The Pennsylvania State University

The Graduate School

College of the Liberal Arts

ESSAYS ON INTERNATIONAL TRADE, LABOR MARKETS AND HUMAN CAPITAL

A Dissertation in
Economics
by
Ahmet Kerem Coşar

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2010

The dissertation of Ahmet Kerem Coşar was reviewed and approved* by the following:

Andrés Rodríguez-Clare
Professor of Economics
Dissertation Co-Adviser, Co-Chair of Committee

James R. Tybout
Professor of Economics
Dissertation Co-Adviser, Co-Chair of Committee

Edward J. Green
Professor of Economics

Alexander Monge-Naranjo
Assistant Professor of Economics

David G. Abler
Professor of Agricultural, Environmental and Regional Economics and Demography

Vijay Krishna
Professor of Economics
Director of Graduate Studies

*Signatures are on file in the Graduate School.

Abstract

This dissertation consists of three chapters.

Chapter 2 analyzes the reallocation of labor following a trade liberalization. These episodes typically display three features: slow net absorption of labor by export-oriented sectors, large reallocation costs for displaced workers, and a disproportionate adjustment burden for older workers. To explain these facts and to study alternative policy responses, I develop a two-sector small open economy model with overlapping generations, labor market search and matching, and sector-specific human capital accumulated through learning-by-doing. The model is calibrated to Brazilian data in order to study the dynamics of an economy in transition after trade liberalization. The calibrated model shows that human capital plays a much bigger role than search frictions in generating the observed slow adjustment to reforms. I then use the model to compare the distributional and efficiency effects of alternative worker-assistance programs in general equilibrium. A targeted employment subsidy that rewards mobility not only improves the distribution of income but also enhances efficiency gains from trade by facilitating faster formation of necessary skills during the adjustment period. The market failure corrected by the policy is the disincentives of experienced workers to invest in new skills which is in turn caused by the interaction of rent-sharing and intra-sectoral transferability of human capital to future employers. The paper contributes to a better understanding of trade-induced transitional dynamics and the labor market policies aimed at compensating the losers from trade.

Chapter 3, a joint work with Nezih Guner and James Tybout, develops a dynamic general equilibrium trade model to explore the interaction between openness, firm dynamics and labor markets. The motivation comes from the observation that in many liberalizing

countries, job turnover rates have risen, informal sectors have become larger, and wage distributions have become less equal. The model combines standard search frictions in labor markets with heterogeneous firms that experience ongoing productivity shocks. Each period, firms decide whether to exit or continue producing. Those firms that remain active choose their export volumes and adjust their employment levels through vacancy postings or lay-offs. Openness affects labor markets in our model because it increases rents for efficient firms and reduces rents for inefficient firms, as in Melitz (2003). These well-known effects interact with idiosyncratic productivity shocks and with scale economies in hiring costs to induce adjustments in the equilibrium job turnover rate, unemployment rate and wage distribution as trade barriers are dismantled. After fitting this model to Colombian micro data on establishments and households, we isolate the effects of trade frictions on labor market outcomes using counter-factual simulations. The results suggest that the mechanisms highlighted by our model can be important.

Chapter 4 presents a model of development in which skilled labor is an input in technology adoption. The model combines Nelson and Phelps (1966) type technology dynamics with a growth model in which intermediate goods are used to produce a final good. The intermediate good producers hire skilled labor to increase their productivity by adopting techniques from an exogenously evolving stock of world knowledge. I solve for the stationary equilibrium and derive analytic expressions for steady state income level and wage premium. In a quantitative exercise, I calibrate the model and compare its predictions with data. The model successfully accounts for cross-country income differences and within-country wage premia on skilled labor. These results strengthen the idea that different types of human capital perform separate tasks and should not be aggregated into a single stock of human capital in development accounting exercises. The availability of skilled labor is potentially much more important for development than such aggregative exercises have so far suggested.

Contents

List of Figures

List of Tables

Acknowledgments

I am deeply indebted to my advisors, Andrés Rodríguez-Clare and James R. Tybout. They have generously shared their time and expertise with me. Without their constant encouragement, this dissertation would have been impossible.

I am grateful to my committee members Alexander Monge-Naranjo and Edward J. Green for their insights, comments and suggestions on my work. Their advice has much improved this dissertation.

I am also very thankful to Nezih Guner from whom I have learned many of the techniques and methods I have used in my research. The doctoral course he taught as a faculty member in Penn State, and his close mentorship after he left Penn State, were very valuable for this dissertation. I am indebted to Barry Ickes for his encouragement and feedback during my doctoral studies.

I was fortunate to have many great friends and peers in my graduate program. I am thankful to all my classmates, senior and junior colleagues for the helpful discussions, joint learning and the support.

I especially would like to thank Margaret A. Neeley whose comments have vastly improved the presentation of this work.

This research was supported in part by the National Science Foundation (Grant SES-0617888) and the Human Capital Foundation through its financial support to Center for Research on International Financial and Energy Security (CRIFES). Any opinions, findings, and conclusions or recommendations expressed in this dissertation are those of the author and do not necessarily reflect the views of the National Science Foundation or the Human Capital Foundation.

Dedication

To my mother, Nalan Kayhan, and my father, Vedat Ahsen Coşar, who instilled the love of learning in me.

Chapter 1

Overview

A central theme in the globalization debate is how openness affects different groups of workers. Trade reforms and decreasing trade costs shift the fortunes of sectors and firms, along with the livelihood of workers associated with them. Some firms contract whereas some expand. Workers loose their existing jobs and search for new ones. This dynamic realloaction allows economies to adjust to a changing environment. Two factors, among others, play an important role in determining the pace and nature of this adjustment: the effectiveness of labor markets in matching job-seekers with vacancies, and availability of skills useful in expanding industries.

Another common claim regarding the effects of international trade is that it increases the turbulence in domestic labor markets. The hypothesis popularized by Rodrik (1997) suggests that greater integration to world markets increases the elasticity of demand for labor due to heightened competitive pressures on firms.

The first two chapters of this dissertation deal with these linkages between openness and labor markets. Chapter 2 analyzes short-run labor market responses to trade liberalization. These typically exhibit three features: slow net absorption of labor by export-oriented sectors, large reallocation costs for displaced workers, and a disproportionate adjustment burden for older workers. To explain these features and to analyze alternative policy responses, I develop a two-sector small open economy model with overlapping generations, labor market search and matching, and sector-specific human capital accumulated through

learning-by-doing. The model is calibrated to Brazilian data in order to study the dynamics of an economy in transition after trade liberalization. The calibrated model shows that human capital plays a much bigger role than search frictions in generating the observed slow adjustment to reforms. I then use the model to compare the distributional and efficiency effects of alternative worker-assistance programs in general equilibrium. A targeted employment subsidy that rewards mobility not only improves the distribution of income but also enhances efficiency gains from trade by facilitating faster formation of necessary skills during the adjustment period. The market failure corrected by the policy is the disincentive of experienced workers to invest in new skills which is in turn caused by the interaction of rent-sharing and intra-sectoral transferability of human capital to future employers. The chapter contributes to a better understanding of trade-induced transitional dynamics and the labor market policies aimed at compensating the losers from trade.

Empirical evidence confirms that in many liberalizing countries, notably in Latin American, job turnover rates have risen, and wage distributions have become less equal. Chapter 3, a joint work with Nezih Guner and James Tybout, develops a dynamic general equilibrium trade model that explains these phenomena. The model combines standard search frictions in labor markets with heterogeneous firms that experience ongoing productivity shocks. Each period, firms decide whether to exit or continue producing. Those firms that remain active choose their export volumes and adjust their employment levels through vacancy postings or lay-offs.

Openness affects labor markets in our model because it increases rents for efficient firms and reduces rents for inefficient firms, as in Melitz (2003). These well-known effects interact with idiosyncratic productivity shocks and with scale economies in hiring costs to induce adjustments in the equilibrium job turnover rate, unemployment rate and wage distribution as trade barriers are dismantled.

After fitting this model to Colombian micro data on establishments and households, we isolate the effects of trade frictions on labor market outcomes using counter-factual simulations. The results suggest that the mechanisms highlighted by our model can be important.

Finally, the ability of the workforce to adopt to new technologies determines the extent to which an economy benefits from trade, multinational production and global flow of ideas and techniques. Plausibly, some types of human capital matter more than others in determining this absorptive capacity. In fact, policy makers and industrialists in developing countries frequently cite the lack of availability of technical ability, especially engineering shortages, as a major constraint on growth.[1] The last chapter investigates this mechanism by addressing the following question: how much of the income disparity between countries can be explained by the lack of skills in less developed countries necessary to adopt technologies from abroad? It presents a model of development in which skilled labor is an input in technology adoption. The model combines Nelson and Phelps (1966) type technology dynamics with a growth model in which intermediate goods are used to produce a final good. The intermediate good producers hire skilled labor to increase their productivity by adopting techniques from an exogenously evolving stock of world knowledge. I solve for the stationary equilibrium and derive analytic expressions for steady state income level and wage premium. In a quantitative exercise, I calibrate the model and compare its predictions with data. The model successfully accounts for cross-country income differences and within-country wage premia on skilled labor. These results strengthen the idea that different types of human capital perform separate tasks and should not be aggregated into a single stock of human capital in development accounting exercises. The availability of skilled labor is potentially much more important for development than such aggregative exercises have so far suggested.

[1] See the article "Wanted: Skilled Workers for a Growing Economy in Brazil" published in New York Times on July 2, 2008. (`http://www.nytimes.com/2008/07/02/business/worldbusiness/02real.html?_r=1`)

Bibliography

Nelson R.R, Phelps E.S. (1966), "Investment in Humans, Technological Diffusion, and Economic Growth," *The American Economic Review* 56, 69-75.

Melitz, M. (2003), "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica* 71, 1695-1725.

Rodrik, D. (1997), "Has Globalization Gone too Far?," Washington, D.C.: Institute for International Economics.

Chapter 2

Adjusting to Trade Liberalization: Reallocation and Labor Market Policies

2.1 Introduction

Trade liberalization generates efficiency gains by moving resources toward an economy's comparative advantage.[1] As these adjustments occur, however, older workers with experience in import-competing sectors suffer earnings losses, unemployment spells, or both. Despite the centrality of these outcomes to the policy debate, economists have devoted little attention to formally modeling the short to medium-term dynamics that derive from trade liberalization.[2] Attempts to rigorously quantify these processes in the context of dynamic structural models are rarer still.[3] This has led to a disconnect between economists who stress long-run benefits of openness and policy makers who are concerned with short-run effects on employment and income distribution.

[1] Production gains in classical theories of trade are due to exploiting comparative advantages. More recent theories emphasize increasing returns to scale (Krugman (1979)), selection (Melitz (2003)), pro-competitive effects (Melitz and Ottaviano (2008)), and complementarities between trade and multinational production (Ramondo and Rodriguez-Clare (2008)).

[2] Exceptions are Mayer (1974), Leamer (1980), Mussa (1984), and Davidson and Matusz (2004).

[3] Artuc et al. (2007) and Kambourov (2009) are two recent exceptions.

To inform this debate and analyze policy alternatives, I develop and calibrate a dynamic two sector small open economy model that captures both the aggregate effects of trade liberalization and the adjustment experiences of heterogeneous workers. Key features of the model include overlapping generations, labor search and matching, and on-the-job human capital accumulation. Calibrated to aggregate and micro data from Brazil's pre-liberalization period, the model provides a basis for counterfactual experiments. In particular, it allows me to analyze the distributional and efficiency effects of income support programs that have been used in Brazil and elsewhere to facilitate labor market transitions after trade liberalization. These experiments suggest that targeted compensation programs rewarding work and mobility can bring distributional as well as aggregate welfare gains, while unemployment insurance exacerbates the short-run adverse effects by hampering labor reallocation and skill formation.

The motivation for the model comes from three common patterns of post-liberalization labor market adjustments. First, the transition period is marked by simultaneous creation and destruction of jobs within industries, and a slow net reallocation towards industries with comparative advantage.[4] Using industry-level panel data, Wacziarg and Wallack (2004) find that trade liberalization leads to little or no inter-industry worker reallocation, depending upon the level of aggregation. The case of Brazil's liberalization is examined using a linked employer-employee dataset by Menezes-Filho and Muendler (2007), who find that workers were displaced from previously protected industries, but comparative advantage industries failed to absorb them for years.

Second, insofar as inter-industry reallocation takes place, it implies costs for workers who move. These costs take the form of initial unemployment and earning losses upon reemployment. That US workers who change sectors have longer unemployment spells than

[4]Evidence shows that the dominant channel of labor reallocation in the short run is reshuffling of jobs within sectors rather than between sectors. According to Wacziarg and Wallack (2004), a liberalizing country experiences an increase of yearly inter-sectoral job reallocation from 1.1% to 1.5% within five years after reforms. Annual intra-sectoral excess job reallocation dominates this figure: Haltiwanger et al. (2004) report an 11% for a panel of Latin American countries, ranging from 8.9% in Argentina to 16.4% in Brazil. For Chile, Levinsohn (1999) documents that only about 10% of excess job reallocation is between industries in the seven years subsequent to liberalization. Recent literature also explores how openness can increase turnover permanently. Bernard et al. (2007) construct a model where job turnover increases in both margins as a result of falling trade costs. In Cosar et al. (2009), we show how increased openness can lead to higher intra-sectoral gross job reallocation in steady state.

those who return to the same industry is documented by Murphy and Topel (1987). That they also incur large wage losses when they find employment in a different industry is documented by Neal (1995). Evidence suggests that openness amplifies this link. Using US data, Krishna and Senses (2009) find that higher import penetration in the original industry is associated with larger income shocks to workers who switch industries. This result confirms an earlier finding by Kletzer (2001) that the sector of reemployment is very important in accounting for the variation in earnings losses of trade-related displacements.[5]

Third, reallocation patterns display a life-cycle effect. Older workers face a higher risk of not finding reemployment after being displaced from import competing industries.[6] In the case of Brazil, Menezes-Filho and Muendler (2007) document that the fraction of displaced workers unemployed after a year of separation increased from 32% in 1990, the year before Brazilian trade liberalization, to 41% in 1992. For workers with less than 10 years of labor market experience, the increase is from 30% to 35% only in the same time period (Table 1 in their paper). Concurrently, older workers are more likely to drop out of the labor force, or take up self-employment. According to Gonzaga et al. (2003), the propensity to transit from unemployment to self-employment increased dramatically for workers of age 40 and older in Brazil after 1990 (from 20% in 1988 to 40% in 1996) whereas it was flat for workers younger than 24. As a result, sectors that expanded more rapidly in terms of employment did so by hiring young workers at the entry margin.[7] Finally, in a survey of transition countries undergoing structural change from a planned economy to a market-oriented one, Boeri and Terrell (2002) conclude that older workers typically lose ground to younger ones since the value of the experience gained in the sectors favored by the Communist regimes was much lower in a free market.

[5] Although there is evidence for displacement-related earnings losses in developing countries, there is no study of whether displacement costs get amplified in the aftermath of trade liberalization. In the case of Brazil, Hoek (2007) and Menezes-Filho and Fernandes (2004) document earning losses associated with displacements over a of period time. For Mexico, Krebs et al. (2008) show that liberalization led to a short-run increase in income risk but they do not explore the channels.

[6] According to Kletzer (2001), displaced US workers below 44 years old are 11 percentage points more likely to be reemployed within two years than workers 45 years or older at the time of displacement.

[7] See page 137 in Pagés et al. (2009). The decomposition of changes in youth employment shows that sectoral reallocation increased demand for young workers in Brazil between 1990 and 2003. Similarly, Kim and Topel (1995) find that the dominant channel of manufacturing sector expansion during the industrialization of South Korea was the hiring of new cohorts in the labor force.

In order to capture these features of post-liberalization adjustment, I build three key features into my model. First, to make worker mobility and adjustment costs age-dependent, agents are finite-lived. Second, to allow for endogenous unemployment spells and job-specific rents, labor markets are subject to search frictions. Young and old workers search for jobs and are randomly matched with firms. Depending on their match-specific productivity draws, they continue or separate. Rents arising from the bilateral monopoly are split by Nash bargaining. Third, to allow for earnings losses when workers switch sectors, employed workers accumulate human capital through learning-by-doing. Skills formed on the job are only transferable to subsequent jobs in the same sector.

Importantly, search frictions and the sector-specificity of skills interact to generate an externality between workers and future employers. The effect is similar to Acemoglu (1997): part of the productivity improvement due to the skill formation is captured by future employers, so workers do not fully internalize the returns to their investment in accepting a job and giving up the opportunity to search for more productive ones. In this sense, switching to an industry in which one has no experience is an investment for which the social return is higher than the private one. This market failure could help explain why post-liberalization labor reallocation takes so long, and it raises the possibility that policies encouraging labor mobility may be efficiency-enhancing. Indeed, my policy experiments suggest that this is the case.

To perform these experiments, I calibrate my model to Brazil's pre-liberalization age-earning profiles and labor market flows (as well as various macro variables). I then consider a decline in the tariff rate that matches the observed increase in trade intensity during Brazil's trade liberalization and I solve for the equilibrium transition path to the new steady state. This is a complicated task since the distribution of heterogeneous workers over the state space evolves endogenously during the transition. I use a numerical algorithm similar to Costantini and Melitz (2009) to compute the transition path.

The calibrated model enables me to address two questions. First, given that search frictions and sector-specificity of human capital are both barriers to instantaneous adjustment, which one is the quantitatively dominant channel in explaining the sluggishness of

transition? The answer to this question is that sector-specific human capital is a bigger impediment to mobility. Second, what are the distributional and aggregate effects of labor market policies observed in Brazil and elsewhere? I first consider an unemployment insurance program that approximates the policy Brazil instituted in 1988, just before the liberalization of trade. As a counterfactual experiment, I design a targeted employment subsidy paid to the initial old employed in the previously protected industry conditional on working in the export-oriented industry.[8] My model is especially suitable for comparing these two policies in general equilibrium since it captures both the endogenous formation of heterogeneously productive matches and on-the-job accumulation of human capital.[9]

The unemployment insurance (actual policy) experiment does a good job in matching post-liberalization unemployment patterns. In particular, it is capable of explaining the initial overshooting in unemployment. On aggregate, it leads to an output loss during the transition by hampering what the economy needs most: reallocation and skill formation in the expanding sector. On the other hand, the employment subsidy (counterfactual policy) experiment suggests that it is possible to not only redistribute income toward workers harmed by the liberalization, but also to increase net output during the transition. The subsidy mitigates the market failure due to the learning externality: the underinvestment in skill formation is especially problematic during the transition which is a time for human capital build-up in the export-oriented industry. A policy that rewards work and mobility for workers adversely affected by trade not only compensates them, but it also speeds up the transition and helps the economy reap the gains from trade earlier on.

Relation to the Literature The paper builds on several existing literatures. First, it is related to earlier models that analyze the interactions between imperfect labor markets and international trade. Davidson et al. (1988) and Hosios (1990) apply a two-sector model with search frictions to a small open economy in order to study the validity of conventional

[8]This policy is inspired by the wage insurance program under the 2002 US Alternative Trade Adjustment Assistance (ATAA) which compensates workers age 50 or older who have lost their jobs as a consequence of increased imports. Recipients receive a wage supplement worth half the difference between their previous and new jobs up to $\$10,000$ over two years. This program is extended in 2009 under the name "Reemployment Trade Adjustment Act".

[9]This counterfactual is comparable to the actual policy in that both are financed by the same tax rate on firms' revenues.

trade theorems. Using a two-country two-sector model of trade, Helpman and Itskhoki (2007) show that the flexibility of labor markets can be a source of comparative advantage. None of these papers deal with transitional dynamics.

Second, it is related to a theoretical literature that characterizes the sectoral reallocation of labor in an overlapping generations framework with human capital specificity. Matsuyama (1992) assumes away mobility by allowing occupational choice only when agents enter the labor force. Rogerson (2005) is a two-period model with mobility but old workers prefer non-employment to switching sectors when their sector is adversely affected by a relative price shock. In both models, sectoral adjustment occurs through demographic change rather than the reallocation of existing factors. The stylized nature of these papers, however, restricts their quantitative applicability.

Third, this paper is also related to a literature which analyzes policies aimed at displaced workers. In a macro context, Ljungqvist and Sargent (1998) and Rogerson and Schindler (2002) show that unemployment insurance is a highly distortionary method of assisting displaced workers since it reduces the opportunity cost of unemployment. In a trade context, Davidson and Matusz (2006) analyze the least distortionary policies to compensate workers of different ability levels. They find that, depending on the type being compensated, targeted employment and wage subsidies are generally less costly then unemployment insurance. I emphasize the role of experience rather than ability. Moreover, I find that policies that induce mobility may actually achieve distributional goals without trading off efficiency.

Finally, my paper is most closely related to Artuc et al. (2007) and Kambourov (2009) who study the transition under barriers to labor mobility. Artuc et al. (2007) develop a dynamic structural model with competitive labor markets. Workers are hit by idiosyncratic shocks to their moving costs which limits their inter-sectoral mobility. Given the little amount of inter-sectoral reallocation, estimated costs are large in the US data. This paper provides a micro-foundation for their cost estimates which enables me to address policy-related questions. Using a calibrated island model of labor market search, Kambourov (2009) shows that firing distortions can substantially reduce gains from trade by hampering the needed reallocation of resources. There are two key differences between my paper and

his. First, I introduce life-cycle effects in order to distinguish the welfare impact of reforms on workers with different remaining work lives. Second, the interaction of rent-sharing and sector-specificity of human capital in my model raises the possibility that even when there are no institutional barriers, mobility may be suboptimally low. As a result, there is a potential efficiency role for policies that encourage workers with different levels of sectoral experience to switch industries.

The rest of the paper is organized as follows: Section 2.2 describes the model. Section 2.3 provides some brief background information on Brazilian trade and labor market reforms. Section 2.4 calibrates the model and Section 2.5 conducts counterfactual experiments to assess the effects of labor market policies. Section 2.6 concludes.

2.2 The Model

2.2.1 The Environment

The economy is populated by workers who have finite lives with two stages, old and young. Let $g \in \mathcal{G} = \{y, o\}$ denote these generations. Each worker is born young and faces a constant probability $\delta_a \in (0, 1)$ of becoming old. Once she becomes old, each worker faces a constant probability $\delta_m \in (0, 1)$ of death. There is no population growth, and the size of the total population is normalized to one. Preferences are defined by a momentary utility function linear in consumption. I assume that there is a measure one of value-maximizing firms owned by workers. Workers receive dividend payments d. Agents discount the future at rate $\beta \in (0, 1)$. Time is discrete.

Production A non-tradable final good is produced competitively using two tradable intermediate goods. By the small open economy assumption, world prices for intermediate goods, (p_1, p_2), are taken as given. The country has a comparative advantage in the production of good 1 and protects sector 2 with an ad-valorem import tariff $\tau \geq 0$. In the absence of trade costs, the domestic price of good 2 is $p_{2d} = p_2(1 + \tau)$ if it is imported in equilibrium, and that of good 1 is equal to the world price, $p_{1d} = p_1$.

Final good production is Cobb-Douglas in the two intermediate inputs,

$$Y = Q_1^{\gamma} Q_2^{1-\gamma}, \tag{2.1}$$

and competition in the final good market results in unit-cost pricing:

$$p_Y = \frac{p_{1d}^{\gamma} p_{2d}^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}. \tag{2.2}$$

The production of intermediate goods takes place in bilateral matches between workers and firms who randomly meet in a labor market subject to search frictions. At each point in time, a worker is characterized by her labor market status and a vector $h = (h_1, h_2) \in \mathcal{H}$ of sector-specific human capital stocks in sector 1 and 2 respectively. A match between a sector-i firm and a worker with human capital h produces output according to

$$q_i(z, h) = A_i z h_i, \tag{2.3}$$

where A_i is sectoral aggregate productivity, and z is a productivity level idiosyncratic to the match. Relative productivity across sectors, $A_1 \,/\, A_2 > 1$, is the only source of comparative advantage in the model. I assume that A_1 is sufficiently large that the country is a net exporter of good 1 and a net importer of good 2 in equilibrium.

Labor Markets Unemployed workers search for jobs in an undirected fashion and are randomly matched with a vacant firm, taking the match probability ϕ_w as given. On the other side of the market, idle firms draw a pair of vacancy creation costs (c_1, c_2) in terms of the final good independently from a distribution $F_c(c)$ with support $[0, \infty)$. They then decide whether to create vacancies, and if so, which sector to enter. The economy-wide measure of new matches is

$$m(U, V) = \frac{U \cdot V}{(U^{\lambda} + V^{\lambda})^{1/\lambda}}, \tag{2.4}$$

where U is the measure of unemployed workers, and V is the measure of total vacancies.[10]

[10] This constant-returns-to-scale functional form, proposed by Den Haan et al. (2000), has the desirable feature that it generates matching probabilities bounded between 0 and 1.

Matching probabilities for workers and firms are thus defined as $\phi_w = m(U,V)/U$ and $\phi_f = m(U,V)/V$ respectively. Defining market tightness as $\theta = V/U$, these probabilities are given by:

$$\phi_w = (\theta^{-\lambda} + 1)^{-1/\lambda}, \tag{2.5}$$

$$\phi_f = (\theta^{\lambda} + 1)^{-1/\lambda}. \tag{2.6}$$

Conditional on locating a vacancy, the probability of the match being in sector i is given by μ_i, an endogenous object to be characterized later. The probability that an unemployed worker will match with a sector-i vacancy is

$$\phi_{w_i} = \phi_w \mu_i.$$

Not all matches in this economy are transformed into jobs. A newly formed worker-firm pair draws a match-specific productivity level z from the distribution $F_z(z)$ with support $[0, \overline{z}]$ and density $f_z(z)$. The pair decides whether it is optimal to produce output, taking into consideration their outside options. Since some matches do not result in production, job filling and job finding probabilities differ from matching probabilities. If a pairing generates positive rents, the parties produce output and split the associated surplus through Nash bargaining, with the worker's share being $\sigma \in (0,1)$. Match specific productivity is fixed thereafter. Firm-worker pairings are exogenously destroyed with probability $(\delta^y_{JD}, \delta^o_{JD})$ for young and old respectively, or endogenously terminated when the surplus falls below zero because of on-the-job learning. More details on the latter source of separation will be given below.

Figure 2.1 summarizes the sequence of events for idle firms. All such firms are ex-ante homogeneous and cost draws are independent across time. In other words, firms do not carry these costs as a state variable and the outside option has the same value for all matched firms. There is free entry to vacancy posting.[11] If an idle firm finds its cost draws for both sectors prohibitively expensive, it remains inactive and redraws next period. If it creates a

[11] The measure of potential entrants, however, is bounded by one.

vacancy, matching uncertainty is resolved at the beginning of next period. Vacancy creation costs are sunk before the matching uncertainty is resolved.[12]

Human Capital Accumulation Human capital is sector-specific and accumulated through on-the-job learning. Each newborn worker starts her life with an initial endowment $\underline{h} = (\underline{h}_1, \underline{h}_2)$ normalized to $\underline{h}_1 = \underline{h}_2 = 1$. The law of motion for h depends on the labor market state of the worker:

$$h_i' = \begin{cases} h_i^{\alpha} H^{1-\alpha} & \text{if employed in sector } i, \\ \max\{1\ ,\ (1-\delta_h)h_i\} & \text{otherwise,} \end{cases} \tag{2.7}$$

with $\alpha \in (0,1)$. This expression implies that human capital is an element in the closed and bounded set $\mathcal{H} = [1, H] \times [1, H]$. Over time, a worker's sector-i human capital continues to accumulate as long as she is employed in that sector, approaching H asymptotically. Also, if a worker is not employed in sector i, her human capital for that sector depreciates at the rate $\delta_h \in [0, 1)$ per period but never falls below the initial level.

The age-earnings profile implied by this functional form is consistent with the micro-estimates of life-cycle earnings growth. Murphy and Welch (1990) document the concave earning profiles with rapid initial earnings growth and a leveling off after mid-career in the US data. Menezes-Filho et al. (2008) provide a similar picture for Brazil. Note that unlike Mincer (1974) and Ben-Porath (1967), skill formation is simply a by-product of market work. Heckman (1971) and Shaw (1989) use similar models of learning-by-doing to analyze labor supply over the life-cycle.

State Space At any point in time, a worker is either employed in a sector with match

[12] In order to pay the sunk cost c_i, an idle firm needs to have access to credit markets. The entry process can be decentralized with the following ownership structure. Suppose that there is a mutual fund whose shares are equally owned by workers. It can borrow funds from the market at a rate $1 + r = 1/\beta$ which makes *young* agents indifferent between lending or not. Borrowed funds are used to finance vacancy creation costs. The mutual funds holds a diversified portfolio and owns productive matches until the debt on them is paid back. Since firms constitute a fixed factor, the fund earns positive profits which is distributed to its owners as dividend.

specific productivity z, or unemployed. Denote these states by

$$\ell \in \mathcal{L} = \{\ell_1(z), \ell_2(z), \ell_u\}.$$

The state space for a worker is a collection of terms indicating her labor market state, human capital stock and generation:

$$s_w \in \mathcal{S}_w = \mathcal{L} \times \mathcal{H} \times \mathcal{G}.$$

A firm is either idle, or it is producing with a worker (h, g) in sector i and has productivity z. This defines the state space for firms:

$$s_m \in \mathcal{S}_m = \{m_1(z, h, g), m_2(z, h, g), m_u\}.$$

Next, I describe the job acceptance and vacancy creation problems.

2.2.2 Job Acceptance Problem

A firm-worker pair jointly decides to continue or terminate the match, depending on the value of the job and their outside options. Using time subscripts, let $\Pi_{it}(z, h_t, g)$ denote the value at time t of a sector-i job with productivity z and a worker (h_t, g). For an old worker $(g = o)$,

$$\Pi_{it}(z, h_t, o) \;=\; p_{idt} \cdot q_i(z, h_t) + \beta(1 - \delta^o_{JD})(1 - \delta_m)\Pi_{it+1}(z, h_{t+1}, o) \tag{2.8}$$

where human capital level h_{t+1} evolves according to the law of motion (2.7). For a young worker $(g = y)$, the same sector-i match has value:

$$\Pi_{it}(z, h_t, y) \;=\; p_{idt} \cdot q_i(z, h_t) + \beta(1 - \delta^y_{JD})\Big[\delta_a \Pi_{it+1}(z, h_{t+1}, o) + (1 - \delta_a)\Pi_{it+1}(z, h_{t+1}, y)\Big]. \tag{2.9}$$

The continuation values in equations (2.8) and (2.9) reflect the different life-cycle shocks faced by young and old agents. An old worker survives the period with probability $(1 - \delta_m)$.

