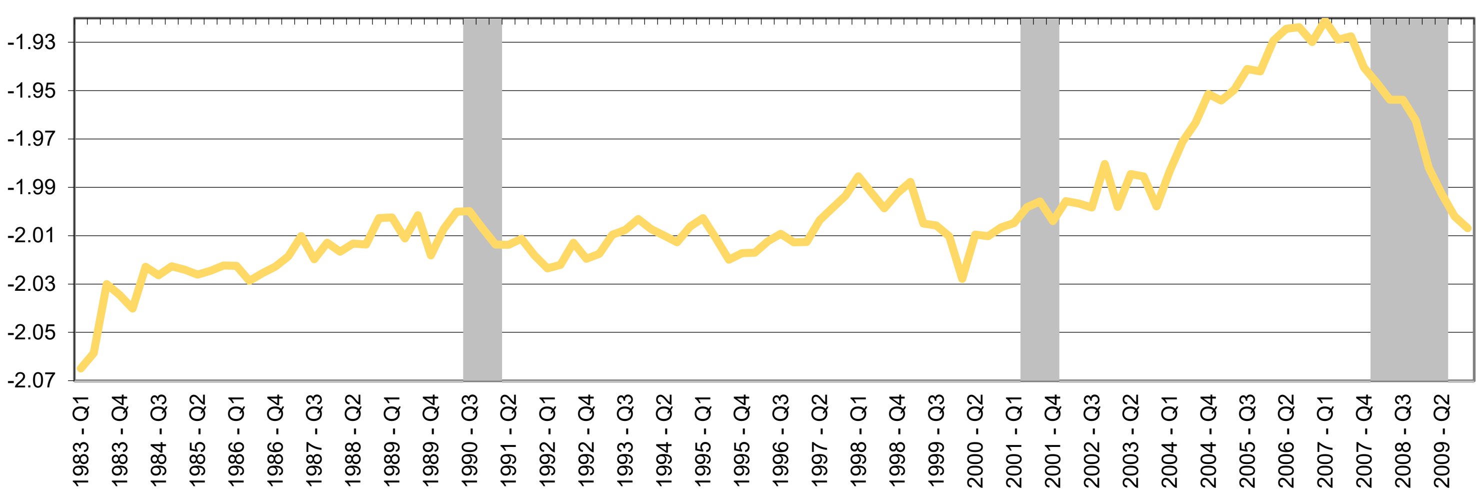
High-Skilled



Middle-Skilled

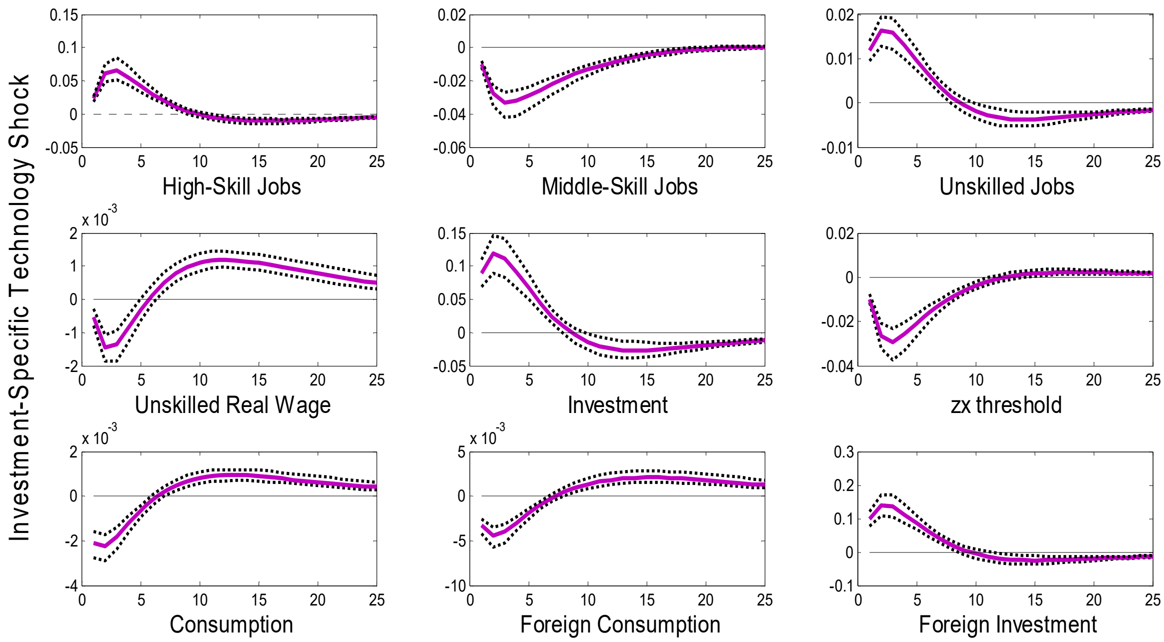


Low-Skilled



Impulse Responses

Investment-Specific Technology Shock (Decline Relative Price of Capital)



Negative Ice-Melting Shock (Decline in Offshoring Costs)