A young worker has a probability of δ_a of becoming old. Otherwise, she remains young. As a result, old agents have a higher effective discounting rate which leads to generational differences in unemployment and inter-sectoral mobility over and above of the level of human capital.

The worker's outside option is to go back to the unemployment pool, and that of the firm is to become idle and redraw a new pair of costs within the same period. Let the values of their outside options be $W_t(\ell_u, h_t, g)$ and $J_t(m_u)$ respectively (see Appendix A.1 for the derivation of these expressions). An accepted job yields a surplus over the sum of worker's and firm's outside opportunities:

$$\Delta_{it}(z, h, g) \ = \Pi_{it}(z, h, g) \ - \ \big[W_t(\ell_u, h, g) \ + \ J_t(m_u)\big]. \tag{2.10}$$

If the job is accepted, the parties split the surplus by Nash bargaining with a worker share $\sigma \in [0, 1)$. The worker's decision is solved by

$$W_t[\ell_i(z), h_t, g] \ = \ \max_{\text{accept,reject}} \Big\{\sigma\Delta_{it}(z, h_t, g) + W_t(\ell_u, h_t, g) \ , \ W_t(\ell_u, h_t, g)\Big\}. \tag{2.11}$$

The firm solves a similar problem taking into account the value of its outside option of becoming idle again:

$$J_t[m_i(z, h_t, g)] \ = \ \max_{\text{accept,reject}} \Big\{(1-\sigma)\Delta_{it}(z, h_t, g) + J_t(m_u) \ , \ J_t(m_u)\Big\}. \tag{2.12}$$

The solutions to these two problems agree: only matches with a positive surplus are accepted. Since the value of a job is monotonically increasing in z, the acceptance decision has a cutoff property. For each (h, g), there exists a reservation level $\tilde{z}_{it}(h, g)$ in sector i, defined by $\Delta_{it}(\tilde{z}, h, g) = 0$, such that worker-firm pairings with $z \geq \tilde{z}_{it}(h, g)$ will produce output. The indicator function $\mathcal{I}^a_{it}(z, h, g)$ summarizes the sectoral job acceptance policy:

$$\mathcal{I}^a_{it}(z, h, g) \ = \ \begin{cases} 1 & \text{if } \Delta_{it}(z, h, g) \geq 0, \\ 0 & \text{otherwise.} \end{cases} \tag{2.13}$$

Although match-specific productivity is fixed after the initial draw, the model allows for endogenous separations. Because of the complementarity between the productivity term z and human capital h_i in the production function (2.3), a worker may accept a match, accumulate human capital and endogenously separate in order to search for a more productive job.

The cutoff productivity for a sector is increasing in the human capital stock of the worker in the other sector. This is a result of the increasing value of the outside opportunity in human capital. The higher the experience of a worker in sector 1, the more productive a job in sector 2 has to be for her to give up the opportunity of searching for a job in sector 1. This behavior decreases inter-sectoral mobility as workers gain experience and specialize in a sector.[13]

2.2.3 Vacancy Creation Problem

I will now characterize the problem of an idle firm with cost draws (c_{1t}, c_{2t}). Besides the matching probability, the firm takes into account the expected value conditional on matching. In order to take this expectation, the firm needs to know the distribution of human capital and generations among the unemployed. Let $\Psi_t(h|\ell_u, g)$ denote the distribution of human capital among the unemployed of generation g. The fraction of unemployed workers who are young is given by $\nu_t(y|\ell_u)$ such that $\nu_t(y|\ell_u) + \nu_t(o|\ell_u) = 1$. Using (2.12), the expected value of the firm conditional on being matched is obtained as

$$EJ_{it} = \sum_{g \in \{y,o\}} \nu_t(g|\ell_u) \int_{\mathcal{H}} \int_0^{\overline{z}} J_t[m_i(z,h,g)]\, dF_z(z)\, d\Psi_t(h|\ell_u, g). \tag{2.14}$$

Taking the cost draws (c_{1t}, c_{2t}) and expected values of matching (EJ_{1t}, EJ_{2t}), an entrant creates a vacancy in sector $i \in \{1, 2\}$ if the discounted expected net gain is greater than the

[13] Since search is undirected, specialization here means a high probability of rejecting matches in the sector in which a worker has little or no experience.

value of starting next period idle, and it dominates entry to sector j (satisfying $i + j = 3$):

$$\phi_{ft}\beta\big[EJ_{it+1} - J_{t+1}(m_u)\big] \;\geq\; p_{Y_t}c_{it}, \tag{2.15}$$

$$\phi_{ft}\beta EJ_{it+1} \;-\; p_{Yt}c_{it} \;\geq\; \phi_{ft}\beta EJ_{jt+1} \;-\; p_{Y_t}c_{jt}. \tag{2.16}$$

Note that (2.15) is obtained by rearranging the condition that the expected value of posting a vacancy, $\phi_{ft}\beta EJ_{it+1} + (1-\phi_{ft})\beta J_{t+1}(m_u) - p_{Y_t}c_{it}$, is greater than the value of spending the period inactive and entering next period as an idle firm. These conditions define the vacancy creation policy for a sector:

$$\mathcal{I}^v_{it}(c_{1t}, c_{2t}) \;=\; \begin{cases} 1 & \text{if (2.15) and (2.16) hold,} \\ 0 & \text{otherwise.} \end{cases} \tag{2.17}$$

Figure 2.2 shows the partition of (c_1, c_2) space into the regions of entry and no entry, as implied by the policy function and the cutoff costs $\tilde{c}_{it} = \phi_{ft}\beta(EJ_{it+1} - J_{t+1}(m_u))/p_{Y_t}$ defined by (2.15).

The size of these regions determines the fractions $(\tilde{\mu}_{1t}, \tilde{\mu}_{2t})$ of idle firms who create vacancies in sectors 1 and 2 respectively:

$$\tilde{\mu}_{it} \;=\; \int_{\mathbb{R}_+}\int_{\mathbb{R}_+} \mathcal{I}^v_{it}(c_i, c_j)dF_c(c_i)dF_c(c_j). \tag{2.18}$$

The remaining $1 - (\tilde{\mu}_{1t} + \tilde{\mu}_{2t})$ fraction finds it too costly to enter and remains idle. Conditional on matching, the probability of the match being with a sector-i vacancy is thus

$$\mu_{it} \;=\; \frac{\tilde{\mu}_{it}}{\tilde{\mu}_{it} + \tilde{\mu}_{jt}}. \tag{2.19}$$

2.2.4 Equilibrium

Agents in this economy are heterogeneous in several dimensions. In order to define an equilibrium, I need to describe how the distribution of individual state variables evolves. Note that it is enough to keep track of workers only because idle firms are ex-ante homogeneous

before the cost draws, and those already matched are attached to a worker with a particular state s_w.

To proceed, define a probability measure Ψ_t on $(\mathcal{S}_w, \mathbb{S}_w)$ where is $\mathcal{S}_w$ the state space for workers introduced above, and $\mathbb{S}_w$ is the Borel σ-algebra. For $S_w \in \mathbb{S}_w$, $\Psi_t(S_w)$ is the mass of agents whose states lie in S_w at time t. A transition function $\Gamma_t : S_w \times \mathbb{S}_w \to [0,1]$ is needed to characterize the evolution of $\Psi_t(S_w)$. The probability that a worker with individual state vector s_w at t will be in S_w next period is $\Gamma_t(s_w, S_w)$. In Appendix A.2, I describe how such a transition function can be constructed from individual decision rules and stochastic processes of the model. In the following definition of the equilibrium, I use the notation $\{x_t\}$ to denote the sequence $\{x_t\}_{t=0}^{\infty}$.

Definition 1: An *equilibrium* for given paths of world prices $\{p_{1t}, p_{2t}\}$ and a trade policy $\{\tau_t\}$ is a sequence of value functions $\{W_t(\cdot), J_t(\cdot)\}$, decision rules $\{\mathcal{I}_{it}^a(\cdot), \mathcal{I}_{it}^v(\cdot)\}$, matching probabilities $\{\phi_{wt}, \phi_{ft}\}$, sectoral composition of vacancies $\{\mu_{1t}, \mu_{2t}\}$, unemployment rates $\{U_t\}$, domestic prices $\{p_{1dt}, p_{2dt}\}$, final good prices $\{p_{Yt}\}$, net output $\{Y_t\}$, dividend payments $\{d_t\}$, aggregate income $\{I_t\}$ and tariff revenues $\{R_t\}$, intermediate good supplies $\{Q_{1t}^s, Q_{2t}^s\}$ and demands $\{Q_{1t}^d, Q_{2t}^d\}$, and the distribution of workers over the state space $\{\Psi_t\}$ such that:

1. value functions $\{W_t(\cdot), J_t(\cdot)\}$ and associated optimal decision rules $\{\mathcal{I}_{it}^a(\cdot), \mathcal{I}_{it}^v(\cdot)\}$ are the solutions to the job acceptance and vacancy creation problems described in Sections 2.2.2 and 2.2.3 respectively. When making these decisions, workers and firms take as given domestic prices, dividends, matching probabilities, the distribution of human capital among the unemployed of generation g,

$$\Psi_t(h|\ell_u, g) \;=\; \frac{\Psi_t(\ell_u, h, g)}{\int_{\mathcal{H}} d\Psi_t(\ell_u, h, g)},$$

and the fraction of unemployed workers in generation g

$$\nu_t(g|\ell_u) \;=\; \frac{\int_{\mathcal{H}} d\Psi_t(\ell_u, h, g)}{U_t}.$$

2. Vacancy posting decisions define the sectoral composition of entry $\left\{\tilde{\mu}_{1t}, \tilde{\mu}_{2t}\right\}$ and that of vacancies $\left\{\mu_{1t}, \mu_{2t}\right\}$ as in (2.18) and (2.19).

3. Matching probabilities are defined by (2.5) and (2.6) such that

$$\begin{aligned} U_t &= \int_{\mathcal{S}_w} \mathcal{I}(\ell = \ell_u) d\Psi_t(s_w), \\ V_t &= (\tilde{\mu}_{1t} + \tilde{\mu}_{2t}) U_t, \end{aligned}$$

   where $\mathcal{I}(\ell)$ is an indicator function that assumes the value one if its argument holds. The second line follows from the fact that the measure of idle firms is equal to the measure of unemployed workers, and only a fraction of them posts vacancies as described in Section 2.2.3. This defines market tightness as $\theta_t = V_t/U_t = \tilde{\mu}_{1t} + \tilde{\mu}_{2t}$.

4. Aggregate supply of intermediate good i is obtained by aggregating the individual supply function over the distribution of workers:

$$Q_{it}^s = \int_{\mathcal{S}_w} q_{it}(s_w)\, d\Psi_t(s_w),$$

   where $q_{it}(s_w) = A_i z h_i$ if $s_w = (l_i(z), h, g)$ for $g \in \{y, o\}$, and zero otherwise.

5. Tariff revenue on good 2 imports, $R_t = \max\{\tau_t p_{2t}(Q_{2t}^d - Q_{2t}^s), 0\}$, is rebated in a lump-sum fashion, and aggregate income is

$$I_t = p_{1dt} Q_{1t}^s + p_{2dt} Q_{2t}^s + R_t. \tag{2.20}$$

   All income is spent on purchasing the final good in the market, which generates the demand for intermediate goods:

$$Q_{1t}^d = \frac{\gamma I}{p_{1dt}}, \qquad Q_{2t}^d = \frac{(1-\gamma) I_t}{p_{2dt}}. \tag{2.21}$$

6. Final goods market clears with the price determined competitively by (2.2),

$$p_{Y_t} Y_t \;=\; I_t.$$

7. Ψ_t is a probability measure that evolves according the transition function Γ_t:

$$\Psi_{t+1}(S) \;=\; \int_{\mathcal{S}_w} \Gamma_t(s_w, S) d\Psi_t(s_w).$$

   In words, the distribution evolves consistently with the decision rules, exogenous job destruction shocks, labor market flows, productivity draws for new matches, the law of motion for human capital accumulation (2.7), and demographic shocks.

8. By Walras Law, trade balance condition hold. Defining net exports of good i by $NX_{it} \;=\; Q^s_{it} - Q^d_{it}$, and using equations (2.20) and (2.21), one can derive

$$p_{1t} NX_{1t} + p_{2t} NX_{2t} \;=\; 0.$$

A *steady state equilibrium* is a special case in which all aggregate variables are constant, policies are time-invariant and there is a stationary distribution Ψ that replicates itself every period. In Section 2.4, the steady state equilibrium concept will help us to calibrate the model to the pre-reform data from Brazil. In Section 2.5, I will characterize the equilibrium transition path after an unexpected and permanent change in trade policy parameter τ.

2.2.5 Discussion

The undirected job search by workers and the entry process for firms are important components of the model that deserve further discussion. First, I assume that all workers enter a common pool when searching, as in Alvarez and Veracierto (1999) and Acemoglu (2001). The alternative approach, directed search, assumes that workers can locate the sector of their choice. In that case, either labor markets within sectors are competitive and all unemployment is due to workers in transit (Lucas and Prescott (1974)), or the matching processes function separately (Hosios (1990)). Under either interpretation, directed search implies an

extreme selectivity where agents receive no information about jobs in a particular industry. Between these two polar cases of directed and undirected search, Moscarini (2001) offers a model in which heterogeneous workers with sector-specific skills decide to search selectively or randomly depending on their comparative advantage. The matching process in my model is similar to the case of random search there. Workers receive offers from both sectors which they can accept or reject. This can be justified by the evidence on search strategies used by workers. Fallick (1993) finds no robust pattern of displaced workers increasing their search intensity in expanding industries. Osberg (1993) emphasizes that many jobs are actually found without any explicit search effort. Unemployed workers simply receive offers through informal networks of former colleagues etc. Such a process is better captured by undirected search.

Second, the vacancy creation process helps to render the model economy diversified by introducing a curvature into firms' entry decision. Some entrants will draw a low vacancy creation cost for the comparative disadvantage sector. A subset of such vacancies will match with unemployed workers because search is undirected. In order to ensure diversification in equilibrium, firms should expect a positive mass of these matches to be accepted. This requires a positive measure of unemployed workers to have a reservation productivity below $\overline{z}$ in the comparative disadvantage sector. A sufficient condition is that newborns have a reservation productivity $\tilde{z}_2(\underline{h}, y)$ lower than $\overline{z}$ in the import competing sector. If, for a given set of parameters, the relative productivity of sector 1, A_1/A_2, is below a certain level, this condition will hold. I assume that this restriction is satisfied to ensure diversification at the initial prices.

Finally, the interaction of rent-sharing due to search frictions, intra-sectoral transferability of human capital and the impossibility of contracting with future employers gives rise to a market failure in which workers under-invest in learning. The channel is similar to Acemoglu (1997). When a firm and a worker form a productive match, they generate a positive externality for potential future employers of the worker: on-the-job learning adds to the stock of sectoral human capital which increases the value of entry to that sector. Workers cannot contract with potential future employers who will benefit from their recent

learning through rent-sharing. Neither of the parties in an ongoing match fully internalizes the returns to the skill formation. The resulting inefficiency is likely to be particularly costly when the economy is adjusting to a change in relative prices across sectors because labor reallocation requires an investment in learning by workers. This observation motivates a key counterfactual policy experiment designed to correct for the market failure during the transition.

2.3 Background Information on Brazilian Reforms

This section intends to give a brief summary of Brazilian trade and labor market reforms between 1988 and 1991. The timing of these policy changes, together with the availability of aggregate and micro data moments, makes Brazil a suitable environment for a quantitative application of the model.

2.3.1 Trade Reforms

After years of pursuing an import-substitution policy, Brazil underwent a big trade liberalization between 1988 and 1991. As Figure 2.3 reveals, the reforms substantially lowered average tariffs. What is not evident in the figure is the removal of all non-tariff barriers in 1991 under the Collar Plan.[14] As a result, import penetration has steadily increased. Furthermore, reforms changed the structure of tariffs across industries. Figure 2.4 plots tariff rates on fifty-three mining and manufacturing industries before and after the liberalization. The high variation in the pre-reform period and the subsequent harmonization indicate a big change in relative domestic prices across industries. Moreover, Pavcnik et al. (2004) cite evidence that the initial tariff structure granted higher protection to industries where Brazil had low comparative advantage. One would thus expect a substantial reallocation of resources between industries as a response to liberalization. Figures 2.5 and 2.6 show that this was not the case. The industry composition of the manufacturing labor force in

[14] According to Menezes-Filho and Muendler (2007), although tariffs decreased gradually starting with late 1980s, the removal of binding non-tariff barriers happened in the first day of the Collor administration. In that sense, Brazilian trade liberalization can be considered as a sudden and unexpected policy change.

1995 was quite similar to the pre-reform period.[15] One of the objectives of the paper is to explain this inertia.

2.3.2 Labor Market Reforms

Trade liberalization was not the only big policy change in Brazil at that time. The country also instituted an unemployment insurance in 1986, and increased its coverage as part of a broader labor market reform in 1988. Other programs initiated by that reform included an employment subsidy and active labor market policies such as training, and job search assistance.

The unemployment insurance is paid to claimants who worked in the formal sector within the last six months. The duration of benefits varies between three to five months depending on seniority, and the replacement rate is around 50% of the average wage prior to unemployment. According to Cunningham (2000), the program coverage increased significantly in 1990 when eligibility criteria were relaxed.[16] As of 1990, 43% of workers who had been laid off from formal sector jobs were covered. The employment subsidy program, *Abono Salarial* (salary bonus), is similar to the US Earned Income Tax Credit in that the government makes a transfer to workers with earnings below a certain threshold. According to Paes de Barros et al. (2006), 5% of the workforce was receiving this wage supplement in 1997.

These programs are financed by a special 0.65% tax levied on firms' revenues (*FAT: Fundo de Amparo ao Trabalhador*; Workers Protection Fund). According to Berg et al. (2006), total cost of these policies amounted to around 1% of GDP in 1995. Expenditure on unemployment insurance and employment subsidies constituted roughly 70% and 15% of total governmental labor market expenditures respectively, with the rest going to training programs.[17] Because of the dominant expenditure share of unemployment insurance, I will consider the actual policy change to be a simultaneous lowering of tariffs and introduction of unemployment insurance. Of particular interest will be the comparison of the transition

[15] For further details on Brazilian trade policy, see Pavcnik et al. (2004).

[16] These criteria include employment in the formal sector prior to dismissal and payment of insurance premium for a minimum period.

[17] Berg et al. (2006) provides further details about Brazilian labor market policies

after the actual policy change with the outcomes of counterfactual labor market policies accompanying trade liberalization. In order to run these simulations, I first quantify the model in the following section.

2.4 Calibration

This section calibrates the model to Brazilian data in the pre-reform period. Since labor market reform was only legislated in 1988 and became effective in early 1990s, the only distortion in the calibrated model is the import tariff. After a discussion of steady state outcomes, the next section will then analyze the transition to the new steady state when trade is liberalized.

I calibrate the model in two stages. In the first stage, I set the parameters that can be identified without solving the model. In the second stage, I pin down the remaining parameters by matching five model-generated moments to data. The algorithm used to solve for the steady state is described in Appendix A.3.

Parameters Chosen Without Solving the Model Table 2.1 summarizes the parameters that I set either by modeling choice, normalization, or by matching direct empirical counterparts. The model period is a quarter. New born workers have an expected life span of 40 years. They expect to be young for the first half of that time. This implies $\delta_a = \delta_m = 1/80$. The time discount parameter is set as $\beta = 0.97$ to match an average quarterly real interest rate of 3.1% between 1995-2009, a financially stable period compared to the hyperinflationary episodes before 1995. The real interest rate is a quarterly aggregate of the monthly government primary rate (SELIC) minus the quarterly rate of change in the consumer price index (INPC) obtained from IPEADATA (www.ipeadata.gov.br).

I normalize international prices and the productivity of sector 2 by setting $p_1 = p_2 = A_2 = 1$. The tariff rate τ is equal to the pre-reform average of 0.63 reported by Pavcnik et al. (2004). The two intermediate goods are assumed to be used with equal intensity in the production of the final good, hence $\gamma = 0.5$. Match-specific productivity draws are uniformly distributed between 0 and 1. Another normalization is the initial level of human

capital, set as $(\underline{h}_1, \underline{h}_2) = (1, 1)$. Following the survey evidence by Browning et al. (1999), depreciation of human capital is set as $\delta_h = 0$. Workers and firms are assumed to split the rents equally which implies $\sigma = 0.5$.

Separation rates from employment are directly observed from labor market flows in Brazil. The average quarterly separation rate as a fraction of employment in the formal manufacturing sector between 1982 and 1988 is reported as 1.5% by Hoek (2007). Across age groups, workers between ages $24-40$ have a separation intensity from formal manufacturing towards unemployment that is 50% higher than those between ages $40-60$ according to Bosch and Maloney (2007). I thus set $(\delta^y_{JD}\delta^o_{JD}) = (0.018, 0.012)$.

Parameters Obtained by Solving the Model To proceed, a functional form has to be chosen for $F_c(c)$, the distribution of vacancy creation costs. As discussed in Section (2.2.3), this distribution determines the measure of vacancies and hence labor market tightness. Market tightness in turn affects the job finding rate. Since this moment is the only source of discipline for $F_c(c)$, its mean and variance are not separately identified. I thus assume that vacancy creation costs are log-normally distributed with mean zero and standard deviation C_{sd}. The remaining set of parameters is $[\alpha, H, A_1, \lambda, C_{sd}]$. The first two parameters are the curvature and the upper bound for the skill formation process (2.7) respectively. A_1 is the aggregate productivity of the comparative advantage sector. λ is the elasticity parameter in the matching function (2.4).

The data moments used to calibrate these parameters are summarized in Table 2.2. Menezes-Filho et al. (2008) report two moments of the age-earning profile in 1990 which help to identify the parameters governing the accumulation of human capital. A worker with 5 years of labor market experience earns 41% more than her starting wages. This moment pins down the curvature parameter of the skill formation function as $\alpha = 0.974$. Experience of 40 years implies an average gain of 2.43 times the starting wage. This moment is informative for calibrating $H = 2.6$.

The productivity of sector 1 is calibrated as $A_1 = 1.71$ to match the average *export/(value added)* ratio in formal manufacturing between 1987-1990. The data moment is calculated using the time series of manufacturing export/output ratio reported by Pavcnik

et al. (2004) and manufacturing (value added)/output ratio obtained from the Brazilian Input-Output tables published by OECD. Unfortunately, there is no time series on the value added/output ratio for Brazil for the entire period. The IO tables are only available for 1995, 1996 and 2000. However, they all yield similar values. I assume that the average of these values, 33%, applies to the pre-reform period as well. An average exports/output ratio of 9.2% divided by the value added/output ratio yields the data moment as 26.3%.

The matching function elasticity λ and the standard deviation C_{sd} of vacancy cost distribution are calibrated using two moments. First, the elasticity of new matches to unemployment in Brazil is estimated as 0.25 by Hoek (2007). In the model, this implies the following relationship:

$$\frac{\partial m(U,V)/m}{\partial U/U} \;=\; 1-(\theta^{\lambda}+1)^{-1/\lambda} \;=\; 0.25$$

If we had an estimate of market tightness for Brazil, this equation would determine λ. Although there is no such estimate that I am aware of, market tightness in the model is equal to the fraction of idle firms who create a vacancy in each quarter. This moment, in turn, is driven by C_{sd}. The second moment I target is the job finding rate in the formal manufacturing sector. According to Bosch and Maloney (2007), the quarterly transition probability from unemployment to formal employment is 0.375 between 1987 and 1991.[18] In the model, this is equal to $a\phi_w$ where a is the job acceptance ratio. The two parameters (λ, C_{sd}) are calibrated to match the elasticity reported above and the job finding probability. This gives us a value for $\lambda = 2.16$ and $C_{sd} = 1.49$.

2.4.1 Steady State Results

Table 2.3 compares the steady states outcomes of the model to data. The model generates declining sectoral mobility over the life-cycle. Kambourov and Manovskii (2006) document that industry mobility declines with age in the US data. In 1997, the probability of moving between two-digit industries is 30% for non-college educated workers between ages 23-28.

[18] Although the informal sector is not explicitly modeled, one can think of unemployment as a state which captures the usual definition of unemployment and informal employment. According to Goldberg and Pavcnik (2003), informal employment share in manufacturing is relatively low in Brazil (10% in 1987).

For the age group 47-61, the probability falls to 4.8%. In my model, 40% of young workers separating from their jobs switch sectors if they are re-employed within a period, compared to a 5% for old workers. Although there is no empirical study of age-related mobility in Brazil, I expect it to be qualitatively similar to the US evidence. With that qualification in mind, one can say that the model is able to generate the steep decline of mobility over the life-cycle.

A related outcome is the difference in the unemployment rates within generations. In the model, 70% of those who are unemployed are young. This implies a higher than average youth unemployment rate since population shares of the two generations are equal. Note that this is partly due to the higher exogenous separation rate $\delta^y_{JD} > \delta^o_{JD}$. However, the two generations also differ in the job acceptance cutoffs. There are two opposing incentives for the young. They have a lower discount rate, which makes them more willing to tolerate unemployment and search for productive jobs. On the other hand, they forgo learning when unemployed. The net effect is thus ambiguous. With the calibrated values, the cutoff productivity is higher for the young at all levels of h. In other words, not only are flows out of employment larger but flows into employment are lower as well. As a result, the ratio of youth unemployment rate to old unemployment rate is 2.4 in the model. In the data, the unemployment rate is 3.64 (2.61) times higher among males aged 15-24 compared to males aged 50-64 (25-49) in 1992.[19]

Turning to post-separation wage changes, the model predicts that old workers who switch industries experience an average wage loss of 11.6%. The wage drop for old workers who find employment in the same sector is 2.25% only. The average percentage wage change between two subsequent jobs for young workers is 0.51%. Micro level evidence on wage dynamics related to sectoral switching in Brazil is scant. Comparing the wages of Brazilian workers changing jobs involuntarily by going through unemployment, Hoek (2006) finds that switches are associated with an average earnings loss of 22%. This figure, however, is not controlling for selection based on worker characteristics which could affect the probability of involuntarily separating from one's job, and thus should be considered as an upper bound

[19]Data source is Table 11 in the data appendix CD-Rom of IADB (2004).

on the isolated effect of the human capital.

The model does a good job of matching statistics related job turnover.[20] Because there is no net employment change across sectors in steady state, all reallocation is excess job reallocation. In the model, the yearly job destruction rate is 17% which implies a turnover rate of 34%. According to IADB (2004), average job turnover in Brazil between 1987 and 1992 is 32%.

The next section investigates the transitional dynamics of a trade reform using the calibrated model.

2.5 Policy Experiments

This section first replicates the actual policy changes in Brazil in order to compare the simulated transitional dynamics to the data. The actual policy experiment entails tariff cuts and introduction of unemployment insurance. Two counterfactual policy experiments follow. First, I liberalize trade but do not implement any income support program (Counterfactual I). The comparison with the actual policy experiment indicates that the introduction of unemployment insurance jointly with trade reforms might have affected transitional dynamics adversely in Brazil by hampering the reallocation of labor. Counterfactual I is also useful for comparing the transitional dynamics of the model with and without human capital. The results suggest that the dominant barrier to reallocation is sector-specificity of human capital. I then ask whether a different policy could have compensated the losers and facilitated faster reallocation at the same time. Counterfactual II proposes a targeted employment subsidy geared towards encouraging workers to move to the expanding sector. This policy yields a positive outcome in terms of compensation and aggregate output. All transition paths are solved with a numerical algorithm similar to Costantini and Melitz (2009) described in Appendix A.3.

[20] Note that job and worker turnover rates are the same in the model.

2.5.1 The Actual Policy: Trade Liberalization with Unemployment Insurance

Let the economy initially be in the steady state which it is calibrated in Section 2.4 with tariff rate τ_h. In period 0, an unexpected and permanent liberalization lowers the tariff to $\tau_l < \tau_h$, and the government announces that it will tax firms' revenues in the intermediate good sectors by 1% to finance a unemployment insurance program.[21] Tax revenues are equal to labor market expenditures every period. The equilibrium definition now includes a sequence of unemployment benefits $\{b_t\}_{t=0}^{\infty}$ taken as given by agents, tax revenues equal to

$$G_t \;=\; 0.01 \times \int_{\mathcal{S}_w} p_{idt} q_{it}(s_w)\; d\Psi_t(s_w),$$

and balance budget condition

$$G_t \;=\; b_t U_t \qquad \text{for all } t \in \{0, 1, 2, ...\}.$$

Associating the date of reform with the year 1991, I choose τ_l such that the export/value added ratio matches the data in 1997. Terms of trade effects and aggregate shocks after 1998 move the data in ways that the model cannot capture. I thus confine the data comparison to the 1991-1997 time period. With the announced policy changes, the economy starts to move towards a new steady state. The transitional dynamics of openness and unemployment are depicted in Figures 2.7 and 2.8. The initial response of export/output ratio is matched well in the model, but the data shows some business cycle fluctuations which I abstract from.

The model does a good job of capturing the unemployment dynamics. The mismatch between the skill demand and its supply leads to an overshooting in the unemployment rate. Initially, there are many workers experienced in the previously protected industry. The drop in the value of their human capital, together with the increase in the outside option (because of unemployment benefits) leads to the termination of some matches accepted before the

[21] Note that this tax rate is equal to the cost of social safety net policies as a fraction of the GDP in Brazil. It does not matter whether the tax is levied on the final good producer or intermediate good producers. The representative final good producer will pass the incidence of the tax to the consumer by charging a price that is 1/0.99 times higher than the undistorted price. Since real wages and profits are obtained by dividing revenues over the price of the final good, the real value of a match will be 0.99 times its undistorted value.

liberalization. In the long run, the skill stock of the economy adjusts as more members of newborn cohorts accumulate human capital in the export-oriented sector. Unemployment decreases and, because of the new insurance, settles to a higher steady state level than its initial value. The aggregate effect is similar to Ljungqvist and Sargent (1998) who analyze the effect of welfare under structural change: unemployment compensation hinders the adjustment of an economy to large shocks.

Could unemployment insurance ever be welfare improving in this economy? The risk-neutrality of agents implies that there are no gains from consumption smoothing. Models of optimal unemployment insurance such as Acemoglu and Shimer (1999) emphasize another source of welfare gains under risk aversion. When matches have heterogeneous productivity, risk-averse agents are more likely to accept low productivity jobs when they are liquidity constrained in order not to hit the zero consumption bound. By keeping agents' consumption away from zero, unemployment benefits enable them to search for more productive jobs. Although there is match-specific productivity in my model, there is no risk-aversion. However, one cannot rule out the possibility that agents would be under-investing in searching for more productive jobs under some parameter values because of rent-sharing. On the other hand, the moral hazard effect is present.[22] Here, it not only reduces aggregate employment but skill formation as well. The overall effect is thus ambiguous. Finding the optimal policy for this environment is beyond the focus of this paper, but it is an interesting open question.

2.5.2 Counterfactual I: Trade Liberalization with No Labor Market Reform

How would the economy respond if Brazil liberalized its trade regime but left labor market policies unchanged? To address this question, I repeat the experiment without unemployment insurance. Figure 2.10 compares the net output during the transition in response to this counterfactual policy with its path under the actual policy solved above. Two results emerge. First, unemployment insurance eats away the gains from trade liberalization. Out-

[22] In this context, moral hazard arises because workers reject jobs which would have been accepted in the absence of the unemployment insurance.

put remains under its long-run value for a very long period of time. There is an initial dip in net output in line with the overshooting in unemployment. We do not see this pattern in the counterfactual scenario with no unemployment insurance. The flows in and out of employment are enough to accommodate the necessary reallocation in the short run. Note that this is not necessarily a general result: if there were no exogenous separations, the no-insurance economy might have as well experienced an overshooting in unemployment and undershooting in output in order to accommodate the necessary reallocation of labor.

Second, transition is very lengthy under both scenarios. In the counterfactual experiment, output steadily increases towards its long-run level but at a very slow pace. It takes around 80 years, or two generations, for the economy to get close to its new steady state. The model is thus able to explain the low impact of trade reforms on liberalizing countries in the short run. This inertia is caused by two barriers to instantaneous adjustment: search frictions and sector-specificity of human capital.

In order to explore the quantitatively dominant mechanism behind the sluggishness of adjustment, I run a separate counterfactual in which I solve the model without human capital by setting $\alpha = 1$ and keeping other parameters the same. The two economies have different steady states. To facilitate comparison, Figure 2.9 plots a normalized measure of reallocation completed at each point in time during the transition. Half of the overall reallocation towards the new steady state is completed in 6 years in the absence of human capital. Search frictions alone predict a fast reallocation. With human capital, the half-life is 34 years, almost a generation's life-time in the model. Clearly, specificity of human capital is a much bigger barrier to mobility and adjustment than search frictions. The S-shape of the path points out the importance of the generational mechanism. Around 40 years after the transition, when most of those alive during the policy change have died, reallocation speeds up. As new cohorts enter the workforce and accumulate human capital in the comparative advantage sector, and as the initial cohort phases out, aggregate human capital stocks adjust. This in turn affects the composition of vacancies since firms' entry decisions take into account the aggregate stocks of human capital in each sector. Sector-specific skills resemble a form of capital which depreciates very slowly, and takes a long time

to build. The combination of finite life-times and experience is thus a powerful mechanism that slows down the adjustment of the economy.

This result is similar to the finding by Alvarez and Shimer (2008) that search frictions alone cannot explain unemployment arising from inter-industry shifts in US data without assuming an unreasonably large cost of moving. Similarly, Artuc et al. (2007) estimate the mobility costs that can rationalize the sluggishness of trade-induced inter-sectoral mobility in the United States. They find these costs to be on average thirteen times the average wage. This seems to be a very large number for pecuniary costs such as the cost of geographical mobility. Sector-specific human capital acts a barrier to mobility since it increases the opportunity cost of switching sectors for workers.

2.5.3 Counterfactual II: Trade Liberalization with a Targeted Employment Subsidy

I now turn to the analysis of an alternative policy that compensates losers of liberalization while inducing them to work in the expanding sector. The motivation for this policy stems from the increasing interest in compensation policies that reward work. Examples that are not targeted include the Earned Income Tax Credit in the United States, the Working Tax Credit in the United Kingdom, *"Prime Pour l'Emploi"* in France and the *"Abono Salarial"* in Brazil. The US Alternative Trade Adjustment Assistance (ATAA) targets trade-displaced workers and provides a wage subsidy that pays 50% of the difference between worker's old and new wages up to $\$10,000$ for two years.

In this scenario, the government announces an employment subsidy $\{\eta_t\}_{t=0}^{\infty}$ simultaneously with trade liberalization. The policy has three features:

i. It is targeted at the initial old employed in sector 2 (previously protected industry) at the time of liberalization.

ii. It is conditional on mobility: it is paid for sector 1 jobs (export-oriented industry) only.

iii. It has limited duration: it is implemented for 20 years only (80 model periods are

equivalent to the expected life of the initial old). In other words, $\eta_t = 0$ for $t > 80$.

The policy is implemented in the following way. Since it has limited duration, the tax rate is set such that it linearly declines from 1% to zero in 80 periods.[23] Again, the government runs a balanced budget every period. The policy results in a transfer from the beneficiaries of trade (those with experience in sector 1) to losers of trade (workers experienced in sector 2). It can be said that it yields distributional gains (formal analysis and graphs to be completed). It turns out that it also brings about gains in aggregate welfare. Figure 2.11 plots net output during the transition in comparison with the outcome of Counterfactual I (no income support program). After six quarters, net output with the employment subsidy overtakes that under the Counterfactual I and converges to the new steady state at a faster rate. Note that after the phasing out of the employment subsidy, both policies converge to the same long-run value. Remarkably, employment subsidies help to convert the S-shape of the transition to a more concave path with faster initial adjustment. The discounted value of net output stream under Counterfactual II with employment subsidies is 4.17% higher than its value under the actual policy with unemployment insurance, and 0.61% higher than under Counterfactual I with no income support. By encouraging inter-sectoral mobility, this policy fosters skill formation in sector 1 which further affects the sectoral composition of entry (Analysis of distributional outcomes is work in progress).

The source of inefficiency that calls for a public policy is the learning externality between workers and future employers discussed in Section 2.2.5. Because of rent-sharing, workers displaced from the import-competing sector under-invest in skill formation by rejecting some matches in the expanding sector with low starting wages but learning prospects. The employment subsidy acts like an investment subsidy to human capital accumulation. The returns to such an investment are especially high during the transition period because the skill mix of the economy is very different than its long run value.

[23] Otherwise, firms postpone entry as the economy get closer to $t = 80$, and the economy contracts before the phasing out of the policy. A gradual decline in the tax rate avoids this kind of behavior.

2.6 Conclusion

I develop and solve a two-sector small open economy model of equilibrium search with overlapping generations and sector-specific human capital in order to analyze inter-sectoral reallocation of labor after trade reforms. Modeling choices are motivated by the evidence that reallocation is very sluggish, it is costly for displaced workers, and these costs are increasing with age. I calibrate the model using aggregate and micro moments of the Brazilian economy before the trade liberalization of 1991. This helps me to perform policy experiments on trade and labor market reforms undertaken simultaneously in Brazil.

The first contribution of the paper is to discern the role of search frictions from sector-specificity of human capital in accounting for the slow pace labor reallocation. A comparison of the transition paths of the model with and without human capital suggests human capital is a much bigger barrier to mobility then search frictions. This result indicates the limitations to the often cited policy prescription that flexible labor markets are key to rapid restructuring after reforms, and hence active labor market policies such as job search assistance could be helpful. If the dominant source of slow adjustment is the disincentives of mid-to-old age workers to accept jobs in new sectors, policies aimed at matching them with employers will have low returns. The second contribution of the paper is the analysis of a particular policy that addresses these disincentives. Performing a counterfactual policy experiment, I find that a targeted employment subsidy paid to workers experienced in the shrinking sector conditional on employment in the expanding sector not only compensates their welfare loss, but also increases aggregate net output. The market failure behind this result is underinvestment in human capital of the comparative advantage sector. Because of search frictions, workers split their human capital rents with their employers. Not being a full claimant of their investment, they accept sub-optimally low number of jobs. A policy that rewards work and mobility mitigates this market failure. Compensation policies such as the wage insurance under the US Alternative Trade Adjustment Assistance (ATAA) constitute a viable alternative to unemployment insurance or retraining when dealing with the effects of globalization. In contrast to the policy experiment in this paper, ATAA is not conditional on the sector of reemployment. Plausibly, there are informational limitations to

a government's ability in choosing the sectors in which employment should be subsidized. Whether public policy can be improved in that direction is an open question.

Finally, the model can be applied to study other phenomena that alter relative prices across sectors, such as technological change. The decline of manufacturing and the rise of the service sector is one example. Such structural change, however, is more secular in nature and agents have a longer time horizon to adjust. One can thus expect the room for policy to be smaller. A formal quantitative analysis is yet to be done.

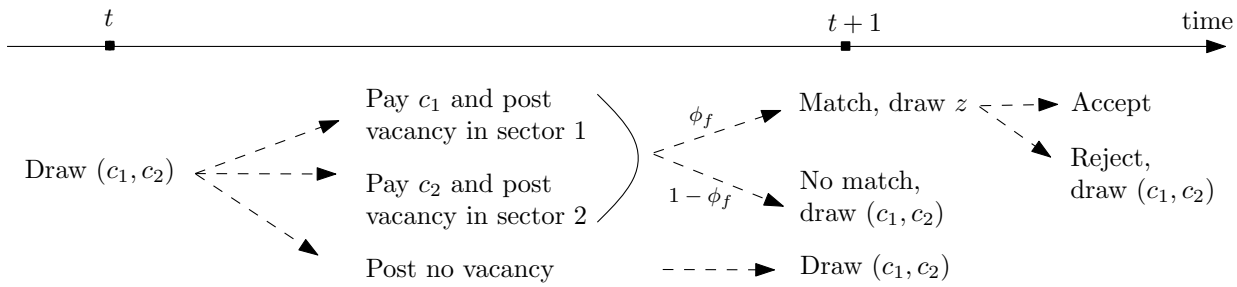

Figure 2.1: Timing of Events for Idle Firms

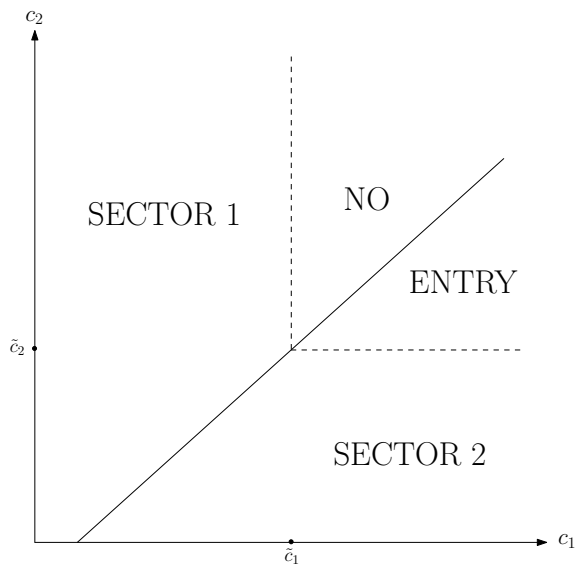

Figure 2.2: Sectoral Entry Decision of an Idle Firm

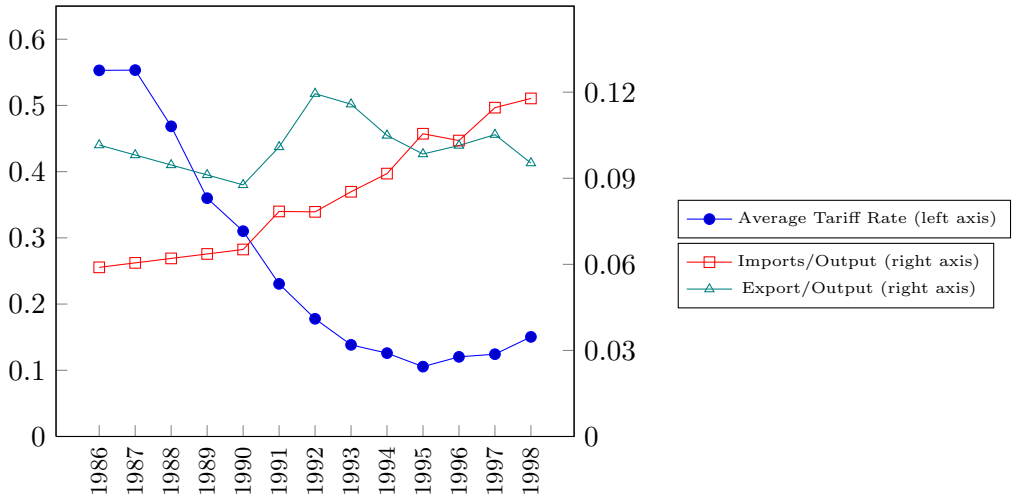

Figure 2.3: Trade Policy and Openness in Brazil

Source: All series are simple annual averages for Brazilian mining and manufacturing sectors by Classification Nivel 80 compiled by Marc Muendler, data files tariffs-outp.csv and imp-penetrat.csv are available in http://www.econ.ucsd.edu/muendler/html/brazil.html.

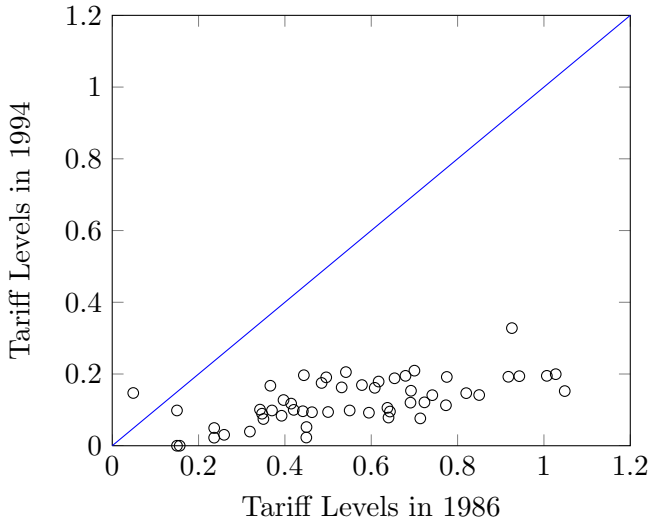

Figure 2.4: Industry Level Tariff Rates Before and After Trade Reforms

Source: Annual tariffs for Brazilian mining and manufacturing sectors by Classification Nivel 80 compiled by Marc Muendler, data file tariffs-outp.csv available in http://www.econ.ucsd.edu/muendler/html/brazil.html.

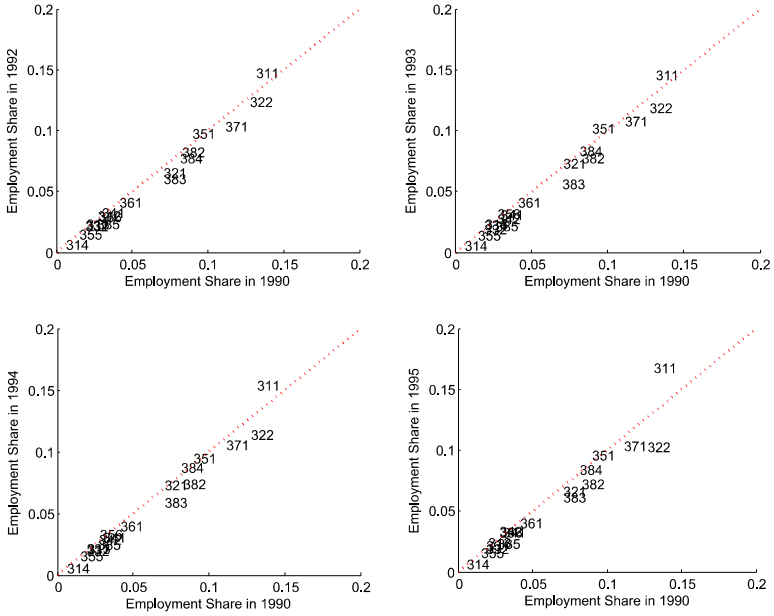

Figure 2.5: Manufacturing Workforce Composition across 3-digit Industries in Brazil
The sub-figures plot the employment share of industries at the 3-digit level of ISIC (Rev.2) at different years. Source: UNIDO INDSTAT3 2005

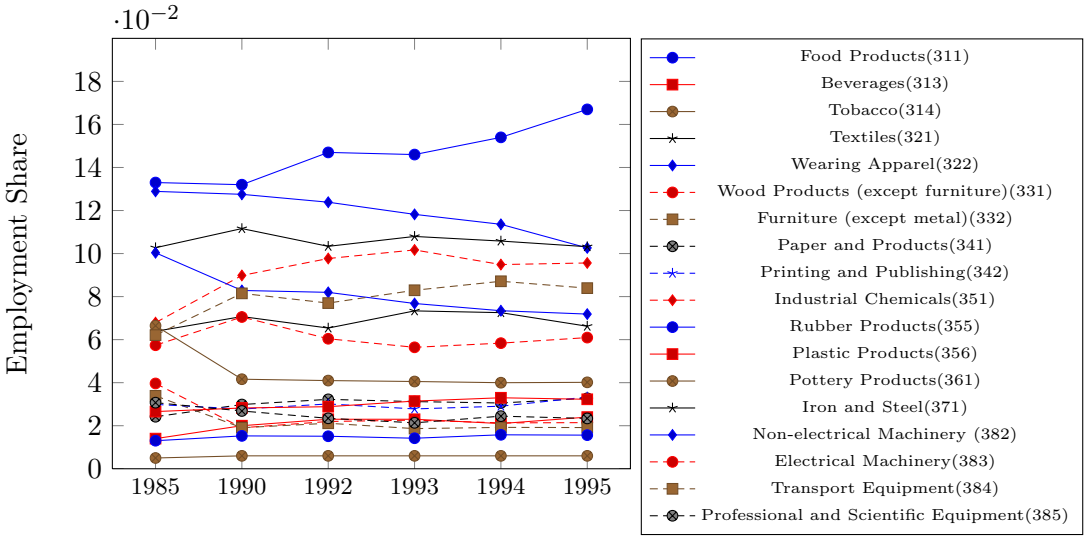

Figure 2.6: Manufacturing Workforce Composition across 3-digit Industries in Brazil
Source: UNIDO INDSTAT3 2005, data for 1986-1989 and 1991 are missing.

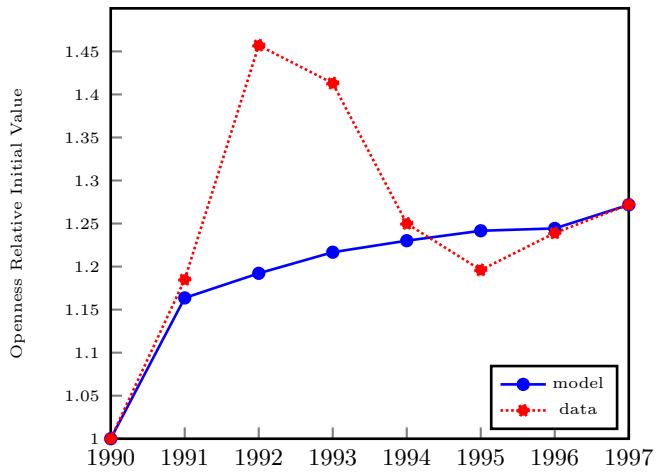

Figure 2.7: Openness during the Transition

Source: Openness in the data is measured as $\frac{Exports}{Output} \cdot \frac{Output}{Value\ Added}$ *for manufacturing. Data on export share of manufacturing output is from Pavcnik et al. (2004). The value added share of manufacturing output is from OECD IO Tables. The model unemployment rate is the yearly average over quarters.*

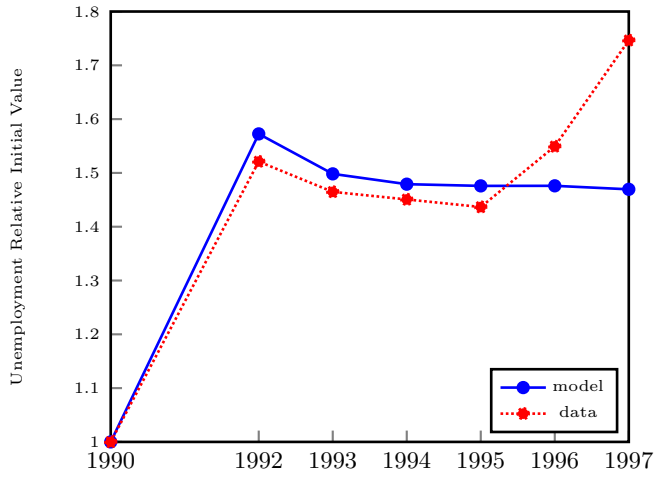

Figure 2.8: Unemployment During the Transition

Source: ILO-KILM 2009, male unemployment rate. The values for 1991 and 1994 are missing in the original data. The initial level of unemployment in 1990 is set as the average for 1981-1990 which is equal to 3.6%*. For 1994, I report the average of 1993-1995 values. The model unemployment rate is the yearly average over quarters.*

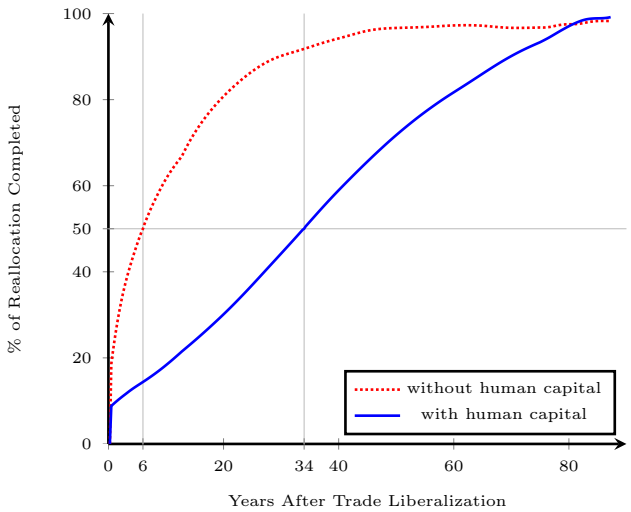

Figure 2.9: Employment Share Reallocation During the Transition

The lines plot the amount of reallocation completed at each period as a percentage of total share reallocation between initial and terminal steady states. Specifically, let E_t^1 is the share of employment in sector 1 at time t, E_0^1 and E_T^1 the initial and terminal shares respectively. I transition paths plot $100 \cdot \frac{E_t^1 - E_0^1}{E_T^1 - E_0^1}$.

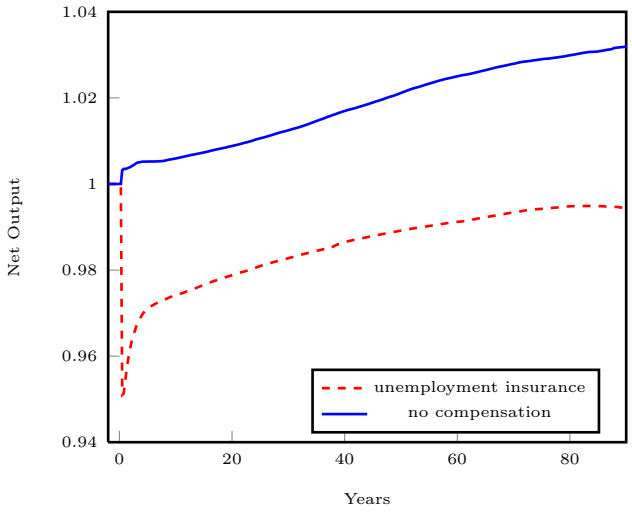

Figure 2.10: Net Output under Unemployment Insurance

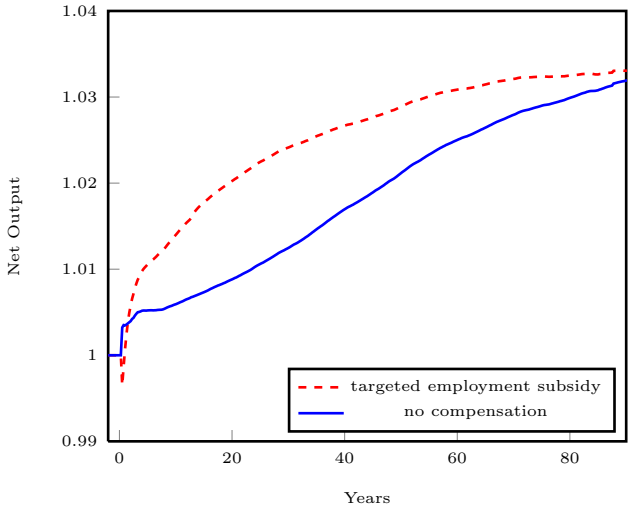

Figure 2.11: Net Output under Targeted Employment Subsidy

Parameter	Definition	Value	Source/Target
δ_m	death probability	1/80	20 years of youth
δ_a	aging probability	1/80	20 years of old-age
$f_z(z)$	productivity	uniform $[0, 1]$	-
γ	Cobb-Douglas share of good 1	0.50	-
σ	worker's bargaining share	0.50	-
$\underline{h}_i$	Initial HC level	1	normalization
A_2	sector 2 productivity	1	normalization
τ	import tariff	0.63	Pavcnik et al. (2004)
β	discounting rate	0.97	real interest rate, IPEA
δ^y_{JD}	job destruction for young	0.018	Bosch and Maloney (2007)
δ^o_{JD}	job destruction for old	0.012	Bosch and Maloney (2007)
δ_h	depreciation of HC	0	Browning et al. (1999)

Table 2.1: Parameters Set Without Solving the Model

Parameter	Value	Target	Source
α	0.98	$\frac{\text{ave. earnings at 5 years of experience}}{\text{ave. beginning of the career earnings}} = 1.41$	Menezes-Filho et al. (2008)
H	2.60	$\frac{\text{ave. earnings at 40 years of experience}}{\text{ave. beginning of the career earnings}} = 2.43$	Menezes-Filho et al. (2008)
A_1	1.71	Export / (Value Added) = 0.26	Pavcnik et al. (2004),OECD
λ	2.16	elasticity of hiring to unemployment = 0.25	Hoek (2007)
C_{sd}	1.49	transition probability from U to E = 0.38	Domeland and Fiess (2006)

Table 2.2: Parameters Obtained by Solving the Model

Moment	Model	Data	Source
Share of youth unemployment	0.71	0.71	IADB [2004], ILO KILM Database
annual excess job reallocation	0.34	0.32	IADB [2004]
earning losses of old switchers	0.12	0.22	Hoek (2006)
$90th/10th$ wage percentile	2.37	10.59	Sotomayor (2004)
hiring costs / wage bill	0.09	0.09	Abowd and Kramarz (2003) - blue-collar workers in France

Table 2.3: Steady State Outcomes

Bibliography

J.M. Abowd and F. Kramarz. The costs of hiring and separations. *Labour Economics*, 10 (5):499 – 530, 2003.

D. Acemoglu. Training and Innovation in an Imperfect Labor Market. *The Review of Economic Studies*, 64(3):445 – 464, 1997.

D. Acemoglu. Good Jobs versus Bad Jobs. *Journal of Labor Economics*, 19(1):1–21, 2001.

D. Acemoglu and R. Shimer. Efficient Unemployment Insurance. *Journal of Political Economy*, 107(5):893–928, 1999.

F. Alvarez and R. Shimer. Search and Rest Unemployment. *NBER Working Paper*, 2008.

F. Alvarez and M. Veracierto. Labor-Market Policies in an Equilibrium Search Model. *NBER Macroeconomics Annual*, 14:265–304, 1999.

E. Artuc, S. Chaudhuri, and J. McLaren. Trade Shocks and Labor Adjustment: A Structural Empirical Approach. *NBER Working Paper*, 2007.

Y. Ben-Porath. The Production of Human Capital and the Life Cycle of Earnings. *The Journal of Political Economy*, 75(4):352–365, 1967.

J. Berg, C. Ernst, and P. Auer. *Meeting the Employment Challenge: Argentina, Brazil, and Mexico in the Global Economy.* ILO, 2006.

A. Bernard, S. Redding, and P. Schott. Heterogeneous Firms and Comparative Advantage. *Review of Economic Studies*, 74(1):31–66, 2007.

T. Boeri and K. Terrell. Institutional Determinants of Labor reallocation in Transition. *The Journal of Economic Perspectives*, 16(1):51–76, 2002.

M. Bosch and W.F. Maloney. Comparative Analysis of Labor Market Dynamics Using Markov Processes: An Application to Informality. *World Bank Policy Research Working Paper Series*, 2007.

M. Browning, L.P. Hansen, and J.J. Heckman. Micro Data and General Equilibrium Models. *Handbook of Macroeconomics*, 1:543–633, 1999.

A.K. Cosar, N. Guner, and J. Tybout. Firm Dynamics, Job Turnover and Wage Distributions in an Open Economy. *Working Paper*, 2009.

J. Costantini and M. Melitz. The Dynamics of Firm-level Adjustment to Trade Liberalization. In D. Marin E. Helpman and T. Verdier, editors, *The Organization of Firms in a Global Economy*. Harvard University Press, 2009.

W.V. Cunningham. Unemployment Insurance in Brazil: Unemployment Duration, Wages, and Sectoral Choice. *World Bank Working Paper*, 2000.

C. Davidson and S.J. Matusz. *International Trade and Labor Markets: Theory, Evidence, and Policy Implications*. WE Upjohn Institute, 2004.

C. Davidson and S.J. Matusz. Trade Liberalization and Compensation. *International Economic Review*, 47(3):723–747, 2006.

C. Davidson, L. Martin, and S. Matusz. The Structure of Simple General Equilibrium Models with Frictional Unemployment. *The Journal of Political Economy*, 96(6):1267–1293, 1988.

W.J. Den Haan, G. Ramey, and J. Watson. Job Destruction and Propagation of Shocks. *The American Economic Review*, 90(3):482–498, 2000.

D. Domeland and N. Fiess. Unemployment and unemployment insurance. In F.G. Carneiro, I.S. Gill, and R. Paes de Barros, editors, *The Third Dimension of Labor Markets: De-*

mand, Supply and Institutions in Brazil, pages 169–197, New York, 2006. Nova Science Publishers.

B.C. Fallick. The Industrial Mobility of Displaced Workers. *Journal of Labor Economics*, 11(2):302–323, 1993.

G. Gonzaga, W.F. Maloney, and A. Mizala. Labor Turnover and Labor Legislation in Brazil [with Comments]. *Economía*, 4(1):165–222, 2003.

J.C. Haltiwanger, A. Kugler, M. Kugler, A. Micco, and C. Pages. Effects of Tariffs and Real Exchange Rates on Job Reallocation: Evidence from Latin America. *Journal of Policy Reform*, 2004.

J. Heckman. *Three Essays on Household Labor Supply and the Demand For Market Goods," Chapter 1.* PhD thesis, Ph. D. Dissertation, Princeton University, 1971.

E. Helpman and O. Itskhoki. Labor Market Rigidities, Trade and Unemployment. *NBER Working Paper*, 2007.

J. Hoek. Life Cycle Effects of Job Displacement in Brazil. *IZA Discussion Paper 2291.*, 2006.

J. Hoek. Labor Flows in Formal and Informal Labor Markets in Brazil. *Unpublished manuscript*, 2007.

A.J. Hosios. Factor Market Search and the Structure of Simple General Equilibrium Models. *The Journal of Political Economy*, 98(2):325–355, 1990.

G. Kambourov. Labor Market Regulations and the Sectoral Reallocation of Workers: The Case of Trade Reforms. *Review of Economic Studies*, 76(4):1321–1358, 2009.

D.I. Kim and R. Topel. Labor Markets and Economic Growth: Lessons from Koreas Industrialization, 1970–90. *Differences and Changes in Wage Structures, University of Chicago Press, Chicago*, 1995.

L.G. Kletzer. *Job Loss From Imports: Measuring the Costs.* Peterson Institute, 2001.

T. Krebs, P. Krishna, and W. Maloney. *Trade, Globalization and Poverty*, chapter Human Capital, Trade Liberalization, and Income Risk. Routledge, 2008.

P. Krishna and M.Z. Senses. International Trade and Labor Income Risk in the United States. *NBER Working Paper*, 2009.

P.R. Krugman. Increasing Returns, Monopolistic Competition, and International Trade. *Journal of International Economics*, 9:469–479, 1979.

E.E. Leamer. Welfare Computations and the Optimal Staging of Tariff Reductions in Models with Adjustment Costs. *Journal of International Economics*, 10(1):21–36, 1980.

J. Levinsohn. Employment Responses to International Liberalization in Chile. *Journal of International Economics*, 47(2):321–344, 1999.

L. Ljungqvist and T.J. Sargent. The European Unemployment Dilemma. *Journal of Political Economy*, 106(3):514–550, 1998.

R. Lucas and E. Prescott. Equilibrium Search and Unemployment. *Journal of Economic Theory*, 7(2):188–209, 1974.

K. Matsuyama. A Simple Model of Sectoral Adjustment. *The Review of Economic Studies*, pages 375–387, 1992.

W. Mayer. Short-run and Long-run Equilibrium for a Small Open Economy. *The Journal of Political Economy*, 82(5):955–967, 1974.

M. Melitz and G. Ottaviano. Market Size, Trade, and Productivity. *Review of Economic Studies*, 75:295–316, 2008.

M.J. Melitz. The Impact of Trade on Intra-industry Reallocations and Aggregate Industry Productivity. *Econometrica*, 71(6):1695–1725, 2003.

N. Menezes-Filho and R. Fernandes. The Costs of Displacement in Brazil. *University of Sao Paulo, unpublished manuscript*, 2004.

N.A. Menezes-Filho and M.A. Muendler. Labor reallocation in response to trade reform. *CESifo Working Paper*, 2007.

N.A. Menezes-Filho, M.A. Muendler, and G. Ramey. The Structure of Worker Compensation in Brazil, with a Comparison to France and the United States. *The Review of Economics and Statistics*, 90(2):324–346, 2008.

J. Mincer. Schooling, Experience, and Earnings. Human Behavior & Social Institutions No. 2. 1974.

G. Moscarini. Excess Worker Reallocation. *The Review of Economic Studies*, 68(3):593–612, 2001.

K.M. Murphy and R.H. Topel. The Evolution of Unemployment in the United States: 1968-1985. *NBER Macroeconomics Annual*, 2:11–58, 1987.

K.M. Murphy and F. Welch. Empirical Age-earnings Profiles. *Journal of Labor economics*, 8(2):202, 1990.

M.L. Mussa. The Adjustment Process and the Timing of Trade Liberalization. *NBER Working Paper*, 1984.

D. Neal. Industry-specific Human Capital: Evidence from Displaced Workers. *Journal of labor Economics*, 13(4):653–677, 1995.

L. Osberg. Fishing in Different Pools: Job-search Strategies and Job-finding Success in Canada in the Early 1980s. *Journal of Labor Economics*, 11(2):348–386, 1993.

R. Paes de Barros, M.B. Cossio, and J.L. Teles. The efficiency of active labor market policies for poverty reduction in brazil. In F.G. Carneiro, I.S. Gill, and R. Paes de Barros, editors, *The Third Dimension of Labor Markets: Demand, Supply and Institutions in Brazil*, pages 199–229, New York, 2006. Nova Science Publishers.

C. Pagés, G. Pierre, and S. Scarpetta. *Job Creation in Latin America and the Caribbean.* World Bank, 2009.

N. Pavcnik, A. Blom, P. Goldberg, and N. Schady. Trade Liberalization and Industry Wage Structure: Evidence from Brazil. *The World Bank Economic Review*, 18(3):319, 2004.

N. Ramondo and A. Rodriguez-Clare. The Gains from Openness: Trade, Multinational Production and Diffusion. *University of Texas-Austin Manuscript*, 2008.

R. Rogerson. Sectoral Shocks, Human Capital, and Displaced Workers. *Review of Economic Dynamics*, 8(1):89–105, 2005.

R. Rogerson and M. Schindler. The Welfare Costs of Worker Displacement. *Journal of Monetary Economics*, 49(6):1213–1234, 2002.

K.L. Shaw. Life-cycle Labor Supply with Human Capital Accumulation. *International Economic Review*, 30(2):431–456, 1989.

O.J. Sotomayor. Education and Changes in Brazilian Wage Inequality. *Industrial and Labor Relations Review*, 58(1):94–111, 2004.

R. Wacziarg and J.S. Wallack. Trade Liberalization and Intersectoral Labor Movements. *Journal of International Economics*, 64(2):411–439, 2004.

Chapter 3

Firm Dynamics, Job Turnover, and Wage Distributions in an Open Economy

3.1 Introduction

In developing countries, globalization is often blamed for exacerbating wage inequality, reducing job security, and increasing the size of the informal sector. This has been particularly true in Latin America, where many countries that pursued trade liberalization programs also experienced greater wage dispersion, heightened job turnover, and/or informality.[1]

But the extent to which trade liberalization is to blame remains an open question. Labor market outcomes reflect many factors besides foreign competition, and reduced-form regressions have not convincingly isolated causal relationships. To better isolate the effects of openness on developing countries' workers, we formulate a dynamic structural model of trade with labor market frictions. Then we fit our model to plant-level panel data

[1] "Between the mid-1980s and the beginning of the 1990s, countries in Latin America began trade liberalization programs, with reductions of at least 15 percentage points in the average tariff rate, which fell from an average of 48.9 percent in the pre-reform years to 10.7 percent in 1999." (Inter-American Development Bank, 2004, p. 137). Haltiwanger et al (2004) document the association between job turnover and openness in Latin America. Goldberg and Pavcnik (2007) survey the evidence linking openness to wage inequality and informality in Latin America and other developing regions.

and household survey data from Colombia, a country that in many respects typifies Latin American experiences.

Openness affects labor markets in our model because it increases rents for efficient firms and reduces rents for inefficient firms, as in Melitz (2003). These well-known effects interact with idiosyncratic productivity shocks and with scale economies in hiring costs to induce adjustments in the equilibrium job turnover rate, unemployment rate, and wage distribution as trade barriers are dismantled.

Our model shares some features with a number of recent trade models that describe the effects of openness on labor markets (Helpman and Itskhoki (2010), Helpman et al. (2008), Egger and Kreickemeier (2007), Amiti and Davis (2008), Davis and Harrigan (2008), Felbermayr et al. (2008)).[2] In particular, it embodies Melitz's (2003) basic insight that openness compounds the advantages enjoyed by relatively efficient firms. However we depart from this literature in two ways. First, we assume that firms experience ongoing, idiosyncratic productivity shocks (as in Hopenhayn (1992), and Hopenhayn and Rogerson (1993)), and they respond by adjusting their vacancy postings, lay-offs and exit decisions. (as in Bertola and Caballero (1994), and Bertola and Garibaldi (2001)). [3] Second, we fit our model to micro data and use it to perform numerical experiments that quantify the effects of openness under alternative assumptions.

While we do not pretend to capture all of the channels through which openness can affect labor market outcomes, our focus on firm-level entry, exit and idiosyncratic productivity shocks is supported by existing empirical evidence on the sources of job turnover and wage heterogeneity. Studies of job creation and job destruction invariably find that most reallocation is due to idiosyncratic (rather than industry-wide) adjustments (Davis

[2]Several less-related linkages between openness and labor market outcomes have been modeled in the recent trade literature. One strand of this literature emphasizes the changes in skill-premia and/or unemployment rates that result from trade-induced changes in the relative demand for different types of labor (e.g., Albrecht and Vroman (2002), Yeaple (2005), Davidson et al. (2006)). Another characterizes the adjustments in wages, unemployment and labor turnover patterns that derive from trade-induced changes in sectoral output prices (e.g., Kambourov (2009), Artuc, Chaudhuri and McClaren (2008)). And finally, some studies have focussed on cross-country differences in the flexibility of labor markets as a source of comparative advantage (Davidson et al. (1999), Cunat and Melitz (2007); Helpman and Itskhoki (2010)).

[3]Other recent papers that study firm dynamics and labor market frictions in a closed economy context include Cooper et al. (2007), Hobijn and Sahin (2007), Koeniger and Prat (2007), and Lentz and Mortensen (2008). Utar (2008) studies firm dynamics and labor market frictions in an import-competing industry that takes the wage rate as given.

et al. (1998), Roberts (1996), Inter-American Development Bank (2004)). "This is true even in Latin America's highly volatile macro environment" where producer entry and exit alone account for 30-40 percent of job creation and destruction (Inter-American Development Bank (2004), chapter 2). Further, as Goldberg and Pavcnik (2007) note, if openness has had a significant effect on job flows, it has mainly been through intra-sectoral effects: "Most studies of trade liberalization in developing countries find little evidence in support of [trade-induced labor] reallocation across sectors." Finally, while cross-worker differences in wages are obviously partly due to differences in worker characteristics, much is attributable to labor market frictions and firm heterogeneity.[4]

3.2 The Model

The model extends Bertola and Cabellero (1994) and Bertola and Garibaldi (2001) to a general equilibrium setting with fully articulated product markets, international trade, arbitrary (stationary) Markov processes for productivity shocks and endogenous firm entry and exit.

3.2.1 Preferences

There are two types of output in our economy – services and differentiated industrial goods. Worker-consumers of measure one have lifetime utility given by

$$\mathcal{U} = \sum_{t=1}^{\infty} \left(\frac{1}{1+r} \right)^t U(s_t^c, q_t^c),$$

where r is the rate of time preference, s_t^c is consumption of services, and q_t^c is an index of differentiated good consumption. The momentary utility function U takes the form

$$U(s^c, q^c) = \frac{(s^c)^{1-\gamma} (q^c)^{\gamma}}{(1-\gamma)^{1-\gamma}\gamma^{\gamma}}, \tag{3.1}$$

[4]Studying data from France and the United States, Abowd et al.(1999) and Abowd et al.(2002) show that roughly half of the cross-worker variation in compensation in French workers is due to employer effects. The only study of employer-employee data in developing countries we are aware of is Menezes-Filho and Muendler (2007). This paper does not report results on sources of wage variation.

where $\gamma \in (0,1)$ and our index of industrial goods consumption is

$$q^c = \left(\int_0^N q^c(n)^{\frac{\sigma-1}{\sigma}} dn \right)^{\frac{\sigma}{\sigma-1}}. \tag{3.2}$$

Here N is our measure of differentiated varieties, $q^c(n)$ is consumption of variety n, and $\sigma > 1$ is the elasticity of substitution between varieties. Only industrial industrial goods can be traded internationally. Consumers have access to N_F foreign varieties, and N_H domestic varieties such that $N_H + N_F = N$. We assume that the set of available foreign varieties and their foreign currency-denominated f.o.b. prices $p_F(n)$ are exogenously determined, and home country is too small to affect foreign income levels. In short, we model a small open economy.

The price of services is our numeraire. Let k be the price of foreign currency, $(\tau_c - 1)$ be the iceberg transport cost per unit shipped and $(\tau_m - 1)$ be the *ad valorem* tariff rate on imports. $P_F = \tau_m \tau_c k \left[\int_0^{N_F} p_F(n)^{1-\sigma} dn \right]^{1/(1-\sigma)}$ is the exact price index for imported varieties. The term $\left[\int_0^{N_F} p_F(n)^{1-\sigma} dn \right]^{1/(1-\sigma)}$, the producer price of the composite import good, is an exogenous constant, so we normalize it to unity by choice of foreign currency units. However, we allow the domestic currency price of imported goods to be endogenously determined as the nominal exchange rate k adjusts to establish balanced trade.

The measure of domestic varieties, N_H, is determined endogenously by free entry. The price index for the composite domestic industrial good is $P_H = \left(\int_0^{N_H} p_H(n)^{1-\sigma} dn \right)^{1/(1-\sigma)}$. Given our representation of preferences above, the exact price index for the composite good q^c is

$$P = \left(P_F^{1-\sigma} + P_H^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \tag{3.3}$$

Letting I_i be the income of worker i and disallowing savings, the period-by-period budget constraint is

$$I_i = s_i^c + P q_i^c.$$

Utility maximization implies that consumer i spends a fraction γ of her income on the composite industrial good. Her demand for imported and domestic varieties can be written

as

$$q^c_{Fi}(n) = \frac{\gamma I_i}{P}\left(\frac{\tau_m \tau_c k p_F(n)}{P}\right)^{-\sigma},$$

and

$$q^c_{Hi}(n) = \frac{\gamma I_i}{P}\left(\frac{p_H(n)}{P}\right)^{-\sigma}, \tag{3.4}$$

respectively. Defining $D_i = \gamma I_i P^{\sigma-1}$ and aggregating over the measure of worker-consumers, the term $D_H = \int_0^1 D_i di$ captures the level of domestic demand for industrial goods.

3.2.2 Production Technologies

Services are supplied by firms and, less efficiently, by unemployed workers engaged in home production. Regardless of their source, services are produced with labor alone, homogeneous across suppliers, and sold in competitive product markets. Firms that supply services use a common constant returns technology, and face no hiring or firing costs. All service-sector firms exploit a common constant-returns technology to produce the homogeneous good. So with an appropriate choice of output units, we may write their combined supply of services as

$$S = L_S,$$

where L_S is labor hired in services.

Industrial goods cannot be home-produced. They must be supplied by firms, which pay a sunk start-up cost to initiate production of a single variety of output. Each firm produces its output using labor alone, and competes in the monopolistically competitive product market. Unlike service sector firms, suppliers of industrial goods are subject to ongoing idiosyncratic productivity shocks, and they must create costly vacancies in order to attract new workers. The shocks they face can equally well be thought of as affecting the relative appeal of their products.In the industrial sector, output of producers with productivity level z is given by

$$q(z, l) = z l^{\alpha}, \tag{3.5}$$

where l is the labor input and $\alpha > 0$. Productivity is firm-specific, independent across firms,

and serially correlated. Its evolution is characterized by the transition density $h(z'|z)$, which is common to all firms. These shocks together with firms' decisions determine the steady state distribution across (z, l), which we denote by $f(z, l)$.

Producer dynamics in the industrial sector resemble those in Hopenhayn and Rogerson (1993) in that firms react to their productivity shocks by optimally hiring, firing or exiting. Also, new firms enter whenever their expected future profit stream exceeds the entry costs they face. However, unlike Hopenhayn and Rogerson (1993), we assume hiring in the industrial sector is subject to search frictions captured by a standard matching function. Labor market frictions generate rents that are bargained over between worker and firms, and firms end up paying different wages depending on their current productivity and labor force as well as whether they are hiring or firing workers.[5] Further, workers maximize the present value of their expected welfare by making forward-looking decisions concerning which sector to work in and what job offers to accept. We now describe the functioning of labor markets in more detail.

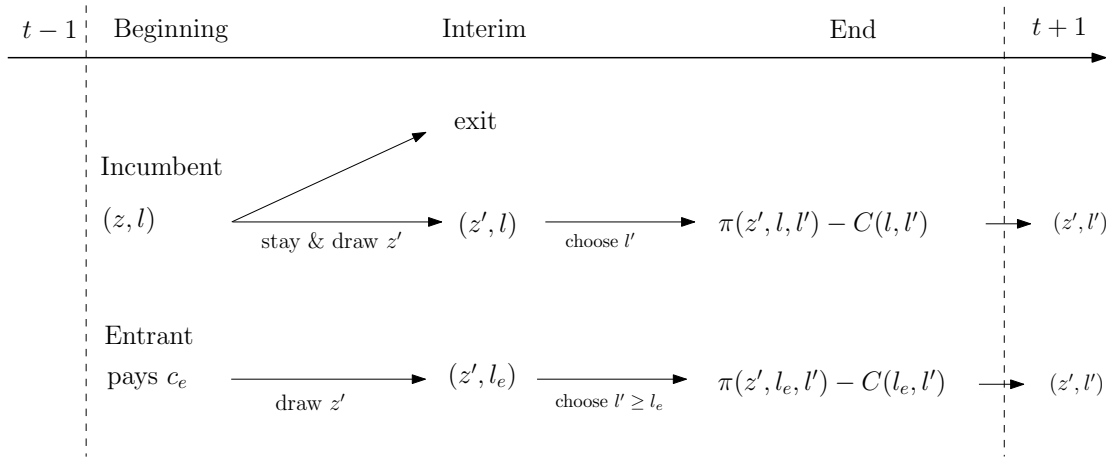

Figure 3.1: Within-period Sequencing of Events for Firms

[5]Hornstein, Krusell and Violante (2009) show that in standard search models with identical workers, the frictional wage inequality is very small. In the current environment, firm dynamics generates realistic wage dispersion across identical workers.

3.2.3 Labor Markets and the Matching Technology

The service sector labor market is frictionless so, given that the price of services is unity, the service sector wage is $w_s = 1$. Search frictions make things more complicated in the industrial sector. Each period the number of new matches between unemployed workers and vacancy posting firms is given by

$$M(V, L_u) = \frac{V L_u}{(V^\theta + L_u^\theta)^{1/\theta}},$$

where L_u is the measure of unemployed workers searching in industrial sector and V is the measure of vacancies in industry.[6] Consequently, industrial firms fill each vacancy they post with probability

$$\phi_f(V, L_u) = \frac{M(V, L_u)}{V} = \frac{L_u}{(V^\theta + L_u^\theta)^{1/\theta}},$$

while unemployed workers searching for industrial jobs find matches with probability

$$\phi_w(V, L_u) = \frac{M(V, L_u)}{L_u} = \frac{V}{(V^\theta + L_u^\theta)^{1/\theta}}.$$

Each worker decides whether to participate in the industrial labor market at the beginning of each period. Those who are already employed in the industrial sector can continue with their current job unless their employer lays them off or shuts down entirely. (They can also quit in order to move to the service sector or to search for other industrial sector jobs, although in equilibrium none find it optimal to do so.) Those not yet employed in the industrial sector can forego certain employment with a service sector firm in order to search for a higher-wage industrial sector job, but they risk remaining unemployed if they fail to match with an industrial sector producer.[7] Those who end up unemployed subsist during the current period by using a relatively inefficient technology to home-produce services.

Each period, after firms learn their current productivity, they decide whether to post

[6] The functional form of the matching function follows den Haan et al. (2000). It is constant returns to scale, and increasing in both arguments. In contrast to the standard Cobb-Douglas form, it has no scale parameter and the implied matching rates are bounded between zero and one.

[7] The notion that workers trade job security in a low wage sector for the opportunity to search in a higher wage sector traces back at least to the Harris and Todaro (1970) model.

vacancies and hire workers or shrink by firing some of their workers. Firing is subject to dismissal costs. We follow Hopenhayn and Rogerson (1993) in modeling dismissal costs as a tax c_f that firms have to pay for every job they destroy.

After hiring and firing take place, firms pay wages that are determined by bargaining between workers and firms. Workers not fortunate enough to be retained–because their employers either contracted or exited–choose whether to look for work in the industrial sector or the service sector. Workers who spent the previous period producing services also decide where to seek work. Those who choose the service sector are employed with certainty at the wage w_s. Those who choose the industrial sector must match with a vacancy-posting producer before they begin to work. If they succeed in doing so, their wages reflect the rents associated with their match (details are provided below). The probabilities of these different events shape workers' sectoral choices, as well as firms' employment policies. We start by describing the latter.

3.2.4 Incumbent Firm's Problem

The demand function (3.4) and the production function (3.5) imply that any producer with productivity z who chooses employment level l will earn revenues

$$r_d(z, l, \eta) = D_H^{\frac{1}{\sigma}} \left[(1-\eta) z l^{\alpha}\right]^{\left(\frac{\sigma-1}{\sigma}\right)}, \tag{3.6}$$

from its domestic sales if a fraction $1-\eta$ of its output is sold domestically.

In the export market, let D_F be the foreign market analog to D_H, denominated in foreign currency.[8] Then a firm in state (z, l) that exports the fraction η of its output generates foreign sales revenues amounting to:

$$r_x(z, l, \eta) = k D_F^{\frac{1}{\sigma}} \left[\frac{\eta}{\tau_c} z l^{\alpha}\right]^{\frac{\sigma-1}{\sigma}}.$$

There are are no start-up costs or adjustment costs associated with exporting, so firms

[8]More precisely, $D_F = \gamma \left(\bar{P}_F\right)^{\sigma-1} I_F$, where $\bar{P}_F$ is the exact price index for industrial goods available abroad and I_F is foreign income, both expresesd in foreign currency. These objects are exogenous to the model, given our assumption that the home country is too small to influence foreign market aggregates.

choose η each period to maximize their total current revenues, net of fixed exporting costs, c_x. The associated revenue function is

$$\begin{aligned} r(z,l) &= \max_{\eta\in[0,1]} \left(r_d(z,l,\eta) + r_x(z,l,\eta) - c_x\mathcal{I}^x(z,l)\right) \qquad (3.7) \\ &= \max\left\{\left[D_H^{\frac{1}{\sigma}}(1-\eta^o)^{\frac{\sigma-1}{\sigma}} + kD_F^{\frac{1}{\sigma}}\left(\frac{\eta^o}{\tau_c}\right)^{\frac{\sigma-1}{\sigma}}\right](zl^\alpha)^{\frac{\sigma-1}{\sigma}} - c_x\mathcal{I}^x(z,l,k),\ D_H^{\frac{1}{\sigma}}(zl^\alpha)^{\frac{\sigma-1}{\sigma}}\right\}, \end{aligned}$$

where

$$\eta^o = 1/\left(1 + \frac{\tau_c^{\sigma-1}D_H}{k^\sigma D_F}\right) \qquad (3.8)$$

is the optimal fraction of output to export, *given* foreign market participation, $r_d(z,l,\eta)$ is the revenue generated by selling $(1-\eta)zl^\alpha$ units of output in the domestic market, and $\mathcal{I}^x(z,l)$ is an indicator function that takes a value of unity when $\eta > 0$. Whether the latter occurs simply depends upon zl^α, since the gains from foreign market participation increase monotonically with production.

Embedded in our general equilibrium model, this standard revenue function delivers a number of desirable features. First, it implies that for any given (z,l), the marginal revenue product of labor is larger when the economy is open. This is the underlying reason that productivity shocks induce larger adjustments in vacancy postings or firings when foreign markets are accessible. Second, since larger revenues at a given (z,l) mean more surplus to bargain over, it is also the reason that the wage paid by a firm that exports in state (z,l) is higher than what it is in the closed economy equilibrium. This result is consistent with the empirical finding that, controlling for employment, exporters pay higher wages (Bernard and Jensen (1999)). Third, combined with the fact that search frictions make marginal costs vary across firms with identical z values, it explains why productive efficiency is a noisy predictor for exporting status.[9] Fourth, re-interpreting z shocks to be product appeal indices rather than productivity indices, it explains why exporters manage to be larger than

[9]This fact has attracted some attention recently. Hallak and Sividasan (2008) explain it by assuming that (1) firms differ in terms of both their quality and their productivity efficiency, and (2) exporting requires that firms meet a minimum quality standard.

non-exporters, even though they charge higher prices and pay higher wages.[10]

Finally, and perhaps most interestingly, this expression implies that firms' exporting status affects their total revenue for a *given* amount of labor and a *given* productivity level. (Consider, for example, the change in revenue induced by a reduction in τ_c sufficiently large to cause a firm to begin exporting.) Thus, it provides a new interpretation for the common finding that measured productivity—i.e., deflated revenue per unit input bundle—is higher among exporters.[11] The reason this result emerges is that labor market frictions prevent firms from freely adjusting their size as exporting opportunities come and go.

To derive firms' optimal employment policies, we first specify the sequencing of events within each period (Figure 3.1). An incumbent firm enters the current period with the productivity z and work force l, which were determined at the end of the previous period. Immediately the firm decides whether to stay in business or to exit. If it stays, it proceeds to an *interim stage* in which it observes its current-period productivity realization z'. Then, taking stock of its updated state, (z', l), the relevant wage schedules, and the sector-wide worker arrival rate, ϕ_f, it chooses its current period work force, l'. If the firm decides to hire $(l' > l)$ workers, they are immediately available to produce output in the current period. If it fires workers $(l' \leq l)$ it clears them from the payroll prior to production and in doing so incurs no severance costs. Finally, revenues accrue and wages and other costs are paid at the end of the period.

Given the presence of search frictions, workers at hiring firms generate rents, and as we will detail shortly, these are bargained over to determine wages. However, since firms can shed workers costlessly, the marginal worker at a firing firm creates no rents and has no bargaining power. Hence expanding and contracting firms face different wage schedules, and current operating profits depend upon both l and l'. More precisely, defining $w_h(z', l')$ to be the wage function faced by a hiring firm and $w_f(z', l')$ to be the wage function faced

[10] Kugler and Verhoogen (2008) note that this pattern could alternatively be due to complementarities in production between worker ability and product quality.

[11] In support of this interpretation, De Loecker and Warzynski (2009) report evidence that mark-ups are higher among exporting firms.

by a firing firm, profits are

$$\pi(z', l, l') = \begin{cases} r(z', l') - w_h(z', l')l' - c_p & \text{if } l' > l, \\ r(z', l') - w_f(z', l')l' - c_p & \text{otherwise.} \end{cases} \tag{3.9}$$

where c_p, the per-period fixed cost of operation, is common to all firms. Using (3.9), the beginning-of-period value of a firm in state (z, l) is

$$\mathcal{V}(z, l) = \max\left\{0, \frac{1}{1+r} E_{z'|z} \max_{l'}[\pi(z', l, l') - C(l, l') + \mathcal{V}(z', l')]\right\}, \tag{3.10}$$

where the max of the term in square brackets is the value of the firm in the interim state (after it has realized its productivity shock), and

$$C(l, l') = \begin{cases} C_h\left(l, l'\right), & \text{if } l' > l, \\ C_f\left(l, l'\right), & \text{otherwise.} \end{cases}$$

The solution to (3.10) implies an employment policy function,

$$l' = L(z', l), \tag{3.11}$$

an indicator function that distinguishes hiring and firing firms from others,

$$\mathcal{I}^h(z', l) = \begin{cases} 1, & \text{if } L(z', l) > l, \\ 0, & \text{otherwise.} \end{cases} \tag{3.12}$$

$$\mathcal{I}^f(z', l) = \begin{cases} 1, & \text{if } L(z', l) < l, \\ 0, & \text{otherwise,} \end{cases} \tag{3.13}$$

and an indicator function that characterizes firm's continuation/exit policy,

$$\mathcal{I}^c(z, l) = \begin{cases} 1, & \text{if } \mathcal{V}(z, l) > 0 \\ 0, & \text{otherwise.} \end{cases} \tag{3.14}$$

3.2.5 Entry

In the steady state, a constant (endogenous) fraction μ_{exit} of firms exits the industry. These firms are replaced by an equal number of entrants, who find it optimal to pay a sunk entry cost of c_e and create new firms. Upon creating their firms, these entrants acquire $l_e > 0$ workers and learn their initial productivity, which is drawn from the density function $f_e(z)$ with support $[\underline{z}, \overline{z}]$. (The search costs for the initial l_e workers are included in c_e.) Thereafter entrants behave exactly like incumbent firms in the interim stage (see Figure 3.1), with their interim state given by (z, l_e). So by the time they begin producing, most new entrants have adjusted their workforce (subject to search costs) in accordance with their initial productivity. Free entry implies that

$$\mathcal{V}_e = \int_{\underline{z}}^{\overline{z}} \mathcal{V}(z, l_e) f_e(z) dz \leq c_e, \tag{3.15}$$

which holds with equality if there is a positive mass of entrants, M.

3.2.6 Worker's Problem

Figure 3.2 presents the intra-period timing of events for workers. Consider first a worker who is employed by an industrial firm in state (z, l) at the beginning of the current period. This worker learns immediately whether her firm will continue operating. If her firms exits, she joins the pool of industrial job seekers (enters state u) in the interim stage. Otherwise, she enters the interim stage as an employee of the same firm that she worked for in the previous period. (No one voluntarily quits because, in equilibrium, firms always pay their workers at least their reservation wage.) Her firm then realizes its new productivity level z' and enters the interim state (z', l). At this point her firm decides whether to hire or fire workers. In the former case it expands its workforce to $l' > l$, she earns $w_h(z', l')$, and she is positioned to start the next period in state (z', l'). In the latter case, she either loses her job and reverts to state u or she retains her job, earns $w_f(z', l')$, and starts next period in state (z', l'). All workers at contracting firms are equally likely to be laid off, so each loses her job with probability $p_f = (l - l')/l$.

Workers in state u are searching for industrial jobs. They are hired by entering and expanding firms that post vacancies. If they are matched with a firm, they receive the same wage as those who were already employed by the firm. If they are not matched, they remain unemployed in the current period, and support themselves by home-producing $b \in [0, 1)$ units of the service good. At the start of the next period, they can choose to work in the service sector (enter state s) or look for a job in the industrial sector (remain in state u). Likewise, workers who start the current period in the service sector choose between continuing to work at the service wage $w_s = 1$ and entering the pool of industrial job-seekers. As these workers have the option to choose either labor market, they are said to be in state o.

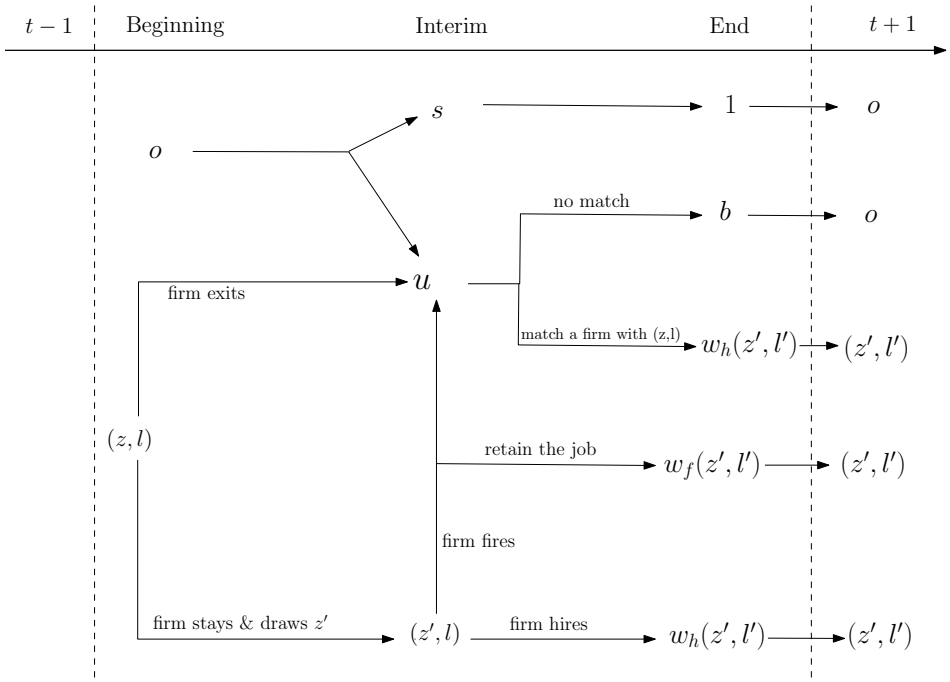

Figure 3.2: Within-period Sequencing of Events for Workers

We now specify the value functions for the workers in the interim stage. Going to the service sector generates an end-of-period income of 1 and returns a worker to the o state at

the beginning of next period. Accordingly, the interim value of this choice is

$$J^s = \frac{1}{1+r}\left(1 + J^o\right), \tag{3.16}$$

Searching in the industrial sector exposes workers to the risk of spending the period unemployed, supporting themselves by home-producing b units of the service good. But it also opens the possibility of landing in a high-value job. Since the probability of finding a match is ϕ_w, the interim value of searching for an industrial job is

$$J^u = \frac{1}{1+r}\left[\phi_w EJ_h^e + (1-\phi_w)(b + J^o)\right], \tag{3.17}$$

where EJ_h^e is the expected value of matching with a hiring firm.

The value of the sectoral choice is $J^o = \max\{J^s, J^u\}$, and since services and industrial goods are both consumed in equilibrium, workers must be equally attracted to both types of production:

$$J^o = J^s = J^u. \tag{3.18}$$

Combined with (3.16), this condition implies that J^o, J^s, and J^u are all equal to $1/r$.

The expected value of matching with an industrial job, EJ_h^e, depends on the distribution of hiring firms and the value of the jobs they offer. For workers who match with a hiring firm in the interim state (z', l), the interim period value is given by

$$J_h^e(z', l) = \frac{1}{1+r}\left[w_h(z', l') + J^e(z', l')\right], \tag{3.19}$$

where $l' = L(z', l)$ and $J^e(z', l')$ is the value of being employed at an industrial firm in state (z', l') at the start of the next period. Accordingly, the expected value of a match for a worker as perceived at the interim stage is

$$EJ_h^e = \int_{z'}\int_{l} J_h^e(z', l) g(z', l) dl dz', \tag{3.20}$$

where $g(z', l)$ is the density of vacancies across hiring firms

$$g(z', l) = \frac{v(z', l)\widetilde{f}(z', l)}{\int_{z'} \int_l v(z', l)\widetilde{f}(z', l) dl dz'}. \tag{3.21}$$

Here $v(z', l) = \mathcal{I}^h(z', l) \left[L(z', l) - l\right] / \phi_f$ gives the number of vacancies posted by a firm in interim state (z', l), and $\widetilde{f}(z', l)$ is the interim stage unconditional density of firms over (z', l). (The latter density is generally distinct from the end-of-period stationary distribution of firms, $f(z, l)$.)

It remains to specify the value of starting the period matched with an industrial firm, $J^e(z, l)$, which appears in (3.19) above. The value of being at a firm that exits immediately is simply the value of being unemployed, J^u. This is also the value of being at a firing firm, since workers at these firms are indifferent between being fired and retained. Hence $J^e(z, l)$ can be written as

$$J^e(z, l) = \mathcal{I}^c(z, l) E_{z'|z} \left\{ \mathcal{I}^h(z', l) J_h^e(z', l) + \left[1 - \mathcal{I}^h(z', l)\right] J^u \right\} + \left[1 - \mathcal{I}^c(z, l)\right] J^u \tag{3.22}$$

3.2.7 Wage Schedules

We now characterize the wage schedules. After hiring firms have posted their vacancies and matching has taken place, the labor market closes. Firms then bargain with their workers simultaneously and on a one-to-one basis, treating each worker as the marginal one. At this point vacancy posting costs are already sunk and workers who walk away from the bargaining table cannot be replaced in the current period. Similarly, if an agreement between firm and the worker is not reached, the worker remains unemployed in the current period. These timing assumptions create rents to be split between the firm and the worker.

As detailed in Appendix B.1, it follows that the wage schedule for expanding/replenishing firms with an end-of-period state (z', l') is given by

$$w_h(z', l') = (1 - \beta) r \frac{b + J_o}{1 + r} + \Gamma(\alpha, \beta, \sigma) D^{\frac{1}{\sigma}} (z')^{\frac{\sigma - 1}{\sigma}} (l')^{-\left[\frac{\alpha}{\sigma} + (1 - \alpha)\right]} - \beta P_f(z', l') c_f, \tag{3.23}$$

where $r \frac{b + J_o}{1 + r}$ is the flow value of unemployment for a worker who is bargaining with a firm

at the end of the period, $\beta \in [0,1]$ measures the bargaining power of the firm, $P_f(z', l')$ is the probability of being fired next period, and $\Gamma(\alpha, \beta, \sigma) = \frac{\alpha\beta(\sigma-1)}{\sigma(1-\beta)+\alpha\beta(\sigma-1)}$ is a constant.

The marginal worker at a contracting firm generates no rents, so the firing wage just matches her reservation value (see Appendix B.1):

$$w_f(z', l') = rJ^u - \left[J^e(z', l') - J^u\right]. \tag{3.24}$$

Note that $w_f(z', l')$ varies across firms, since those workers who continue with a firing firm may enjoy higher wages next period. This option to continue has positive value (captured by the bracketed term), so firing firms may pay their workers less than the value of being unemployed.

3.3 Equilibrium

Six basic conditions characterize our equilibrium. First, the distribution of firms over (z, l) states reproduces itself each period through the Markov processes on z, the policy functions (including hiring, firing, entry and exit), and the productivity draws that firms receive upon entry. Second, supply matches demand for services and for each differentiated good, where supplies are determined by employment and productivity levels in each type of good. Third, the flow of workers into unemployment matches the flow of workers out of unemployment—that is, the Beveridge condition holds. Fourth, aggregate income matches aggregate expenditure. Fifth, workers optimally choose the sector in which they are working or seeking work.

The final condition is trade balance. It follows from (3.4) that total domestic spending on imported varieties is given by

$$E_F = \tau_m \tau_c k \int_0^1 \int_0^{N_F} p_F(n) q_{Fi}^c(n) dn di = D_H \left[\tau_m \tau_c k\right]^{1-\sigma},$$

and domestic demand for foreign currency (expressed in domestic currency) is

$$R_F = \frac{E_F}{\tau_m} = \frac{D_H \left[\tau_m \tau_c k\right]^{1-\sigma}}{\tau_m} = D_H \tau_m^{-\sigma} \left[\tau_c k\right]^{1-\sigma}.$$

Tariff revenues collected by the home country government amount to $T = R_F(\tau_m - 1)$. We assume all tariff revenues are returned to worker/consumers in the form of lump-sum transfers.

Total export revenues are

$$R_x = N \int_z \int_{l_e}^{\infty} r_x(z, l, k)\mathcal{I}^x(z, l, k) f(z, l) dl dz,$$

and since service goods are non-traded, balanced trade obtains when $R_F = R_x$. The exchange rate k moves to ensure that this condition holds. Appendix B.2 provides further details and confirms that if all other market clear, trade balance holds by Walras' Law.

3.4 Quantitative Analysis

3.4.1 An Application to Colombia

To explore the implications of the small open economy version of our model, we use a combination of econometric estimation and calibration techniques to fit it to Colombia. This country suits our purposes for several reasons. First, Colombia underwent a significant trade liberalization during the late 1980s and early 1990s, reducing its average nominal tariff rate from 21.5 percent to 11 percent (Table 1). [12] Second, despite stable average unemployment rates, these trade reforms were associated with an increase in job turnover rates from 18.4 percent to 23 percent, an increase in informal self-employment from 17.8 to 20.7, and an increase of 0.34 in the ratio of wages at the 90th percentile to wages at the 10th percentile, controlling for observable worker characteristics (Table 1). These patterns are typical of

[12] Pre-liberalization data covers 1986-88 period for tariffs, 1978-91 for job turnover, 1988-91 for the unemployment rate, 1986-90 for wage inequality, and 1986-90 for informal sector self-employment. Post reform data are for 1992-98, 1992-99, 1992-98, 1992-99, 1992-98 periods, respectively. The tariff data come from Attanasio, Goldberg and Pavcnik (2004), Table 1a. Job turnover figures are based on DANE's annual industrial survey, which covers all manufacturing establishments with at least 10 workers. The log wage distribution is based on the residuals from a Mincerian regression of log wages on education, age, and sectoral and occupational dummies. The data set pools biennial household survey data from Colombia's national statistical agency (DANE) for the period 1986-98. Coefficients on all variables are allowed to shift through time in order to exclude changing skill premiums as a source of dispersion. The informal self employment rate is constructed from the same data base. It is the fraction of the work force that is self-employed, non-professional, and informal (i.e., not paying social security).

Latin American experiences. Finally, although Colombia did experience some macro shocks during the period of interest, they were relatively mild. Thus the consequences of Colombia's liberalization are relatively likely to come through in its data.

Table 1: Trade Reforms and Labor Market Outcomes - Colombia

Variable	**pre-liberalization**	**post-liberalization**
Average nominal import tariff	21.50	11.30
Job turnover rate	18.43	22.95
Economy-wide unemployment rate	9.99	9.87
Informal self-employment rate	17.79	20.68
Log wage gap (90th versus 10th percentile)	1.43	1.51

3.4.2 The Revenue Function and Productivity Process

The job turnover and wage inequality documented in Table 1 help us to calibrate our model, as we will discuss shortly. But the parameters that characterize the revenue function and the productivity process can be estimated econometrically using Colombia's annual industrial survey. Note that the revenue function (3.7) and CES preferences imply that log revenues (gross of fixed exporting costs) can be written as a function of employment, productivity and an index of market-wide demand,

$$d_H = \ln[D_H^{\frac{1}{\sigma}}(1-\eta^o)^{\frac{\sigma-1}{\sigma}}], \tag{3.25}$$

an index of the *percentage increase* in total demand associated with exporting,

$$d_F = \ln[(k^\sigma D_F)^{\frac{1}{\sigma}}\,(\eta^o/\tau_c)^{\frac{\sigma-1}{\sigma}}e^{-d_H}+1], \tag{3.26}$$

and an indicator for whether firm i is an exporter, $\mathcal{I}_{it}^x$:

$$\ln r_{it} = d_H + \mathcal{I}_{it}^x d_F + \frac{\sigma-1}{\sigma}\ln z_{it} + \alpha\frac{\sigma-1}{\sigma}\ln l_{it} \tag{3.27}$$

Further, assuming that $\ln(z)$ follows an exogenous AR(1) process,

$$\ln z_{it} = \rho \ln z_{it-1} + \epsilon_{it}, \tag{3.28}$$

equation (3.27) can be restated as:

$$\begin{aligned} \ln r_{it} &= (d_H + \mathcal{I}^x_{it} d_F) - \rho \left(d_H + \mathcal{I}^x_{it-1} d_F\right) + \rho \ln r_{it-1} \\ &\quad -\alpha\rho \left(\frac{\sigma - 1}{\sigma}\right) \ln l_{it-1} + \alpha \left(\frac{\sigma - 1}{\sigma}\right) \ln l_{it} + \frac{\sigma - 1}{\sigma} \epsilon_{it}, \end{aligned} \tag{3.29}$$

If we could obtain consistent estimates of the coefficients that appear on the right-hand-side observable variables, these would allow us to infer consistent estimates of ρ, α, and σ. Also, the variance of the error term would allow us to infer σ_ε, the standard deviation of error terms in (3.28). However, selection bias and simultaneity bias prevent us from consistently estimating (3.29) with ordinary least squares. The former problem occurs because firms choose whether to exit the market partly on the basis of their ϵ_{it} realizations, so the ϵ_{it} realizations observed for active producers are not random draws from the unconditional distribution of $\epsilon' s$. The latter problem occurs because firms' current exporting decisions and employment levels are chosen after the current realization on ϵ is observed, so ϵ_{it} is correlated with both $\mathcal{I}^x_{it}$ and $\ln l_{it}$. Appendix B.3 develops a generalized method of moments (GMM) estimator related to Olley and Pakes' (1996) that deals with both problems.

Applying this estimator to the set of all Colombian manufacturing plants observed for at least three years during the pre-liberalization period 1982 and 1991, we obtain the results summarized in Table 1 below.[13] Since σ is not identified, we fixed this parameter at a value typical of the literature, $\sigma = 5$. All remaining parameters are estimated with considerable precision. It should be noted, however, that the estimates are somewhat sensitive to choice of the instrument set, and to the weights we used on different types of workers—managers, technicians, skilled laborers, unskilled workers, and apprentices—when constructing the

[13]The data are annual observations on all manufacturing firms with at least 10 workers. They were collected by Colombia's National Statistics Department (DANE) and cleaned as described in Roberts (1996). Given that fixed capital and intermediate inputs do not appear in our model, we define revenue to be the value of output net of intermediate input and capital costs. Annual capital costs are 10 percent of the book value of firms' capital stocks.

number of "effective" workers.[14]

Table 2: Revenue function and productivity process

(GMM estimates, given $\sigma = 5.0$)

Parameter	Estimate	Std. error	z-ratio
α	0.592	0.057	10.41
ρ	0.848	0.007	118.73
σ_ε^2	1.668	0.042	39.54
d_H	1.682	0.047	35.78
d_F	0.213	0.004	51.31

3.4.3 Remaining Parameters

Using our estimates for d_F and d_H, equations (3.25), (3.26), and (3.8), and the fact that exporters earned 8.03% of their revenue from foreign sales during the base period, we can solve for D_H, $k^\sigma D_F$ and τ_c. The results appear in table 3 below, along with several other parameters values we fix using observable aggregates. First, the real borrowing rate in Colombia fluctuated around 15 percent between late 1980s and early 2000s, so we set r to be 0.15 (Bond et al. (2008)). Second, since the share of tradables in total consumption expenditure in Colombia was about 40 percent in 2005, we set γ to be 0.4 (Wold Bank, 2008, Table 11, p. 134).[15]

We take several other parameters from the existing literature. Following den Haan, Ramey and Ramey (2000), we set the elasticity of the matching function, θ, to be 1.27. As a benchmark we give equal bargaining power to firms and workers, i.e. $\beta = 0.5$, assume that entrants have start with the lowest possible employment level.[16]

[14]The weights used for reported estimates are based on cross-plant mean wage premiums for each type of employee, relative to unskilled workers. Weighting means (using plant size as weights) yields a larger α value, although it has little effect on ρ.

[15]In order to find the expenditure share on tradables we sum the expenditure shares for food and nonalcoholic beverages, alcoholic beverages and tobacco, clothing and footwear. We also added half of furnishing, household equipment and maintenance and half of other consumption items as tradable. This leaves housing, water, electricity, health, transportation, communication, recreation and culture, education, restaurants and hotels as non-tradable items.

[16]Although newly created firms start at the lowest possible employment level, by the time they begin production they will have adjusted their initial labor force, and their observed employment will reflect their initial productivity.

Table 3: Parameter Values

Parameters that are set before simulations

Parameter	Value	Description	Source
α	0.592	production function	GMM estimate (Table 2)
ρ	0.848	persistance of z process	GMM estimate (Table 2)
σ_ε	1.291	std. dev. of shocks to z	GMM estimate (Table 2)
$k^\sigma D_F$	635.6	foreign demand level	from GMM estimates (Table 2)
τ_c	2.837	iceberg trade costs	from GMM estimates (Table 2)
l_e	$l(1)$	initial size of entering firm	assumed (smallest possible)
β	0.5	bargaining power	assumed (literature)
σ	5	elasticity of subs.	assumed (literature)
r	0.15	discount rate	Bond, et al (2008)
γ	0.4	share, Q goods in utility	World Bank (2005)
θ	1.27	elas. of matching function	den Haan et al (2000)

Table 3 collects the parameters discussed thus far, and implies that 8 parameters remain to be determined: firing cost c_f, the fixed cost of operation c_p, the vacancy posting cost parameter c_h, the fixed cost of exporting c_x, the value of home production b, the value of entry c_e, and the parameters of hiring cost function, λ_1 and λ_2. The value of entry is determined endogenously in the model to satisfy the free entry condition, as in Hopenhayn and Rogerson (1993). In the benchmark calibration below, we set $c_f = 0$. We estimate c_p, c_h, c_x, b, λ_1 and λ_2 by a method of moments. We select twelve targets that summarize key features of our model: the firm exit rate, the job turnover rate, the fraction of firms that export, the unemployment rate, the autocorrelation of firms employment levels, correlation between firms productivity and employment and the employment growth rates among expanding firms at the different quintiles of the size distribution.

While it is not possible to associate individual parameters with individual statistics, experiments do suggest that particular statistics play relatively key roles in identifying

particular parameters. First, the fraction of firms that export is sensitive to fixed exporting costs, c_x, and the rate of firm turnover is very responsive to the per-period fixed costs of operating a business, c_p. Second, the quintile-specific job growth rates and the aggregate labor turnover rate are responsive to the parameters of the vacancy cost function $(c_h, \lambda_1, \lambda_2)$, with cross-quintile differences governed by the scale economies parameter, λ_2. Finally, the unemployment rate is very responsive to the productivity of unemployed workers, b.

The data-based statistics that we use for calibration come from several sources. The firm exit rate and the fraction of firms that exit are calculated from Colombian plant level data for the pre-liberalization period, 1978-91. The quintile-specific rates of job creation and the statistics $corr(l, l')$ and $corr(z, l)$ are based on the same data base, using the technology estimates in Table 2 to calculate z. The job turnover rate is calculated from Inter-American Development Bank Job Flows Data Set for 1978-1992 period. The unemployment rate is taken from Inter-American Development Bank (2004), and is based on DANE's biennial household surveys.

Table 4 shows the data-based statistics and their model-based simulated counterparts. Note that we have (somewhat arbitrarily) divided the correlation statistics by 10 in order to keep all statistics a similar order of magnitude, and thereby prevent the correlation statistics from dominating the calibration exercise. Although we are using 6 parameters to try to match 12 statistics, the does a nice job of fitting the data overall.[17] In particular, the model captures the contributions of firm entry/exit and intra-firm size adjustments to overall job turnover, the persistence in employment levels, the overall unemployment rate, and higher job turnover rate among small firms.

[17]The metric of fit we used was $\|X - Y\| / \|X\|$ where X is the vector of data-based statistics and Y is the vector of the model-based counterparts. At its minimized value, this metric was 0.098.

Table 4: Calibration

Data-based versus simulated statistics

Industry-wide Statistics	Data	Model	**Employment Growth Rates, by Quintile**	Data	Model
exit rate	0.091	0.083	<20th percentile	0.319	0.341
job turnover	0.211	0.226	20th-40th percentile	0.218	0.248
export rate	0.120	0.122	40th-60th percentile	0.191	0.209
Unempl.	0.086	0.100	60th-80th percentile	0.183	0.168
$corr(l, l')/10$	0.095	0.083	>80th percentile	0.157	0.145
$corr(z, l')/10$	0.059	0.066			
$corr(z, l)/10$	0.057	0.074			

Table 5 reports the parameter values associated with the calibration. Except for λ_1 and λ_2, parameters are measured in terms of the 1990 average annual wage for a service sector worker, taken from the annual household survey, which amounted to roughly \$1,300 US (1977), or about \$4,500 current US dollars. Accordingly, our model implies that the fixed costs of operating a business amount to about \$85,500, while the fixed costs of exporting are only about \$38,500. Note also that those who end up doing home production take about an 88 percent wage cut relative to what they could have earned if they had committed to working for a service sector firm. Finally, the parameters of the vacancy cost function imply both short-run convexities ($\lambda_1 = 1.68$) and modest scale economies ($\lambda_2 = 0.30$). The latter, of course, is a reflection of the quintile-specific growth rates reported in Table 4 and the (mean-reverting) productivity process reported in Table 2. That is, if there were no scale effects, mean reversion would imply somewhat smaller growth rates among the largest firms that are posting vacancies, and slightly higher growth rates among the smallest firms that are posting vacancies.

Table 5: Calibrated Parameter Values

Parameter	Value	Description
c_p	19.0	fixed cost of operation
c_h	5.31	posting cost scalar
c_x	8.57	fixed exporting cost
b	0.12	value of home production
λ_1	1.68	convexity, vacancy cost function
λ_2	0.30	scale effect, vacancy cost function

3.4.4 Simulated effects of openness

We are now prepared to examine the effects of trade reforms in our calibrated model. To do so we reduce the import tariff from 21 percent to 11 percent, mimicking the reforms documented in Table 1. This reduction in protection generates an increase in the fraction of firms that export from 12.2 percent to 14.2 percent, while the actual data show an increase to approximately 20 percent, so tariff reforms alone are insufficient to explain all of the extra trade that Colombia generated during the post liberalization period. Exchange rates, increased openness among trading partners, and falling transport costs presumably account for the rest.

Table 6 shows how key labor market statistics change with the reduction in τ_m. Although the model predicts a modest increase in the fraction of firms that export and a simultaneous increase in the share of output that exporters ship abroad, the impact of this liberalization on labor markets is very small. It is true that liberalization shifts the distribution of jobs toward larger firms, and these firms enjoy lower vacancy posting costs because of scale economies. But large firms also tend to experience relatively small productivity shocks, since their productivity is typically above average and the productivity process is mean-reverting. These two factors roughly offset one another, leaving aggregate turnover rates essentially unchanged. For the same reasons, and because the size of the differentiated good sector remains roughly constant, trade liberalization has no effect on unemployment. This latter finding is consistent with the stable unemployment rates documented in Table

1, although one might argue that the rising importance of informality/self-employment is a symptom of increasing labor market slackness.

In contrast to the turnover and unemployment findings, our figures *do* suggest that trade liberalization helped increase Colombian wage inequality. (Refer again to Table 1.) The reason is that workers share in their firms' rents through the bargaining process, and liberalization creates more cross-firm heterogeneity in rents. Workers lucky enough to be employed by exporting firms experience wage increases as their employers' profits rise with liberalization, while workers at inefficient firms experience wage reductions as their employers face heightened import competition. Finally, although some workers benefit from trade reforms and others are hurt, the average effect on current utility is negligible.

Table 6: The Labor Market Effects of Trade Reform

Variable	base case $\tau_m = 1.21$, $\tau_c = 2.84$	tariff reductions $\tau_m = 1.11$ $\tau_c = 2.84$	modest globalization $\tau_m = 1.21$ $\tau_c = 2.55$	major globalization $\tau_m = 1.21$ $\tau_c = 2$
Fraction of firms that export	0.122	0.140	0.158	0.264
Job turnover	0.226	0.222	0.224	0.224
Unemployment, or	0.100	0.100	0.098	0.094
Log 90-10 wage ratio	2.035	2.047	2.049	2.070
Std. dev., log wages	0.775	0.776	0.778	0.781
Average indirect utility, $IP^{-\gamma}$	0.772	0.771	0.781	0.829

As noted above, the fraction of Colombian firms that exported some of their output rose from 12 percent to roughly 20 percent–much more than the simulations in column 2 predict. Thus, at the same time as τ_m was falling, it is likely that other forces were encouraging trade, e.g., reductions in transport costs and changes in protection rates among trading partners. To approximate the effects of these other trade-inducing forces, we next consider reductions in τ_c.

The column labeled "globalization" describes the effects of scaling τ_c by a factor of 0.9, holding τ_m fixed at its pre-liberalization value. Qualitatively, the results look similar to those reported for Colombian tariff reductions, although the induced changes are slightly larger. This pattern simply reflects the fact that reductions in either type of trade friction promote both imports and exports. The last column of table 6 shows that larger reductions in τ_c generate correspondingly larger increases in the fraction of firms that are exporting. Wage inequality, utility gains and the unemployment rate also respond more dramatically.

Figure 1 shows the change in the export policy function $\mathcal{I}^x(z, l)$ that accompanies a regime shift from the base case ($\tau_c = 2.84$) to a world in which $\tau_c = 2$. High-productivity firms continue to export, and low productivity firms continue to abstain from exporting, but there is an intermediate group of firms that is drawn into foreign markets when transport costs fall—these firms create the ridge in the figure.

Once in the export market, firms respond more dramatically to productivity shocks because they react by adjusting their sales in both the foreign and the domestic market. This is apparent in Figure 3, which shows how the hiring policy function changes as τ_c drops. Most of the extra job creation occurs among small firms that draw high productivity shocks; openness also depresses job creation among firms with productivity levels too small to profitably export, since these firms lose market share to imports. These changes in job creation patterns are mirrored by changes in the cross-firm distribution of rents, and therefore in the value of being employed at different types of firms.

Figure (3.3) depicts the change in the $J^e(z, l)$ surface when τ_c falls from 2.84 to 2. Note that the value of employment at relatively inefficient firms drops as rents fall at these employers, while the value of employment at high-productivity firms rises. The biggest drop occurs among firms that are induced to exit in the relatively free-trade equilibrium, which are concentrated at low z and l values.

In a sense, we have stacked the deck against finding large turnover effects. Our model filters all shocks to the prices of imported goods through a general price index, and thus does not allow idiosyncratic shocks to foreign suppliers' prices to affect different Colombian firms differently. Nor have we allowed the elasticity of demand in product markets to increase

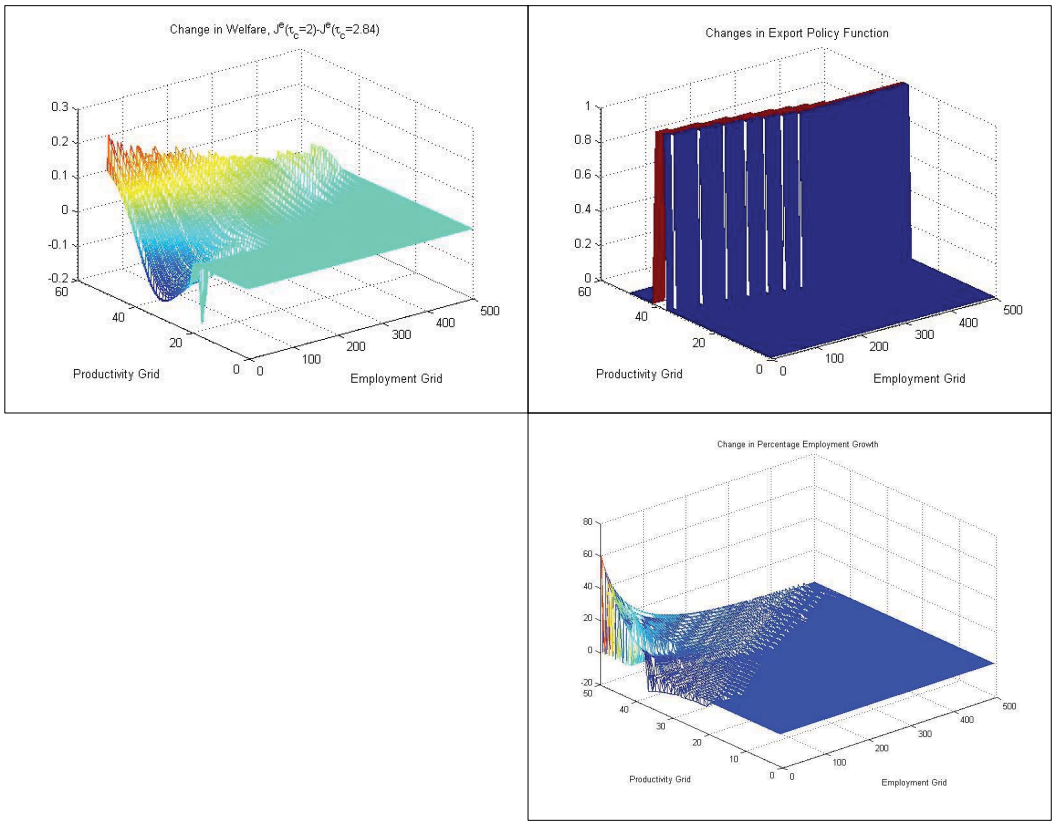

Figure 3.3: Effects of Openness

when firms are exposed to heightened import competition. If we were to use a demand system in which these effects of openness were operative, the effects of openness on job turnover would be magnified.[18] And since all producers compete with imports while only 10 to 20 percent export, the effects could be dramatic.

3.5 Summary

In Latin America and elsewhere, globalization has been associated with less job security, more wage inequality, and more informality. We have formulated a dynamic structural

[18] Atkeson and Burstein (2009) provide an example of this type demand specification. An alternative specification, due to Arkolakis (2008), presumes convex marketing costs of reaching consumers, so that adding new customers becomes increasingly costly as a firm exhausts the pool of easily-reachable buyers. We plan to incorporate Arkolakis's mechanism in a generalized version of our model.

model that explains these association as a consequence of heightened firm responsiveness to idiosyncratic productivity shocks, and we have shown that this mechanism alone could account for a substantial fraction of the heightened volatility and wage dispersion in Colombia.

In addition to providing a lens through which to interpret recently-observed changes in Latin American labor markets, our paper makes several methodological contributions. First, we have generalized the representation of labor markets developed by Bertola and Caballero (1994) to an open economy setting with fully articulated product markets, multiple sectors, and arbitrary Markov processes for productivity shocks. Second, we have demonstrated how to quantify some welfare and distributional effects of openness that had not yet been empirically explored.[19] Finally, we have developed a means to characterize plant-level productivity processes that does not require us to observe a measure of physical output, matches a large set of stylized facts, and is robust with respect to simultaneity bias and selection bias.

[19]Previous attempts to examine Rodrik's conjecture empirically have amounted to tests for structural shifts in the elasticity of demand for labor, pre-versus post-globalization.

Bibliography

Abowd, J., F. Kramatz and D. Margolis (1999). "High Wage Workers and High Wage Firms," *Econometrica*, Vol. 67, No. 2, 251-333.

Abowd, John, Robert Creecy and Francis Kramarz. 2002. "Computing Person and Firm Effects Using Linked Longitudinal Employer-Employee Data," Working Paper, Cornell University.

Albrecht, J. and S. Vroman. (2002) "A Matching Model with Endogenous Skill Requirements" *International Economic Review*, 43: 238-305.

Amiti, Mary and Donald R. Davis (2008). "Trade, Firms, and Wages: Theory and Evidence," NBER Working Papers 14106.

Artuc, Erhan, Chaudhuri, Shubham and McLaren, John (2007) "Trade Shocks and Labor Adjustment: A Structural Empirical Approach" NBER Working Paper No. W13465.

Atkeson, Andrew and Ariel Burstein (forthcoming) "Pricing-to-Market, Trade Costs, and International Relative Prices," *American Economic Review*.

Attanasio, Orazio, Golberg, Pinelopi K. and Nina Pavcnik (2004) "Trade Reforms and Wage Inequality in Colombia", *Journal of Development Economics*, 74, August 2004, pp. 331-366

Bernard, Andrew B. and J. Bradford Jensen, 1999. "Exceptional exporter performance: Cause, Effect, or both?" *Journal of International Economics*, 47(1): 1-25.

Bertola, Giuseppe and Ricardo Caballero (1994) "Cross-sectional Efficiency and Labour Hoarding in a Matching Model of Unemployment," *Review of Economic Studies* 61, 435-47.

Bertola, Giuseppe and Pietro Garibaldi (2001) "Wages and the Size of Firms in Dynamic Matching Models," *Review of Economic Dynamics* 4, 335-368.

Bond, Eric, Tybout James and Hale Utar (2008).“Credit Rationing, Macro Volatility, and Industrial Evolution in Developing Countries,” mimeo.

Cahuc, Pierre, Etienne Wasmer (2001). “Does Intrafirm Bargaining Matter in Large Firm Matching Model?” *Macroeconomic Dynamics*, Volume 5, Issue 05, pp 742-747.

Cooper, Russell, John Haltiwanger, and Jonathan Willis (2007). ”Search Frictions: Matching Aggregate and Establishment Observations,” *Journal of Monetary Economics* 54, pp. 56-78.

Cunat, Alejandro and Marc J. Melitz (2007). ”Volatility, Labor Market Flexibility, and the Pattern of Comparative Advantage,” NBER Working Papers 13062.

Das, Mita, Roberts, Mark and James Tybout (2007) “Market Entry Costs, Producer Heterogeneity and Export Dynamics,” *Econometrica*, 75 (3), 837-873.

Davidson C., S. Matusz and A. Shevchenko (2006) ”Globalization and Firm-Level Adjustment with Imperfect Labor Markets,” Working Paper, Michigan State University.

Davidson, C., L. Martin, and S. Matusz (1999) ”Trade and search generated unemployment,” *Journal of International Economics* 48(2), pp. 271-299.

Davis, Donald R. and James Harrigan (2007). ”Good Jobs, Bad Jobs, and Trade Liberalization,” NBER Working Papers 13139.

Davis, S., J. Haltiwanger, and S. Shuh (1998). *Job Creation and Destruction* (MIT Press).

Demidova, S., and Rodríguez-Clare (2008). ”Trade Policy under Firm-Level Heterogeneity in a Small Economy,” Working Paper, Pennsylvania State University.

den Haan, Wouter J., Garey Ramey and Joel Watson (2000). “Job Destruction and the Propagation of Shocks,” *American Economic Review*, 90, 482—98.

De Loecker, Jan and Frederick Warzynski (2009). ”Markups and Firm-Level Export Status,” Working Paper, Department of Economics, Princeton University.

Eaton, Jonathan, Marcela Eslava, Maurice Kugler and James Tybout (2007). "The Margins of Entry into Export Markets: Evidence from Colombia," forthcoming in *The Organization of Firms in a Global Economy*, edited by Elhanan Helpman, Dalia Marin, and Thierry Verdier (Harvard University Press).

Egger, Hartmut and Udo Kreickemeier (2007). "Firm Heterogeneity and the Labour Market Effects of Trade Liberalisation," CESifo Working Paper Series CESifo Working Paper No.2000.

Feenstra, Robert C., Lipsey, Robert E., Deng, Haiyan, Ma, Alyson C. and Hengyong Mo (2005) "World Trade Flows: 1962-2000" NBER Working Paper 11040.

Felbermayr, Gabriel, Prat, Julien, and Hans-Jorg Schmerer (2008) "Globalization and Labor Market Outcomes: Wage Bargaining, Search Frictions, and Firm Heterogeneity" IZA DP No. 3363.

Goldberg, PK, Pavcnik, N, 2007, "Distributional Effects of Globalization in Developing Countries," *Journal of Economic Literature* XLV: 39-82.

Hallak, Juan Carlos and Jagadish Sividasan (2008). "Productivity, Quality, and Exporting Behavior Under Minimum Quality Requirement," Working Paper, The University of Michigan.

Haltiwanger, John, Adriana Kugler, Maurice Kugler, Alejandro Micco, and Carmen Pages, "Effects of Tariffs and Real Exchange Rates on Job Reallocation: Evidence from Latin America," *Journal of Policy Reform*, Special Issue December 2004, 7 (4), 191-208.

Harris, J. and M. Todaro (1970) "Migration, Unemployment, and Development: A Two-Sector Analysis," *American Economic Review* 60: 126-142.

Helpman, Elhanan and Oleg Itskhoki (2007) "Labor Market Rigidities, Trade and Unemployment," Working Paper, Harvard University.

Helpman, Elhanan, Itskhoki , Oleg and Stephen Redding (2008). "Wages, Unemployment and Inequality with Heterogeneous Firms and Workers", Working Paper, Harvard

University.

Hobijn, Bart and Aysegul Sahin (2007), "Firms and Flexibility," Working Paper, Federal Reserve Bank of New York,

Hopenhayn, Hugo (1992), "Entry, Exit, and Firm Dynamics in Long Run Equilibrium," *Econometrica*, 60(5): 1127-1150.

Hopenhayn, H. and Rogerson, R. (1993). Job Turnover and Policy Evaluation: A General Equilibrium Analysis. *Journal of Political Economy*, 101 (5), 915-938.

Hornstein, A., Krusell, P. and G. Violante (2009). "Frictional Wage Dispersion in Search Models: A Quantitative Assessment," Working Paper, NYU.

Inter-American Development Bank (2004). *Good Job Wanted: Labor Markets in Latin America*. Economic and Social Progress Report, Published by the Inter-American Development Bank, Distributed by The Johns Hopkins University Press, Washington, D.C.

Kambourov, G. (2009). "Labor Market Regulations and the Sectoral Reallocation of Workers: The Case of Trade Reforms," *Review of Economic Studies*,76 (4), 13211358.

Koeniger, W. and Prat, J. (2007). "Employment Protection, Product Market Regulation and Firm Selection," *The Economic Journal*, 117 (521), F302-F332.

Kugler, Maurice and Eric Verhoogen (2008). "The Quality-Complementarity Hypothesis: Theory and New Evidence from Colombia," Working Paper, Columbia University, Department of Economics.

Lentz, Rasmus and Mortensen, Dale T. (2008) "Labor Market Frictions, Firm Heterogeneity, and Aggregate Employment and Productivity," mimeo.

Melitz, Marc (2003) "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica* 71, 1695-1725.

Melitz, Marc and Gianmarco Ottaviano (2008). "Market Size, Trade and Producitivty," *Review of Economic Studies* 75(1): 295-316.

Menezes-Filho, Naercio Aquino and Marc-Andreas Muendler. 2007. "Labor Reallocation in Response to Trade Reform," Working Paper, University of California, San Diego.

Nilsena, Øivind A., Kjell G. Salvanesa, and Fabio Schiantarelli (2007) "Employment Changes, the Structure of Adjustment costs, and Plant Size, *European Economic Review* 51, 577-98.

Olley, G. Steven and Ariel Pakes. (1996). The Dynamics of Productivity in the Telecommunications Equipment Industry. *Econometrica* 64, 1263-98.

Pissarides, Christopher A. (2000). *Equilibrium Unemployment Theory*,second edition, Cambridge, MA: MIT Press.

Roberts, M. (1996) "Employment Flows and Producer Turnover" in M. Roberts and J. Tybout, eds., *Industrial Evolution in Developing Countries* (Oxford University Press).

Rodrik, Dani (1997). *Has Globalization Gone too Far*?, Washington, D.C.: Institute for International Economics.

Rogerson, R.; Shimer, R. and Wright, R. (2005). "Search-Theoretic Models of the Labor Market." *Journal of Economic Literature*, 43(4): 959-988. Also NBER Working Paper 10655, http://www.nber.org/papers/w10655.

Stole, Lars A. and Jeffrey Zwiebel (1996) "Intra-Firm Bargaining under Non-Binding Contracts." *The Review of Economic Studies*, 63(3), pp. 375-410.

Utar, Hale (2008). "Import Competition and Employment Dynamics," Working Paper, Department of Economics, University of Colorado.

Veracierto, M. (2001), "Employment Flows, Capital Mobility, and Policy Analysis", *International Economic Review* 42(3), 571–595. 33.

World Bank (2008), *Global Purchasing Power Parities and Real Expenditures,* 2005 International Comparison Program, World Bank, Washington D.C.

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

Chapter 4

Human Capital, Technology Adoption and Development

4.1 Introduction

As it is well-known in the growth literature, productivity differences explain a significant part of the variation observed in cross-country income distribution.[1] A major determinant of productivity is the set of technologies available to firms in a country. The model presented here demonstrates that productivity differences may arise as a result of differences in skilled labor endowments which facilitate the adoption of technologies from an exogenously available set.

The idea that a link exists between technology adoption and human capital is not new. The line of thought initiated by Nelson and Phelps (1966) suggests that the role of human capital in development may go beyond its role as a mere factor of production. In this approach, human capital, in general, and education, in particular, help people to perceive, evaluate and implement new production techniques and inputs.

Empirical literature supports this approach. Using aggregate data, Benhabib and Spiegel (1997, 2005) as well as Papageorgiou (2003) find that specifying human capital as a deter-

[1] Notable papers documenting the sources of income differences are Klenow and Rodríguez-Clare (1997), Hall and Jones (1997) and Caselli (2005).

minant of productivity level, instead of using it as an input in the production function, gives better results in growth regressions. On a micro-level, Doms et.al. (1997) show that plants with a higher share of workers in skilled occupational categories or with higher educational levels use a greater number of advanced technologies. Foster and Rosenzweig (1995) document that in the wake of the "Green Revolution" period in India, the profitability of adopting new high-yield seed varieties and chemical fertilizers is increasing in the education level of farmers.

Human capital may affect technological diffusion through various channels.[2] One channel is international trade which makes the transfer of embodied technology possible. Caselli and Coleman (2001), and Caselli and Wilson (2004) demonstrate that the amount of embodied technology in imported capital goods is positively related to the level of educational attainment. Another avenue is foreign direct investment. Xu (2000) demonstrates that the level of human capital is a key factor in explaining the level of technology diffusion from multinational companies to their host countries. Trade in ideas, as reflected by international patenting and licensing, constitutes yet another channel through which technology flows across borders. Using patenting data of OECD countries, Eaton and Kortum (1999) estimate a model of bilateral diffusion of knowledge. According to their findings, human capital of the receiving country, measured as average years of schooling, has a significant positive impact on patenting after controlling for the degree of intellectual property protection, cost of patenting and research intensity.

The theoretical contribution of the paper is to embed the Nelson and Phelps (1966) idea into a general equilibrium model. A homogenous final good is produced competitively by combining unskilled labor with intermediate goods. The producers of intermediate varieties operate with a constant returns to scale technology employing capital only. The productivity of an intermediate variety is a product characteristic that affects its contribution to the production of the final good. A technology adoption function describes how skilled labor helps firms to augment their productivity levels by adopting techniques from an exogenously growing world knowledge stock. The demand for a variety is increasing in its productivity

[2]For a survey of international technology diffusion, see Keller (2004).

in the final good production. Hence, intermediate good producers have an incentive to hire skilled labor by paying them out of the positive operating profits. Skilled labor share of the workforce is the key exogenous variable in my model.

I show the existence of a stationary equilibrium and derive analytical expressions for the steady state income level and wage premium. I calibrate the model and undertake a quantitative exercise to evaluate its success in explaining cross- and within-country income differences. The key parameter of the technology adoption function, the curvature of skilled labor, is calibrated to the US wage premium. Using these parameters, I predict income levels and wage premia for a group of countries.

As a theory of development, the model does a good job in replicating patterns of cross-country income levels by generating large productivity differences. The model simultaneously generates within-country income differences in the form of a wage premium for skilled labor. For a subset of countries with available data, the model performs reasonably well in fitting the wage premia data as well. The main quantitative contribution of the paper is the ability to simultaneously account for cross- and within country income differences.

This paper does not address the endogenous formation of skills. The question I am trying to answer is simply how far we can go in explaining income dispersion through observed skilled labor endowments. Recent models of endogenous skill formation include Manuelli and Seshadri (2005) and Erosa et. al. (2010)

Relation to the Literature This paper contributes to the literature that seeks to explain how countries benefit from an ever expanding technology frontier. Griffith et.al. (2004), Howitt (2000), Klenow and Rodríguez-Clare (2005), and Parente and Prescott (1994), among others, are contributions in this line. All these papers emphasize the role of physical investment and formal research and development (R&D) expenditures in augmenting firm-level productivity. The model presented here takes a different approach. It argues that whereas many R&D activities are geared towards product innovation, certain process innovations on the factory floor or the introduction of new inputs to the production process do not necessarily involve formal R&D activities. To quote R.J. Gordon who is reporting

on anectodal evidence from his visits to six US plants in various industries,

> Clearly, much of the effort directed at productivity improvement we witnessed was not being achieved within any kind of formal R&D activity, but could be classified under the general rubric of "incremental tinkering". - Gordon (2000).

It is conceivable that the knowledge needed to undertake such "incremental tinkering" on the factory floor is based on basic engineering and operations research principles. As a result, R&D intensity data misses a wide range of technology adoption efforts undertaken at firm level. This mismeasurement especially applies to developing countries which, according to UNESCO (1975), only perform 16% of global R&D expenditures in 1996. Firms in developing countries have means other than formal R&D to benefit from the evolution of the frontier. Hence, I argue that many "incremental tinkering" activities are missed by the existing R&D measures.

This last point is also made by Klenow and Rodríguez-Clare (2005) who build a model of technology diffusion where R&D is needed to adopt technologies. Using data on R&D investment rates, their model delivers the results that poor countries have R&D investment rates that are too low to explain their income levels. They conclude that the true research intensities must be higher than the measured ones and call for further research to measure "research". The quantitative application of my model contributes to the literature by proposing an alternative measure of a country's true research effort through its entire stock of skilled labor defined as scientists and engineers.

Another contribution of the paper is to explain cross-country income differences consistently with returns to skills within countries. Growth-accounting exercises based on the Nelson and Phelphs framework, such as Benhabib and Spiegel (1997, 2005) and Papageorgiou (2003), can not take stock of the skill premium implications of particular functional forms. I construct a general equilibrium model and I am thus able to discipline the adoption technology by the evidence on wage premium.

The remainder of the paper is structured as follows: Section two introduces the economic environment, describes the equilibrium concept, and presents analytic steady state

solutions. Section three presents the quantitative exercise, pins down parameter values through calibration and compares model predictions with data. Section four concludes.

4.2 Model Economy

At time t, the economy is composed of a continuum of identical households of measure one, intermediate goods producers with a mass of M_t, a representative firm producing a final good and a government.

Each household consists of workers with measure L_t. Population grows at the rate g_ℓ,

$$\dot{L}_t = g_\ell L_t.$$

There are two types of workers in the economy: skilled and unskilled. A fraction $s \in (0,1)$ of each household is skilled and the rest is unskilled. Each unskilled worker is endowed with u units of efficiency labor and one unit of time. Aggregate endowment of skilled and unskilled labor are sL_t and $u(1-s)L_t$ respectively.

Besides the labor market, there are capital and financial markets in operation where intermediate good producers rent capital from households, and households can trade one-period bonds and the shares of these firms among each other. Now I turn to the description of production technologies.

4.2.1 Production

The structure of production is similar to Howitt (2000). There is a final good and a continuum of intermediate goods indexed by i. The final good can be consumed or employed as capital in the production of intermediate goods. It is produced competitively by a representative firm using intermediate goods and unskilled labor:

$$Y_t \;=\; L_{u,t}^{1-\alpha}\left[M_t^{-(1-\alpha)}\int_0^{M_t} A_t(i)\frac{x_t(i)^{\alpha}}{\alpha(1-\alpha)}\,di\right], \tag{4.1}$$

where $x_t(i)$ is the quantity of intermediate good i used and $A_t(i)$ is its productivity. The normalization with respect to M_t eliminates the growth effect of expanding intermediate good varieties.[3] The final good producer takes the unskilled wage $w_{u,t}$ and intermediate good prices $p_t(i)$ and productivity levels $A_t(i)$ as given, and solves the static problem of maximizing (4.1) by optimally choosing $L_{u,t}$ and $x_t(i)$ every period.

The marginal product of each variety is independent of other varieties used in production. Each variety i is a distinct product and its producer has a monopoly right over its supply.[4] The marginal product of each variety goes to infinity as its quantity goes to zero. This implies that, for any price level, the representative final good firm demands a positive amount of each available variety.

The number of varieties grows proportionally to the size of the population,

$$\dot{M}_t \;=\; \varphi L_t.$$

This assumption eliminates scale effects. The ratio of the population to varieties monotonically converges to the constant given by:

$$\lim_{t\to\infty} \frac{L_t}{M_t} \;=\; \frac{g_\ell}{\varphi},$$

which I assume is equal to one by setting $\varphi = g_\ell$. [5] The number of unskilled production

[3]This channel is well understood through the contribution of endogenous growth models in the style of Romer (1990). In the context of technology diffusion, Barro and Sala-i Martin () study the effects of increasing product varieties through imitation by the South. I abstract from this source of growth since my focus here is on the evolution of what one can call process efficiency, and not TFP gains through expanding product variety.

[4]This assumption is not crucial for the argument here. One can write a CES composite of differentiated intermediate goods, such as

$$Y_t \;=\; L_{u,t}^{1-\alpha} \left[M_t^{-(1-\gamma)} \int_0^{M_t} A_t(i) \frac{x_t(i)^\gamma}{\gamma(1-\gamma)}\, di \right]^{\frac{\alpha}{\gamma}},$$

and derive the same results. The analysis here corresponds to the case $\gamma = \alpha$.

[5]This assumption is not innocuous when one compares income levels across countries unless one also assumes identical population growth rates. This is what I implicitly do in the quantitative section.

workers per variety converges to a constant as well:

$$\ell_u = \frac{L_{u,t}}{M_t} = \frac{L_{u,t}}{L_t}\frac{L_t}{M_t} = u(1-s). \tag{4.2}$$

The last equality holds in equilibrium where unskilled labor demand $L_{u,t}$ is equal to its supply $u(1-s)L_t$. I also assume that the two types of labor cannot be substituted with each other.

Using these results in (4.1), I can restate the production function of the representative final good producer as

$$Y_t = \int_0^{M_t} A_t(i)\ \frac{x_t(i)^\alpha \ell_u^{1-\alpha}}{\alpha(1-\alpha)} di. \tag{4.3}$$

The demand for an intermediate good is given by the inverse demand function:[6]

$$p_t(i) = \frac{A_t(i)}{1-\alpha} x_t(i)^{\alpha-1} \ell_u^{1-\alpha},$$

which yields total revenues as

$$Revenue[x_t(i)] = \frac{A_t(i)}{1-\alpha} x_t(i)^{\alpha} \ell_u^{1-\alpha}.$$

Now I introduce the technology for producing intermediate goods. Capital is the only input and the production function is given by:

$$x_t(i) = \frac{k_t(i)}{A_t(i)}, \tag{4.4}$$

which has the feature that more productive varieties also require a more capital intensive production technology.[7] Intermediate goods producers rent capital at a cost of R_t. The

[6]This is derived by the solution to the problem

$$\max_{\{x_t(i)\},\ell_{u,t}} \int_0^{M_t} A_t(i) \frac{x_t(i)^\alpha \ell_u^{1-\alpha}}{\alpha(1-\alpha)} di - \int_0^{M_t} p_t(i) x_t(i) di - \ell_{u,t} M_t w_{u,t}.$$

[7]This specification is not essential for the results. It only simplifies the algebra.

associated cost function is given by:

$$Cost[x_t(i)] = R_t A_t(i) x_t(i).$$

The demand for capital is determined by setting marginal cost equal to marginal revenue which yields

$$R_t = \frac{\alpha}{1-\alpha}\left(\frac{x_t(i)}{\ell_u}\right)^{\alpha-1}. \tag{4.5}$$

Note that nothing in (4.5) depends on firm characteristics. All firms supply the same quantity of intermediate good, i.e.,

$$x_t(i) = x_t.$$

Static operating profits after rental payment is given by:

$$\pi_t(i) = A_t(i) x_t^{\alpha} \ell_u^{1-\alpha}. \tag{4.6}$$

Since the profit for a variety is increasing in its efficiency in the production of the final good, intermediate good producers have an incentive to invest in the augmentation of $A_t(i)$. In the following subsection, I describe the evolution of the productivity term $A_t(i)$ as a function of skilled labor employed in the process.

4.2.2 Technology Dynamics

The evolution of the technology motivated by the technology adoption model of Nelson and Phelps (1966). At each period, there is a world stock of ideas of size T_t.[8] This stock exogenously grows at a constant rate $\lambda > 0$,

$$\dot{T}_t \;=\; \lambda\, T_t. \tag{4.7}$$

For each firm, however, the growth rate of $A_t(i)$ depends on the number of skilled labor employed and the current distance to T_t. When the firm hires $\ell_{s,t}(i)$ measure of skilled

[8] Nelson and Phelps refer to T_t as 'theoretical level of technology' and to A_t as 'technology in practice'.

labor, its technology evolves according to

$$\dot{A}_t(i) \;=\; \ell_{s,t}^{\beta}(i)\left(\frac{T_t}{A_t(i)}\right)^{\eta} A_t(i). \tag{4.8}$$

The functional form reflects the two mechanisms affecting the evolution of productivity. The first mechanism is automatic diffusion from the frontier given by the term T/A. The bigger the gap to the frontier, the higher is the speed of the productivity increase. The second mechanism is the employment of skilled labor by a firm. The following restrictions on the two technology adoption parameters (β, η) guarantee that the firm problem of optimal skilled labor choice has a solution:

$$\beta \;\in\; (0,1), \tag{4.9}$$

and

$$\eta \;\in\; [\beta, 1]. \tag{4.10}$$

For the rest of the analysis, I restrict attention to the symmetric case where a representative intermediate good-producing firm with average productivity A_t is given by:

$$A_t = \frac{1}{M_t}\int_0^{M_t} A_t(i)\; di.$$

By symmetry, the representative firm employs skilled labor of measure

$$\ell_{s,t} \;=\; \frac{sL_t}{M_t} \;=\; s. \tag{4.11}$$

Using (4.2) and (4.11) in (4.8), the law of motion for technology is given by the function

$$\dot{A}_t \;=\; s^{\beta}\left(\frac{T_t}{A_t}\right)^{\eta} A_t, \tag{4.12}$$

which has the limit property

$$\lim_{t\to\infty}\frac{A_t}{T_t} \;=\; \left(\frac{s^{\beta}}{\lambda}\right)^{\frac{1}{\eta}}. \tag{4.13}$$

The share of skilled labor in employment, s, has a level effect on the distance to the frontier

and on output.

Having introduced the static profit maximization and the adoption technology, we can now define the firms' dynamic problem. The discount rate used by the firm is equal to the interest rate r_t in the bond market. Let $w_{s,t}$ be the wage rate for skilled labor. Firms rent capital and hire skilled labor by rationally anticipating the future path $\{R_t, w_{s,t}, r_t\}_{t=0}^{\infty}$ of factor prices and the interest rate. Since they face a downward-sloping demand curve, they earn strictly positive rents given by $\pi_t = A_t x_t^{\alpha} \ell_u^{1-\alpha}$. Skilled labor is paid out of this rent and the expenditure $w_{s,t}\ell_{s,t}$ can be considered as a technology adoption investment. The net profit after all factor payments is distributed as dividends and is given by:

$$\Pi_t \;=\; A_t x_t^{\alpha} \ell_u^{1-\alpha} - w_{s,t}\ell_{s,t}.$$

Starting with an initial technology level A_0, the representative firm's problem is to choose factor demands $\{k_t, \ell_{s,t}\}_{t=0}^{\infty}$ in order to maximize the discounted sum of dividends,

$$V(A_0) \;=\; \max \int_{t=0}^{\infty} e^{-\bar{r}(t)\cdot t}\, \Pi_t \, dt, \tag{4.14}$$

subject (4.4), (4.7), (4.8), (4.12) and the average interest rate between times 0 and t is defined as $\bar{r}(t) = (1/t) \cdot \int_0^t r_v \; dv$. As discussed in Appendix C, dividends are positive in steady state.

Total dividends, $D_t = M_t \Pi_t$, are collected by the households who own the firms. Next, I turn to the description of the household problem.

4.2.3 Households

The representative household is composed of two types of members: skilled and unskilled. I assume that the fraction of skilled members, s, is exogenously given. The representative household is endowed with $(1-s)uL_t$ units of efficiency units of unskilled labor and sL_t units of skilled labor. Both types of labor are supplied inelastically.

The representative household owns physical capital K_t which depreciates by a rate of δ. It accumulates capital by investing $(1+\theta)\mathrm{N_t}$ out of its budget. The term θ is the time-

invariant tax/subsidy rate that the government implements on purchases of investment goods. Households' capital stock evolves according to

$$\dot{K}_t \;=\; \mathrm{N_t} - \delta K_t. \tag{4.15}$$

Households are also endowed with equal shares of the representative intermediate good producer denoted by a_t. These shares can be traded any period at post-dividend share prices given by q_t. There is a market for bonds with one period maturity where households can borrow and lend by the market interest rate r_t. Bond holdings are given by b_t.

Let C_t denote the total consumption of the household. The budget constraint is given by

$$C_t + (1+\theta)\mathrm{N_t} + q_t \cdot S_t + B_t = w_{s,t} s L_t + w_{u,t}(1-s) u L_t + R_t \cdot K_t + D_t \cdot a_t + (1+r_t) b_t + Z_t, \tag{4.16}$$

where S_t is purchase of new shares, B_t is purchase of new bonds, Z_t is tax rebates (or lump-sum taxation) and a_t is fraction of intermediate firm equity owned by the household. The law of motion for a_t and b_t are given by

$$\dot{a}_t \;=\; S_t. \tag{4.17}$$

and

$$\dot{b}_t \;=\; B_t. \tag{4.18}$$

Household members only value consumption. Members equally split the total consumption C_t. Momentary utility of a member is given by

$$u(C_t/L_t) = \ln(C_t/L_t). \tag{4.19}$$

The future path of dividends and tax rebates, $\{D_t, Z_t\}_{t=0}^{\infty}$, as well as that of prices, $\{q_t, R_t, w_{u,t}, w_{s,t}\}_{t=0}^{\infty}$, are taken as given by the household. The problem faced by the representative household with initial endowments (a_0, b_0, K_0) is then to make consumption and investment decisions

$\{C_t, \mathrm{N_t}\}_{t=0}^{\infty}$, and asset trades $\{S_t, B_t\}_{t=0}^{\infty}$ to maximize the discounted sum of utility,

$$U(a_0, b_0, K_0) = \max \int_0^{\infty} e^{-\rho \cdot t} \, L_t \, u(C_t/L_t) \, dt, \tag{4.20}$$

$$= \max \int_0^{\infty} e^{-(\rho - g_\ell)t} \, \ln(C_t/L_t) \, dt. \tag{4.21}$$

subject to the constraints (4.15), (4.16), (4.17) and (4.18) under the assumption $\rho > g_\ell$.

Finally, the government implements the tax-subsidy policy $(\theta, \{Z_t\})$ with a balanced budget:

$$\theta \mathrm{N_t} = Z_t. \tag{4.22}$$

4.2.4 Equilibrium

An equilibrium for this economy is a tax rate θ and sequence of government rebates $\{Z_t\}_{t=0}^{\infty}$, a set of prices $\{p_t, w_{s,t}, w_{u,t}, R_t, r_t, q_t\}_{t=0}^{\infty}$, a final good producer with factor demands $\{L_{u,t}, x_t\}_{t=0}^{\infty}$, intermediate good producers of measure M_t with factor demands $\{k_t, \ell_{s,t}\}_{t=0}^{\infty}$, identical households of measure one who own capital stock $\{K_t\}_{t=0}^{\infty}$, labor endowments $\{sL_t, (1-s)uL_t\}_{t=0}^{\infty}$ and undertake sequences of asset trades $\{S_t, B_t\}_{t=0}^{\infty}$, consumption and investment decisions $\{C_t, \mathrm{N_t}\}_{t=0}^{\infty}$, such that

1. given $\{w_{u,t}, p_t\}_{t=0}^{\infty}$, the representative final good producer demands the input bundle $\{L_{u,t}, x_t\}_{t=0}^{\infty}$ that minimizes its costs,

2. given $\{w_{s,t}, R_t, r_t\}_{t=0}^{\infty}$, factor demands $\{k_t, \ell_{s,t}\}_{t=0}^{\infty}$ solve the representative intermediate good producer's problem,

3. given $\{D_t, Z_t, q_t, R_t, r_t, w_{u,t}, w_{s,t}\}_{t=0}^{\infty}$, consumption, investment, and asset trade decisions $\{C_t, \mathrm{N_t}, S_t, B_t\}_{t=0}^{\infty}$ solve the representative household problem, yielding a capital supply of $\{K_t\}_{t=0}^{\infty}$,

4. capital market clears: for all t, $k_t M_t = K_t$,

5. labor markets clear: for all t, $\ell_{s,t} M_t = sL_t$ and $\ell_{u,t} M_t = (1-s)uL_t$,

6. asset and bond markets clear with no trade since all households are identical: for all t we have $S(t) = 0$ and $B(t) = 0$,

7. the intermediate goods market clears: the demand for x_t by the final good producers is met by its supply,

8. the final good market clears: for all t, we have $Y_t = C_t + \mathrm{N_t}$,

9. government's budget is balanced: for all t, we have $\theta \mathrm{N_t} = Z_t$.

4.2.5 Aggregation and the Steady State

I first aggregate the variables of interest generated by the model and then analyze their steady state properties. The existence of a steady state equilibrium is shown at the Appendix C.

I have shown that all intermediate good producers supply an equal amount of x_t. The final good producer employs ℓ_u unskilled workers per intermediate good. Aggregating (4.3) over i, aggregate output is equal to:

$$Y_t = \frac{x_t^{\alpha} \ell_u^{1-\alpha}}{\alpha(1-\alpha)} \int_0^{M_t} A_t(i)\, di. \tag{4.23}$$

Aggregating the capital demand $k_t(i) = A_t(i)x_t$ over i, and using the capital market clearance condition $\int_0^{M_t} k_t(i)\, di = K_t$, one obtains:

$$x_t = \frac{K_t}{M_t A_t}.$$

And by labor market clearance, we have

$$\ell_u = (1-s)u\frac{L_t}{M_t} = (1-s)u.$$

Using these expressions in (4.23), and recognizing that $\int_0^{M_t} A_t(i)\, di = M_t A_t$, aggregate output is:

$$Y_t = \nu \cdot [(1-s)u]^{1-\alpha} \cdot K_t^{\alpha} \cdot (A_t L_t)^{1-\alpha}. \tag{4.24}$$

where $\nu = \frac{1}{\alpha(1-\alpha)}$ is a re-scaling constant which I drop for the remainder of the paper. The aggregate output of this economy displays constant returns to scale with labor-augmenting technological change.

Capital-output ratio in steady state is constant and it is a function of taste, technology and distortion parameters. As expected, it is decreasing in the level of distortions:

$$\frac{K}{Y} = \frac{\alpha^2}{(r_{ss} + \delta)(1 + \theta)}. \tag{4.25}$$

In order to analyze the implications of the model on per-capita income, I transform variables into their stationary counterparts. I start with the TFP term. Revoking (4.13), the steady state limiting gap between the frontier and a country's productivity is a function of its skilled labor fraction. With a little abuse of notation in skipping the limit expression, this gap is given by:

$$g(s) \;=\; \frac{A}{T} \;=\; \lambda^{-\frac{1}{\eta}}\, s^{\frac{\beta}{\eta}}.$$

Comparative statics with respect to (s, λ) are intuitive. Relative technology is increasing in s since a higher skilled labor supply facilitates technology adoption form the frontier. It is decreasing in the growth rate λ since a rapidly expanding frontier makes catch-up harder.

Let $\tilde{y} = Y_t/(L_t T_t)$ denote normalized aggregate output per effective worker. Substituting (4.25) into (4.23) and re-arranging terms, per-capita stationary income is equal to:

$$\tilde{y}_{ss} = g(s) \cdot (1 - s) \cdot u \cdot \left[\frac{\alpha^2}{(r_{ss} + \delta)(1 + \theta)}\right]^{\frac{\alpha}{1-\alpha}}. \tag{4.26}$$

The non-substitutability of the two types of labor causes per-capita income to display an inverse-U shaped relationship with s. Although $g(s)$ is increasing, it is bounded by one. As s increases, there are not enough unskilled workers to undertake production tasks and this leads to a decline after a certain level of s^* where $\tilde{y}_{ss}$ is maximized. Alternatively, as u increases, the range of s over which per-capita income is decreasing narrows. In other words, an economy with an increasing share of skilled labor in the workforce can escape a decline in per-capita income by increasing the efficiency of its unskilled labor.

In steady state, technology level A_t grows at a stationary rate equal to λ, which is also

the growth rate of per-capita quantities. The interest rate and rental rate of capital are constant:

$$r_{ss} = \rho + \lambda, \tag{4.27}$$

$$R_{ss} = (r_{ss} + \delta)(1 + \theta). \tag{4.28}$$

The rental rate of capital is increasing in investment distortions which tend to make capital more costly.

Finally, I present the wage premium of the skilled over efficiency units of unskilled labor,

$$\frac{\tilde{w}_s}{\tilde{w}_u} = \frac{\alpha\beta\lambda}{\eta\lambda + \rho} \; \frac{(1-s)}{s} \; u. \tag{4.29}$$

As expected, the wage premium is decreasing in s and increasing in u. A faster rate of growth in the frontier, reflected by a higher λ, leads to an increase in the wage premium, a similar result to Greenwood and Yorukoglu (1997). This result is quite intuitive. If the frontier expands at a faster rate, there is a greater stock of knowledge to adopt and the marginal product of skilled labor increases. A higher discount rate ρ, on the other hand, increases the interest rate which depresses the wage premium since hiring skilled labor is like an investment in technology.

The model generates predictions for the income level and the wage premium in equations (4.26) and (4.29) respectively. Next, I undertake a quantitative exercise to evaluate whether the model can simultaneously account for cross-country and within-country income differences.

4.3 Quantitative Implications of the Model

In order to bring the model to data, I have to define and measure skilled labor in the most pertinent way. The technological frontier defines what type of formal or informal training makes a worker skilled. In the pre-industrial period, skilled craftsman were trained on-the-job through the apprenticeship system. The industrial revolution made the skills of these workers obsolete and created a new set of knowledge necessary to be considered skilled. In

the second half of the 20th century, college education became the channel of skill acquisition. In the following exercise, I measure skilled labor as scientists and engineers (S&E) with a college degree.

The reason I restrict attention to be S&E degrees is that not all university majors are equally relevant for technology adoption activities. Murphy et.al. (1991) report a positive relationship between the share of engineering majors in university enrollment and growth performance of countries. Enrollment in law, on the other hand, has a negative impact on growth.[9]

I choose 1985 as the year of analysis because the college enrollment in the US was relatively stationary around 25% between 1965-1980. [10]

4.3.1 Calibration

I calibrate the set of parameters $(\alpha, \delta, \lambda, \rho, \beta, \eta)$ by matching some key statistics of the US data to the steady state characteristics of the model and the evidence on the rate of convergence to the steady state.

The growth rate of per worker output in the model, λ, is set equal to 0.02 to match the average growth rate of real GDP per equivalent adult in the US between 1950-1985. Using this value, I set $\rho = 0.02$ to match an average real interest rate of $r_{ss} = 4\%$ in (4.27).

The depreciation rate δ and the production function parameter α are calibrated to the US investment rate N/Y and the capital-output ratio K/Y. The law of motion for capital implies that $\delta = N/K - \lambda$. The investment rate and capital-output ratio (based on yearly output) in the US are roughly 0.2 and 2.5 respectively. This implies $N/K = 0.2/2.5 = 0.08$, and $\delta = 0.06$. Finally, α is calibrated to match the capital-output ratio, given by expression (4.25), to its US value of 2.5 which yields $\alpha = 0.5$.

The parameters of the technology adoption function, (β, η), are pinned down by the implied rate of convergence to the steady state and the wage premium. In Appendix C,

[9] Murphy et.al. (1991) consider engineering and law majors as proxies for entrepreneurship versus rent-seeking. For the purpose of this paper, their empirical evidence shows that not all college degrees are the same from a growth perspective.

[10] Data from Current Population Survey, Historical Tables A-5a. Available in http://www.census.gov/population/www/socdemo/school.html

I show that the rate of convergence is equal to $\eta\lambda$. I set η equal to 1, the upper bound of permissible values for this parameter, to be consistent with the evidence of a rate convergence rate around 0.02 reported by Barro and Sala-i Martin (2004). Finally, I use the wage premium expression (4.29) and the US values for (s, u, θ) to pin down β.[11] Table 1 summarizes the parameter values.

How does the assumption of no substitutability between the two types of human capital affect the calibration of β? It is more likely that skilled workers can substitute the unskilled but not the other way. In such a case, the equilibrium wages of both types will be equal if there are skilled workers in unskilled jobs. As long as all skilled workers are employed at technology adoption tasks, both types will be paid their marginal contribution and the wage premium expression above will hold. Also, given the measured (u, s) levels, all countries fall into the range where where per-capita income is increasing is increasing in s.

The calibrated value of α equal to 0.5 is higher than the commonly used value of 1/3. Note that although the model delivers the same aggregate production function (4.23) as the neoclassical model, its micro-foundations are quite different. Similarly high values for α are found to be consistent with the evidence on convergence rates in Howitt (2000). On the other hand, high α values amplify the effects of investment distortions given by θ differences. Restuccia and Urritia (2001) show that a value for the capital share around 5/6 is needed so that the neoclassical model can explain income differences through observed investment distortions. This, however, implies a convergence rate too slow given the evidence. The model presented here is flexible enough to calibrate α to the capital-output ratio without being inconsistent with the evidence on the convergence rate.

4.3.2 Cross-Country Income Differences

In this section, I investigate whether the model can account for the cross-country income differences seen in the data. [12] I assume that the parameter values for $(\alpha, \delta, \lambda, \rho, \beta, \eta)$ are

[11] Scientist and engineers as a share of total US labor force is computed as 3.7% in 1985. According to Heston et. al. (2006), the average relative price level of investment over that of consumption in US between 1950-1985 is one. In the one-sector model presented here, this ratio corresponds to $1 + \theta_{us}$ which yields $\theta_{us} = 0$. Details about the computation of u and s can be found in Appendix C.

[12] Caselli (2005) provides a survey of the success of various models in that regard.

common across economies. I use the steady state income expression (4.26) and the observed variation in (s, u, θ) to derive the cross-country relative income predicted by the model for 1985. I choose the US as the benchmark country and compare the model-generated relative incomes,

$$\frac{\tilde{y}_i}{\tilde{y}_{us}} = \frac{1-s_i}{1-s_{us}} \cdot \left(\frac{s_i}{s_{us}}\right)^{\frac{\beta}{\eta}} \cdot \frac{u_i}{u_{us}} \cdot \left(\frac{1+\theta_{us}}{1+\theta_i}\right)^{\frac{\alpha}{1-\alpha}} \tag{4.30}$$

with the observed ones. Data about relative price of investment and income are from Heston et.al (2006). The former is computed by taking the average price level of investment over that of consumption for the period 1950-1985. Observed income is real GDP per worker for the same year. I have a sample of 58 market economies countries with complete data.

I also calculate the results for two counterfactual experiments: In the first experiment, the stock of skilled labor is assumed to be the same across countries, so the income variations come from u and θ. In the second experiment, the level of distortions are assumed to be the same, and the income variation originates from differences in u and s. These are reported as the "distortion-only model" and "no-distortion model" respectively. Figure 1 and Tables 2-4 summarize the results.

In general, the benchmark and the no-distortion models do a better job than the distortion-only model in matching key moments of data. They match the median accurately and underestimate the mean income level. Even at the relatively high value of the capital share, the distortion-only model overestimates both the mean and median income levels.

Table 2 documents the Pearson's correlation coefficient and rank correlations between the model-generated income levels with the data. Evidently, the no-distortion model does a better job than the distortion-only model in fitting the data in all three measures. The benchmark model further improves the fit because distortions are negatively correlated with skilled labor endowments.

Table 4 reports income levels at various percentiles. The no-distortion model captures the variation up to the 80th percentile better than the distortion-only model. The distortion-only model generates income levels consistently higher than in the data for the $10th$, $20th$, $40th$ and $60th$ percentiles, but matches data quite well for the $80th$ and $90th$ percentiles.

The benchmark model accurately predicts income levels of the poorest countries at the bottom of the distribution ($10th$ and $20th$ percentiles), does a satisfactory job at intermediate ranges ($40th$ and $60th$ percentiles) but its predictions are lower than the data at higher levels of income. In other words, according to the model, developed countries in general have too few scientists and engineers in the workforce to explain their relative income levels vis-à-vis the US.

This last point relates to the literature in the following way. Klenow and Rodríguez-Clare (2005) construct and calibrate a similar model with international diffusion and externalities. They measure technology adoption effort through R&D investment. Quantitatively, they obtain the opposite results. Productivity (and thus income) levels of rich countries are accurately predicted but poor countries have too little R&D investment to be consistent with their levels of development. They suggest that the 'true' research intensities are higher than the observed ones, and that informal research could be potentially important in non-OECD countries. [13] The contribution of my paper is to capture this unobserved technology adoption effort through the measurement of the type of workers who are likely to be engaged in technology related activities regardless of whether they are employed in a formal R&D department or not. Of course, human capital is not the only input into the technology adoption process. Real resources such as labs and equipment are used as well. The model, however, does not take them into account and is thus unable to explain higher income levels. A more elaborate model which includes both types of inputs is likely to explain the data better.

4.3.3 Within-Country Income Differences

I have disciplined the parameters of the model to be consistent with the US wage premium on skilled labor and used these values in the development accounting exercise above. In this section, I investigate whether the same parameter values, together with the observable variation in (s, u), can explain within-country income differences as well.

Empirical wage premia are obtained using the cross-country rates of return education

[13] Córdoba and Ripoll (2007) obtain a similar result using an alternative model.

reported by Psacharopoulos (1994). The measurement of the wage premium is not based on a Mincerian approach because the rental rate of the two types of human capital are different. In the Mincer approach, human capital is measured in efficiency units and more educated workers are simply more efficient in performing the same task. In my model, the two types of human capital perform separate tasks and are paid different rental rates. I employ the method described in Psacharopoulos (1995) to back out the wage premia using the reported rates of return to education. Detailed description of the data is provided in Appendix C.

I report all wage premia in logs. The sub-sample for which data is available consists of 44 countries. The sample mean and standard deviation are 2.99 and 1.53 respectively. The US value used in calibration is 1.82. Using expression (4.29), I generate wage premia predictions for the sub-sample of countries. Figure 2 plots these predictions against the data.[14]

Both Pearson's product moment and Spearman's rank correlation coefficients between model predicted values (in logs) with the data are 0.43 in the full sample and 0.48 when the three outliers are removed. Recovering the general slope of the distribution as it is evident in Figure 2 could be considered a success considering potential measurement problems in the data. The model does not systematically under- or overestimate the wage premia across countries. Given that the values are in logs, there is a non-negligible absolute error for some countries such as Jamaica, Kenya, Pakistan and Taiwan. Most of the countries, however, are aligned around the 45° degree line. A total of 8 countries out of 41 (after excluding the outliers in the data) are predicted within 10% error margin, and 22 countries are within a 20% error margin.

In a recent contribution, Caselli and Coleman (2006) use country-specific wage premia to pin down unobserved productivity levels of skilled and unskilled labor and analyze whether these 'calibrated' productivity differences can explain income differences. The quantitative approach here differs from theirs in that it uses one observation (US wage premium) to discipline the relevant structural parameter, and resorts to observable variables only to

[14]Three outliers in the data - Portugal, Botswana and the Dominican Republic - are dropped from the sample presented in the figure.

generate predictions on cross- and within-country income differences.

4.4 Conclusion

What is the exact role of human capital in development? To answer that question, I propose a growth model in which firms employ skilled workers in order to augment their productivity by adopting technologies from a freely available stock of knowledge in the frontier. The variation in the skilled labor share leads to income differences between countries. The idea that human capital facilitates technology adoption goes back to Nelson and Phelps (1966). The first contribution I make is to build a general equilibrium model around it.

In the quantitative part, I calibrate model parameters to match some key statistics of the US data and measure skilled labor as scientist and engineers. The second contribution of the model is in that it successfully accounts for cross-country income differences, especially at the lower end of the sample. The main departure from the related quantitative literature is the idea that technology diffusion not only takes place through formal R&D, but through the employment of skilled labor in general. Quantitatively, this channel seems to be relevant for countries up to the $60th$ percentile of the global income distribution. Previous research by Klenow and Rodríguez-Clare (2005) suggests that measured differences in formal R&D expenditures across countries is able to explain top two income quantiles in a similar model with technology diffusion. A synthesis of the two models can potentially fit the whole distribution more satisfactorily.

The model also predicts within-country income differences between skilled and unskilled workers. When confronted with data, the model fits the wage premia of a subset of countries with some success. The third contribution of the model is that both cross- and within country income differences can be simultaneously accounted for using the same calibrated parameter values and variation in observable variables.

The implications of the results are twofold. First, the notion put forward by Nelson and Phelps (1966), that human capital contributes to the production process in a different way than direct inputs by being a facilitator of technology adoption seems to be quantitatively relevant. Second, some types of human capital which we denote as 'skilled' are more suitable

to perform the technology adoption activities than others. Given the difference in tasks, it is a misspecification to aggregate all types of human capital into one single stock as it is done in most development accounting exercises. Models with disaggregated human capital, where the specific role played by each type is carefully considered (beyond simple capital-skills complementarity), could substantially improve our understanding of development.

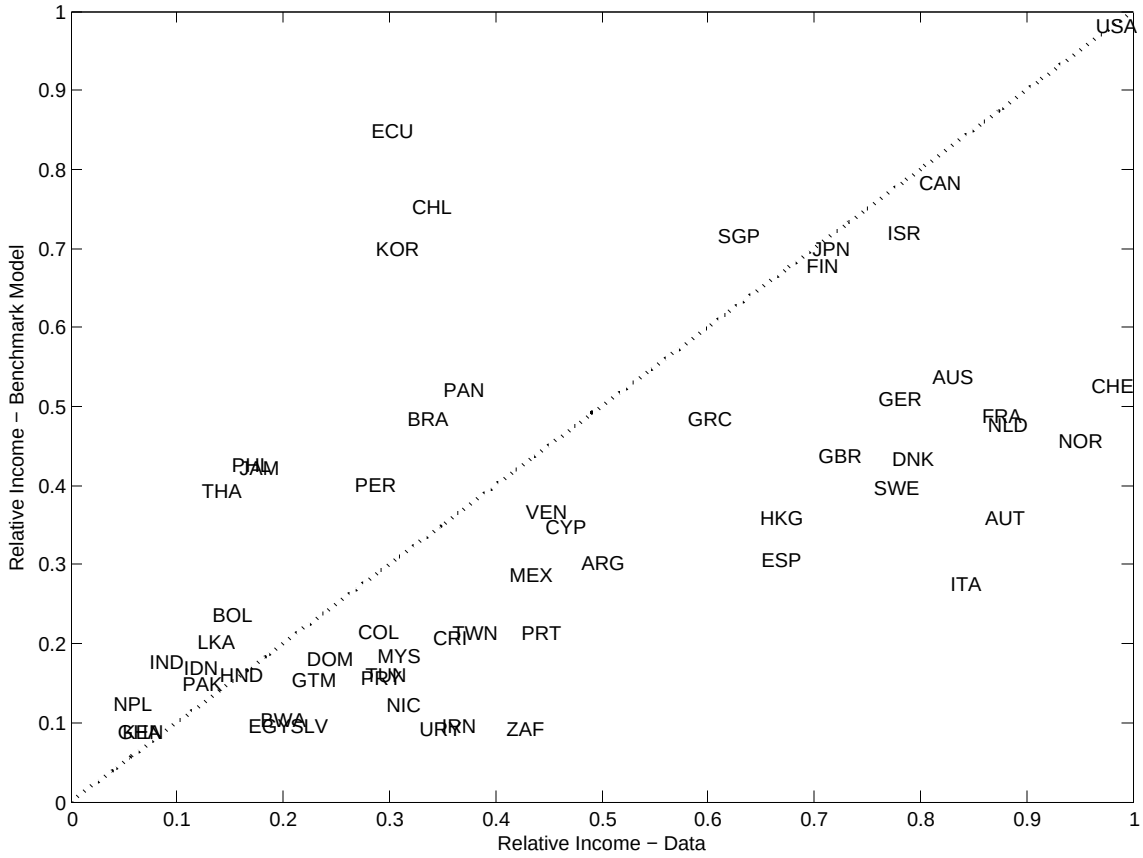

Figure 4.1: Relative Incomes, Benchmark Model vs. Data

Parameter	Target	Value
α	Capital-output ratio	0.5
δ	Investment rate/capital-output ratio	0.06
λ	US per worker growth rate	0.02
ρ	Real interest rate $(= \rho + \lambda)$	0.02
η	Speed of convergence to steady state $(= \eta\lambda)$	1
β	US wage premium	0.30

Table 4.1: Calibrated Parameters

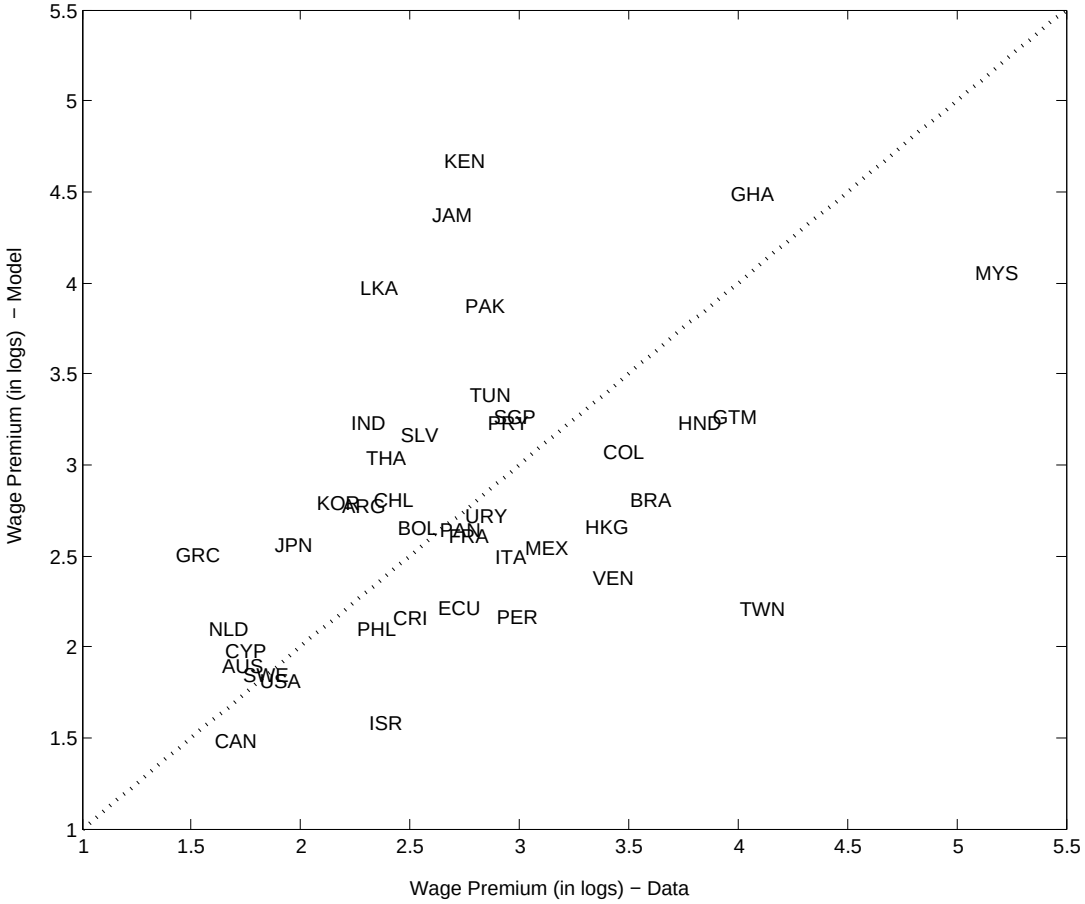

Figure 4.2: Wage Premia, Model vs. Data (in logs)

Statistic	Data	Benchmark Model	Distortion-only Model	No-distortion Model
Mean	0.43	0.36	0.52	0.36
St. Dev.	0.28	0.23	0.26	0.17
Median	0.35	0.33	0.47	0.34
Min.	0.04	0.09	0.11	0.14

Table 4.2: Key Development Accounting Statistics

Statistic	Benchmark Model	Distortion-only Model	No-distortion Model
Pearson's r	0.60	0.46	0.54
Spearman's rho	0.62	0.51	0.58
Kendall's tau	0.44	0.35	0.43

Table 4.3: Correlations of Predicted Incomes with the Data

Percentile	Data	Benchmark Model	Distortion-only Model	No-distortion Model
10th	0.11	0.10	0.22	0.18
20th	0.16	0.16	0.28	0.22
40th	0.29	0.22	0.43	0.32
60th	0.43	0.40	0.54	0.37
80th	0.76	0.52	0.76	0.47
90th	0.85	0.72	0.86	0.58

Table 4.4: Relative Incomes at Various Percentiles

Bibliography

Barro R.J, Lee J. International Data on Educational Attainment: updates and implications. Oxford Economic Papers 2001;3; 541-563.

Barro R.J, Sala-i Martin X. Economic Growth. The MIT Press: Cambridge; 2004.

Barro R.J, Sala-i Martin X. Technological Diffusion, Convergence, and Growth. Journal of Economic Growth 1997;2; 1-26.

Benhabib, J, Spiegel M.M. The Role of Human Capital in Economic Development Evidence from Aggregate Cross-country Data. Journal of Monetary Economics 1994;34; 143-173.

Benhabib J, Spiegel M.M. 2005. Human Capital and Technology Diffusion. In Aghion P, Durlauf S (Eds), Handbook of Economic Growth, North Holland: Amsterdam; 2005.

Caselli F, 2005. Accounting for cross-country income differences. In Aghion P, Durlauf S (Eds), Handbook of Economic Growth, North Holland: Amsterdam; 2005.

Caselli F, Coleman W.J.II. Cross-Country Technology Diffusion: The Case of Computers. American Economic Review 2001;91:2; 328-335.

Caselli F., Coleman W.J.II. The World Technology Frontier. American Economic Review 2006;96:3; 499-522.

Caselli F, Wilson D.J. Importing Technology. Journal of Monetary Economics 2004;51; 1-32.

Córdoba J.C, Ripoll M. Endogenous TFP and Cross-Country Income Differences. Journal of Monetary Economics 2007;55; 1158-1170.

Doms M, Dunne T, Troske K.R. Workers, Wages, and Technology. The Quarterly Journal of Economics 1997;112:1; 253-290.

Eaton J, Kortum S. International Technology Diffusion: Theory and Measurement. International Economic Review 1999;40:3; 537-570.

Erosa A, Koreshkova T, Restuccia D. How Important is Human Capital? A Quantitative Theory Assessment of World Income Inequality. Review of Economic Studies 2010:01; 1-32.

Foster A.D, Rosenzweig M.R. Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. The Journal of Political Economy 1995;103:6; 1176-1209.

Gordon R.J, Reflections on Pin Factory Visits. In Industrial Technology and Productivity: Incorporating Learning from Plant Visits and Interviews into Economic Research - NBER/Sloan Project Report, papers presented at the Annual Meetings of the American Economic Association, January, 2000. MA:Cambridge; 2000.

Greenwood J, Yorukoglu M. 1974. Carnegie-Rochester Conference Series on Public Policy 1997;46; 49-95.

Griffith R, Redding S, Van Reenen J. Mapping the two Faces of R&D: Productivity Growth in a Panel of OECD Countries. The Review of Economics and Statistics 2004;86:4; 883-895.

Grogger J, Eide E. Changes in College Skills and the Rise in the College Wage Premium. The Journal of Human Resources 1995;30:2; 280-310.

Heston A, Summers R, Aten B. Penn World Table Version 6.2, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006.

Howitt P. Endogenous Growth and Cross-Country Income Differences. American Economic Review 2000;90:4; 829-846.

Keller W. International Technology Diffusion. Journal of Economic Literature 2004;42; 752-782.

Klenow P.J, Rodríguez-Clare A. Externalities and Growth. In Aghion P, Durlauf S

(Eds), Handbook of Economic Growth, North Holland: Amsterdam; 2005.

Manuelli R, Seshadri A. Human Capital and the Wealth of Nations. University of Wisconsin Department of Economics Working Paper. 2005 June.

Murphy K.M, Shleifer A, Vishny R.W. The Allocation of Talent: Implications for Growth. The Quarterly Journal of Economics 1991;106:2; 503-530.

Nelson R.R, Phelps E.S. Investment in Humans, Technological Diffusion, and Economic Growth. The American Economic Review 1966;56; 69-75.

Papageorgiou C. Distinguishing Between the Effects of Primary and Post-Primary Education on Economic Growth. Review of Development Economics 2003;7:4; 622-635.

Parente S.L, Prescott E.C. Barriers to Technology Adoption and Development. The Journal of Political Economy 1994;102:2; 298-321.

Psacharopoulos G. Returns to Investment in Education: A Global Update. World Development 1994;22:9; 1325-1343.

Psacharopoulos G. The Profitability of Investment in Education: Concepts and Methods. The World Bank, Human Capital Development and Operations Policy, Working Papers 1995.

Restuccia D, Urrutia C. Relative Prices and Investment Rates. Journal of Monetary Economics 2001;47; 93-121.

Romer P. Endogenous Technological Change. Journal of Political Economicy 1990;98; 71-102.

UNESCO, Higher Education: International Trends 1960-1970. The Unesco Press: Paris; 1975.

Xu B. Multinational Enterprises, Technology diffusion, and Host Country Productivity Growth. Journal of Development Economics 2000;62; 477-493.

Appendix A

A.1 Value Functions for the Outside Options

A.1.1 Value of Unemployment to the Worker

All workers own balanced portfolios of firms and receive a dividend payment of d_t units of the final good at any period. The value of unemployment ($\ell = \ell_u$) for an old worker is:

$$\begin{aligned} W_t(\ell_u, h_t, o) \;=\; p_{Yt} d_t + \beta(1-\delta_m)\Bigg[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, o) f_z(z) dz \\ + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, o) \Bigg] \end{aligned} \tag{A.1}$$

For a young worker:

$$\begin{aligned} W_t(\ell_u, h_t, y) \;&= p_{Yt} d_t + \beta(1-\delta_a)\Bigg[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, y) f_z(z) dz \\ &\qquad + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, y) \Bigg] \\ &\quad + \beta\delta_a \Bigg[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, o) f_z(z) dz \\ &\qquad + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, o) \Bigg] \end{aligned} \tag{A.2}$$

A.1.2 Value of Being Idle to the Firm

The value function of an idle firm before drawing the vacancy posting costs for period t depends, among other things, on the average expected costs conditional on successful entry, $(\hat{c}_{1t}, \hat{c}_{2t})$. These are defined as:

$$\hat{c}_{it} \;=\; \int_{\mathbb{R}_+}\int_{\mathbb{R}_+} c_i\, \mathcal{I}^{v}_{it}(c_i, c_j) dF(c_i) dF_c(c_j). \tag{A.3}$$

Given the expected value of jobs conditional on matching (EJ_{1t+1}, EJ_{2t+1}), and entry probabilities $(\tilde{\mu}_{1t}, \tilde{\mu}_{2t})$,

$$J_t(m_u) \;=\; \sum_{i=1}^{2} \tilde{\mu}_{it}\Big\{\phi_{ft}\beta EJ_{it+1} \,+\, (1-\phi_{ft})\beta J_{t+1}(m_u) - p_{Yt}\hat{c}_{it}\Big\} \,+\, (1-\tilde{\mu}_{1t}-\tilde{\mu}_{2t})\beta J_{t+1}(m_u). \tag{A.4}$$

Note that the values of all potential outcomes are discounted since it takes one period for new matches to be effective. The large parenthesis represents the expected value of vacancy posting. The last term represents the case in which the firm does not enter at all.

A.2 Transition Function for the Distribution

Define a probability function $\Gamma_t : \mathcal{S}_w \times \mathcal{S}_w \to [0,1]$ such that $\Gamma_t(s_w, s'_w)$ is the probability of a worker in state s_w to be in state s'_w next period. Note that the state variable s_w is a vector (ℓ, h, g) which summarizes the labor market state, human capital stock and the generation of a worker. If the worker is matched in sector i with productivity z, it has the form $(\ell_i(z), h, g)$. A generic element for an unemployed worker is (ℓ_u, h, g).

Some transitions are infeasible in this environment. For example, an old worker with (ℓ, h) can not become a young worker with $h' \geq h$. On the other hand, old workers are replaced by young workers when they die, so a transition from (ℓ, h, o) to $(\ell_u, \underline{h}, y)$ is feasible. In order to characterize feasible transitions, let $h'(h)$ denote human capital stock attained from h according to the law of motion (2.7). Noting that $F_z(\cdot)$ is the distribution function for match specific productivity draws with the density $f_z(z)$, Γ_t is defined as follows:

$$
\Gamma_t(s_w, s_w^{'}) \;=\; \begin{cases}
(1-\delta_m)\big\{(1-\phi_{wt}) + \sum_i \phi_{w_{it}} F_z[\tilde{z}_{it}(h'(h), o)]\big\} & \text{if } s_w = (\ell_u, h, o) \text{ and } s_w' = (\ell_u, h'(h), o), \\
(1-\delta_m)\phi_{w_{it}} f_z(z) \mathcal{I}^a_{it+1}(z, h'(h), o) & \text{if } s_w = (\ell_u, h, o) \text{ and } s_w' = (\ell_i(z), h'(h), o), \\
\delta_m & \text{if } s_w = (\ell, h, o) \text{ and } s_w' = (\ell_u, \underline{h}, y), \\
(1-\delta_m)(1-\delta^o_{JD}) \mathcal{I}^a_{it+1}(z, h'(h), o) & \text{if } s_w = (\ell_i(z), h, o)) \text{ and } s_w' = (\ell_i(z), h'(h), o), \\
(1-\delta_m)\delta^o_{JD} & \text{if } s_w = (\ell_i(z), h, o) \text{ and } s_w' = (\ell_u, h'(h), o), \\
(1-\delta_a)(1-\delta^y_{JD}) \mathcal{I}^a_{it+1}(z, h'(h), y) & \text{if } s_w = (\ell_i(z), h, y) \text{ and } s_w' = (\ell_i(z), h'(h), y), \\
\delta_a(1-\delta^y_{JD}) \mathcal{I}^a_{it+1}(z, h'(h), o) & \text{if } s_w = (\ell_i(z), h, y) \text{ and } s_w' = (\ell_i(z), h'(h), o), \\
(1-\delta_a)\delta^y_{JD} & \text{if } s_w = (\ell_i(z), h, y) \text{ and } s_w' = (\ell_u, h'(h), y), \\
\delta_a \delta^y_{JD} & \text{if } s_w = (\ell_i(z), h, y) \text{ and } s_w' = (\ell_u, h'(h), o), \\
(1-\delta_a)\big\{(1-\phi_{wt}) + \sum_i \phi_{w_{it}} F_z[\tilde{z}_{it}(h'(h), y)]\big\} & \text{if } s_w = (\ell_u, h, y) \text{ and } s_w' = (\ell_u, h'(h), y), \\
\delta_a\big\{(1-\phi_{wt}) + \sum_i \phi_{w_{it}} F_z[\tilde{z}_{it}(h'(h), o)]\big\} & \text{if } s_w = (\ell_u, h, y) \text{ and } s_w' = (\ell_u, h'(h), o), \\
(1-\delta_a)\phi_{w_{it}} f_z(z) \mathcal{I}^a_{it+1}(z, h'(h), y) & \text{if } s_w = (\ell_u, h, y) \text{ and } s_w' = (\ell_i(z), h'(h), y), \\
\delta_a \phi_{w_{it}} f_z(z) \mathcal{I}^a_{it+1}(z, h'(h), o) & \text{if } s_w = (\ell_u, h, y) \text{ and } s_w' = (\ell_i(z), h'(h), o), \\
0 & \text{otherwise.}
\end{cases}
$$

A.3 Numerical Implementation and Solution Algorithm

This section describes the numerical solution to the model, and the algorithms used to compute the steady state equilibrium and the transition path. The software used in computations is 32-bit Matlab R2009a.

A.3.1 The State Space

I use a discrete state space for match-specific productivity z and human capital level h_i. For z, I use 40 equally distanced grid points between $[0, 1]$. I use 200 grid points for h_i. For the case with positive depreciation of skills, I use equally distanced grid points between $[1, H]$ and evaluate out-of-grid points through interpolation. For the benchmark case with no depreciation, I construct the grid points in line with the increments implied by the learning function (2.7).

A.3.2 Steady State Algorithm

Step 1. Start iteration j with a pair of values for entrants' expected values of matching (EJ_1^j, EJ_2^j) in the two sectors.

Step 2. Calculate $(J(m_u), \phi_f, \phi_w, \tilde{\mu}_1, \tilde{\mu}_2)$ by simulating a large number of cost draws for firms from the distribution $F_c(c)$, and using expressions (2.5), (2.6), (2.15), (2.16), (A.4) and the fact that market tightness θ is equal to $\tilde{\mu}_1 + \tilde{\mu}_2$.

Step 3. Solve for the job acceptance cutoffs $\tilde{z}_{it}(h, g)$, and the value functions (2.11) and (2.12) using the following subroutine:

i. Start with old workers. Assume initial set of values for unemployment $W(\ell_u, \cdot, o)$ and matches $\Pi_i(z, \cdot, o)$ for both sectors. Use (2.10) to find the job acceptance cutoffs, and update $\Pi_i(z, \cdot, o)$ using equation (2.8).

ii. To update $W(\ell_u, \cdot, o)$, use the job acceptance cutoffs in (A.1). Iterate until convergence.

iii. Repeat the same steps for young workers, using equation (2.9).

Step 4. Simulate the economy with a large number of workers drawing demographic shocks, labor market shocks (matching and separating), and match-specific productivity terms. Aggregate the cross-sections of workers to find the distribution of workers Ψ.

Step 5. Use the distributions to update (EJ_1^{j+1}, EJ_2^{j+1}) using equation (2.14), iterate until the distances $|EJ_1^{j+1} - EJ_1^j|$, and $|EJ_2^{j+1} - EJ_2^j|$ are sufficiently small.

A.3.3 Transition Algorithm

The algorithm used to solve for the transition between two steady states is similar to Costantini and Melitz (2009). The basic idea is to start with an initial path of aggregate variables, to solve the decision functions backward and to simulate agents' behavior forward according to these decision rules and random shocks. The simulation allows us to update the aggregate variables which are iterated upon until convergence. Importantly, I fix the length of the transition at $N = 400$ periods (equivalent to 100 years) such that at period $t = N+1$,

the terminal steady state is attained. To make sure that this is not too restrictive, I check that the distribution of agents over the state space is sufficiently close to the distribution in the terminal steady state. The following description provides the details.

Step 1. Start iteration j with a path of values for entrants' expected values of matching $\{EJ_{1t}^{j}, EJ_{2t}^{j}\}_{t=1}^{t=N}$ in the two sectors.

Step 2. Calculate $\{J_t(m_u), \phi_{ft}, \phi_{wt}, \tilde{\mu}_{1t}, \tilde{\mu}_{2t}\}_{t=1}^{t=N}$ by using the same cost draws from $F_c(c)$ as in the steady state solution. Again, we use expressions (2.5), (2.6), (2.15), (2.16), (A.4) and the fact that market tightness θ is equal to $\tilde{\mu}_1 + \tilde{\mu}_2$.

Step 3. Starting with $t = N$, solve the job acceptance cutoffs backward, using the value functions specified in Section 2.2.2 and Appendix A.1. Store the value functions of firms $\{J_t[m_i(z, h, g)]\}_{t=1}^{t=N}$.

Step 4. Starting with $t = 1$, simulate the economy forward for a large number of workers using the cutoffs obtained in Step 3, random draws for separations, aging, mortality, matching and match-specific productivity. This is the most computationally intense part of the algorithm which can easily be parallelized on a multi-core hardware using Parallel Computing Toolbox of Matlab.

Step 5. Using the simulated economy, compute $\{\Psi_t(S_w)\}_{t=1}^{t=N}$, the distribution of workers during the transition.

Step 6. Use the distributions $\{\Psi_t(S_w)\}_{t=1}^{t=N}$, and the stored firm values $\{J_t[m_i(z, h, g)]\}_{t=1}^{t=N}$ in equation (2.14) to update $\{EJ_{1t}^{j+1}, EJ_{2t}^{j+1}\}_{t=1}^{t=N}$. Iterate until the maximum of the Euclidean distances $||\{EJ_{it}^{j+1} - EJ_{it}^{j}\}||$ for $i = \{1, 2\}$, and $||\Psi_N(S_w) - \Psi_{ss}(S_w)||$ is sufficiently small. $\Psi_{ss}(S_w)$ is the distribution in the terminal steady state.

For the counterfactual labor market policy experiments, I also iterate over the paths of unemployment insurance benefits $\{b_t\}$ and employment subsidy payments $\{\eta_t\}$. These policy paths are updated by dividing the total revenue obtained by 1% tax on match revenues at each period to the measure of agents eligible for income support.

Appendix B

B.1 Wage Functions

B.1.1 Hiring Wages

In order to characterize wages in hiring firms, we first determine the total surplus for a firm and a worker that are matched in the end-of-period state (z', l'). At the time of bargaining, the surplus that the marginal worker generates for a firm is given by

$$\Pi^{firm}(z', l') = \frac{1}{1+r}\left[\frac{\partial \pi(z', l')}{\partial l'} + \frac{\partial \mathcal{V}(z', l')}{\partial l'}\right].$$

Note that at the time of bargaining, the vacancy posting and matching process are over and the costs of vacancy postings are sunk. As a result, if the bargaining fails, the firm is simply left with less workers. The surplus that a marginal worker generates consists of two parts: the current increase in the firms' profits, i.e. marginal revenue product net of wages, and the increment to the value of being in state (z', l') at the start of the next period. If the firm does not exit next period, i.e. if $\mathcal{V}(z', l') > 0$, the marginal worker will have a positive only if the firm expands. Otherwise, the firm will incur the dismissal cost c_f. If the firm exits, its expected marginal value from the current marginal hire will be zero.

Similarly, the surplus for the marginal worker who is matched by a hiring firm in the end-of-period state (z', l') is

$$\Pi^{work}(z', l') = \frac{1}{1+r}\left[w_h(z', l') + J^e(z', l')\right] - \frac{b + J^o}{1+r},$$

where the worker enjoys $w_h(z', l')$ in the current period, and starts next period in a firm with the beginning-of-period state (z', l'). Since at the time of bargaining the vacancy posting and matching process are over, if the bargaining fails, the worker is unemployed this period and starts next period in state o.

The worker and firm split the total surplus by Nash bargaining where the bargaining power of the firm is given by β, i.e.

$$\beta \Pi^{firm}(z', l') = (1-\beta)\Pi^{wor\,\ker}(z', l')$$

Wages are thus determined as a solution to the following equation

$$\begin{aligned} & \beta \left[\frac{\partial \pi(z', l')}{\partial l'} + \frac{\partial \mathcal{V}(z', l')}{\partial l'} \right] \\ = \; & (1-\beta) \left[w_h(z', l') + J^e(z', l') - (b + J^o) \right]. \end{aligned} \tag{B.1}$$

Adding and subtracting $(1-\beta)\frac{b+J^0}{1+r}$ on the the right hand side of (B.1) gives

$$\begin{aligned} & \beta \left[\frac{\partial \pi(z', l')}{\partial l'} + \frac{\partial \mathcal{V}(z', l')}{\partial l'} \right] \\ = \; & (1-\beta) \left\{ w_h(z', l') - r \left(\frac{b + J^o}{1+r} \right) + \left[J^e(z', l') - \frac{b + J^o}{1+r} \right] \right\} \end{aligned} \tag{B.2}$$

where $r\left(\frac{b+J^o}{1+r}\right)$ is the flow value of being unemployed and $\left(J^e(z', l') - \frac{b+J^o}{1+r}\right)$ is the expected continuation value of employment at a (z', l')-type firm net of the continuation value of unemployment. Weighted by $(1-\beta)$, this latter term cancels with $\beta\frac{\partial \mathcal{V}(z',l')}{\partial l'}$, which appears on the left hand side of equation (B.1), since the worker gets the fraction $1-\beta$ of any future rents from the match while the firm gets β. In event of a contraction, the firm cannot enforce contracts that stipulate laid-off workers to pay their share of firing costs. Thus, worker's share of expected firing costs, $\beta P_f(z', l')c_f$, is subtracted from wages in the current period. Conditional on firing taking place, the possibility of losing one's job, $p_f(z', l)$, is

$$p_f(z', l) = \frac{l - L(z'.l)}{l}.$$

The probability of being fired next period is then given by

$$P_f(z', l') = \int \mathcal{I}^f(z, l') p_f(z, l') h(z|z') dz.$$

Rearranging terms, equation (B.2) becomes

$$\frac{\partial w_h(z', l')}{\partial l'} \beta l' + w_h(z', l') - \beta \frac{\partial r(z', l')}{\partial l'} - (1-\beta) r \left(\frac{b + J^o}{1+r} \right) + \beta P_f(z', l') c_f = 0,$$

which is the same as Bertola and Garibaldi (2001)'s equation (10).

Using

$$\frac{\partial r(z', l')}{\partial l} = \alpha \frac{\sigma - 1}{\sigma} D^{\frac{1}{\sigma}} (z')^{\frac{\sigma-1}{\sigma}} (l')^{\alpha\left(\frac{\sigma-1}{\sigma}\right)-1},$$

the wage schedule for expanding firms is given by

$$w_h(z', l') = (1-\beta) r \left(\frac{b + J^o}{1+r} \right) + \Gamma(\alpha, \beta, \sigma) D^{\frac{1}{\sigma}} (z')^{\frac{\sigma-1}{\sigma}} (l')^{-\left[\frac{\alpha}{\sigma} + (1-\alpha)\right]} - \beta P_f(z', l') c_f,$$

where $\Gamma(\alpha, \beta, \sigma)$ is a function of the parameters of the problem

$$\Gamma(\alpha, \beta, \sigma) = \frac{\alpha\beta(\sigma - 1)}{\sigma(1-\beta) + \alpha\beta(\sigma - 1)}.$$

B.1.2 Firing Wages

To derive the firing wage schedule, we begin by writing the value of employment at a firing firm in the interim stage as

$$J_f^e(z', l) = \frac{1}{1+r} \left[p_f(z', l)((1+r)J^u) + \left(1 - p_f(z', l)\right) \left(w_f(z', l') + J^e(z', l') \right) \right],$$

where $l' = L(z', l)$. This expression reflects the fact that workers who are not fired are paid just enough to retain them. Next we note that, since workers are indifferent between staying and leaving

$$w_f(z', l') + J^e(z', l') = (1+r)J^u,$$

and the wage schedule faced by firing firms can be written as

$$w_f(z', l') = rJ^u - [J^e(z', l') - J^u].$$

Note that as a hiring firm increases its employment level toward the point at which $\Pi^{firm}(z', l') = 0$, the hiring wage approaches $w_f(z', l')$ by (B.1).

B.2 Steady State Open Economy Equilibrium

A steady state equilibrium for a small open economy consists of a measure of domestic differentiated goods N_H, an exact price index for composite good P, an aggregate quantity index for composite good Q, aggregate income I, a measure of workforce in services L_S, a measure of unemployed workers in differentiated goods sector L_u, unemployment rate in differentiated goods sector μ_u, job finding rate ϕ_w, vacancy filling rate ϕ_f, the exit rate μ_{exit}, the fraction of firms exporting μ_x, the measure of entrants M, the value functions and associated policy functions $\mathcal{V}(z, l)$, $L(z, l)$, $\mathcal{I}^h(z, l)$, $\mathcal{I}^c(z, l)$, $\mathcal{I}^x(z, l, k)$, J^o, J^u, J^s, and J^e; the wage schedules $w_h(z, l)$ and $w_f(z, l)$, exchange rate k, and end-of-the period and interim distributions $f(z, l)$ and $\widetilde{f}(z, l)$ such that

1. **Steady State Distributions:** In equilibrium, $f(z, l)$ and $\widetilde{f}(z', l)$ reproduce themselves through the Markov processes on z, the policy functions and the productivity draws upon entry. The interim distribution is defined as

$$\widetilde{f}(z, l) = \begin{cases} = \int_{\widehat{z}} h(z|\widehat{z}) f(\widehat{z}, l) I^c(\widehat{z}, l) d\widehat{z} \text{ if } l \neq l_e \\ = f_e(z) + \int_{\widehat{z}} h(z|\widehat{z}) f(\widehat{z}, l) I^c(\widehat{z}, l) d\widehat{z} \text{ if } l = l_e \end{cases}.$$

   In turn, the end-of-the period distribution is

$$f(z, l) = \int_{\widehat{l}} \widetilde{f}(z, \widehat{l}) I_{(L(z,\widehat{l}),l)},$$

   where $I_{(L(z,\widehat{l}),l)}$ is an indicator function with $I_{(L(z,\widehat{l}),l)} = 1$ if $L(z, \widehat{l}) = l$.

2. **Market Clearance in Sector S:** Demand for the $S-$sector goods comes from two sources: consumers spend a $(1-\gamma)$ fraction of aggregate income I on it, and firms demand it to pay their fixed operation costs, labor adjustment and entry costs. Then, the average labor adjustment cost is given by

$$\bar{c} = \int_z \int_l C(l, L(z,l)\widetilde{f}(z,l)dldz.$$

Market clearance condition in this sector is then given by

$$L_S + b\mu_u L_Q = (1-\gamma)I + N_H(\bar{c} + c_p) + Mc_e,$$

where L_S and L_Q are the size of the workforce in the two sectors, and μ_u is the unemployment rate within the Q-sector.

3. **Labor Market:** With a normalized measure of workers, the size of the workforce in the Q-sector is $L_Q = 1 - L_{S.}$ Total production employment in the differentiated good sector is given by

$$E_Q = N_H\bar{l} = N_H \int_z \int_l lf(z,l)dldz = (1-\mu_u)L_Q,$$

where

$$\bar{l} = \int_z \int_l lf(z,l)dldz \tag{B.3}$$

is the average employment in diffrentiated goods sector. The measure of unemployed workers is then

$$L_u = L_Q - E_Q = \mu_u L_Q.$$

The equilibrium condition for the labor market in the $Q-$sector requires that flows out of employment equal the flows into employment. Every period, a fraction μ_l of workers in that sector are laid off due to exits and downsizing

$$\mu_l = \frac{\int_z \int_l lI^c(z,l)f(z,l)dldz + \int_z \int_l (l - L(z,l))(1 - I^h(z,l))lf(z,l)dldz}{\int_z \int_l lf(z,l)dldz}$$

Then, the equilibrium flow condition is

$$\mu_u L_Q \phi_w = (1 - \mu_u) L_Q \mu_l,$$

which yields the usual Beveridge curve

$$\mu_u = \frac{\mu_l}{\mu_l + \phi_w}.$$

On vacancies side, the aggregate number of vacancies in this economy is given by

$$V = N_H \overline{v} = N_H \int_z \int_l v(z,l) \mathcal{I}^h(z,l) \frac{\widetilde{f}(z,l)}{\mu_h} dl dz,$$

where

$$\overline{v} = N_H \int_z \int_l v(z,l) \mathcal{I}^h(z,l) \frac{\widetilde{f}(z,l)}{\mu_h} dl dz, \tag{B.4}$$

is the average level of vacancies, and μ_h is the fraction of hiring firms:

$$\mu_h = \int_z \int_l \mathcal{I}^h(z,l) \widetilde{f}(z,l) dl dz.$$

The total number of vacancies, V, together with $L_u = \mu_u L_Q$, determines matching probabilities $\phi_f(V, L_u)$ and $\phi_w(V, L_u)$ that firms and workers take as given.

4. **Firm turnover:** In equilibrium, there is a positive mass of entry M every period so that the free entry condition (3.15) holds with equality. The fraction of firms exiting is implied by the steady state distribution and the exit policy function,

$$\mu_{exit} = \int_z \int_l [1 - \mathcal{I}^c(z,l)] f(z,l) dl dz,$$

and measure of exits equals that of entrants,

$$M = \mu_{exit} N_H.$$

5. **Income and Market Clearance for the Q-sector:** The domestic composite

good Q_H and its price are given by:

$$P_H = \left(N_H \int_z \int_l p_H(z,l)^{1-\sigma} f(z,l) dl dz \right)^{\frac{1}{1-\sigma}},$$

and

$$Q_H = \left(N_H \int_z \int_l q_H(z,l)^{\frac{\sigma-1}{\sigma}} f(z,l) dl dz \right)^{\frac{\sigma}{\sigma-1}}.$$

Spending on domestic varieties is $E_d = P_H Q_H$. A fraction γ of total income is spent on dometic and foreign differentiated goods:

$$\gamma I = E_d + E_F.$$

By Walras' Law, market clearance in the labor market and the S-sector implies the clearance of the Q-sector. We show that by writing aggregate income in the economy:

$$I = L_s + b\mu_u L_Q + W_Q + \Pi + T, \tag{B.5}$$

where L_S is employment (and income earned) in the S-sector, $\mu_u L_Q b$ is the income earned by the unemployed through home production, W_Q is the total wage bill, Π is total profits, and T is the tariff revenue. Let $\widetilde{\mathcal{I}}^h(z,l)$ be an indicator function which equals one if a firm in state (z,l) at the end of a period achieved this state by hiring in the interim stage. Π is total profits net of entry, vacancy and firing costs,

$$\begin{aligned} \Pi \;=\; & N_H \int_z \int_l [\widetilde{\mathcal{I}}^h(z,l) \{r(z,l) - w_h(z,l)l\} \\ & + \left[1 - \widetilde{\mathcal{I}}^h(z,l)\right] \{r(z,l) - w_f(z,l)l\}] f(z,l) dl dz \\ & - N_H \bar{c} - N_H c_p - M c_e \end{aligned} \tag{B.6}$$

and W_Q is the total wage bill in the Q-sector

$$W_Q = N_H \int_z \int_l \left\{ \widetilde{\mathcal{I}}^h(z,l) w_h(z,l) \cdot l + \left[1 - \widetilde{\mathcal{I}}^h(z,l)\right] w_f(z,l) l \right\} f(z,l) dl dz. \tag{B.7}$$

Since aggregate profits consists of profits from domestic and foreign sales

$$I = L_s + b\mu_u L_Q + W_Q + R_x + R_d - W_Q - N_H\overline{c} - N_H c_p - Mc_e + T.$$

where R_x is total export revenue, R_d is revenue from domestic sales in differentiated goods sector, and $N_H\overline{c}, N_H c_p$ and Mc_e are aggregate labor adjustment costs, overhead and entry costs respectively. The market clearing condition for the service sector is given by

$$L_S + b\mu_u L_Q = (1-\gamma)\, I + N_H\overline{c} + N_H c_p + Mc_e,$$

which implies

$$\gamma I = R_d + R_x + T.$$

By domestic market clearance, $E_d = R_d$. Furthermore, since $R_F = E_F/\tau_m$ and $T = R_F(\tau_m - 1)$, we obtain the trade balance condition

$$R_x = R_F.$$

6. Workers are indifferent between taking a certain job in the undifferentiated sector and searching a job in industrial sector.

$$J^o = J^s = J^u. \tag{B.8}$$

B.3 Estimating the Revenue Function and Productivity Process

B.3.1 The Revenue Function

The equation we wish to estimate is:

$$\begin{aligned}\ln r_{it} &= \rho \ln r_{it-1} + (d_H + \mathcal{I}^x_{it} \cdot d_F) - \rho \left(d_H + \mathcal{I}^x_{it-1} \cdot d_F\right) A3.1 \\ &\quad + \alpha \left(\frac{\sigma - 1}{\sigma}\right) \ln l_{it} - \alpha\rho \left(\frac{\sigma - 1}{\sigma}\right) \ln l_{it-1} + \left(\frac{\sigma - 1}{\sigma}\right) \epsilon_{it} \ .\end{aligned} \tag{B.9}$$

But selection bias and simultaneity bias prevent us from consistently estimating this expression with ordinary least squares. The former problem occurs because firms choose whether to shut down partly on the basis of their ϵ_{it} realizations, and the latter problem occurs because firms' current exporting decisions ($\mathcal{I}^x_{it}$) and employment levels (l_{it}) depend upon their current productivity levels.

B.3.2 Selection Bias and Identification

To deal with these problems, let $\mathcal{I}^c_{it}$ be an indicator variable that takes a value of 1 if the ith firm continues to operate in period t, and 0 otherwise. Then, defining $\xi_{it} = \epsilon_{it} - E\left[\epsilon_{it} | \mathcal{I}^c_{it} = 1, \ln r_{it-1}, \ln \ell_{it-1}, \mathcal{I}^x_{it-1}\right]$, the revenue function can be re-formulated as:

$$\begin{aligned}\ln r_{it} &= \rho \ln r_{it-1} + d_H(1-\rho) + d_F(I^x_{it} - \rho \cdot I^x_{it-1}) + \alpha \frac{\sigma - 1}{\sigma} \ln \ell_{it} A3.2 \\ &\quad - \alpha\rho \frac{\sigma - 1}{\sigma} \ln \ell_{it-1} + \frac{\sigma - 1}{\sigma} E\left[\epsilon_{it} | \mathcal{I}^c_{it} = 1, ...\right] + \frac{\sigma - 1}{\sigma} \xi_{it},\end{aligned} \tag{B.10}$$

where the error term ξ_{it} has zero mean and is orthogonal to $\ln r_{it-1}$, $\ln \ell_{it-1}$, $\mathcal{I}^x_{it-1}$, and $E\left[\epsilon_{it} | \mathcal{I}^c_{it} = 1, ...\right]$. Also, although it is correlated with current exporting decisions (I^x_{it}), ξ_{it} is orthogonal to $E\left[\mathcal{I}^x_{it} | \mathcal{I}^c_{it} = 1, \ln r_{it-1}, \ln \ell_{it-1}, \mathcal{I}^x_{it-1}\right]$. These implications of our model can be used as the basis for a generalized method of moments (GMM) estimator that identifies the parameters of equation (A3.1).[1] And the efficiency of this estimator can be improved by exploiting the moment condition $E\left(\mathcal{I}^x_{it}(1 - e^{-d_F}) - x_{it}\right) = 0$, where $\mathcal{I}^x_{it}(1 - e^{-d_F})$ is the share of exports in total sales implied by our model and x_{it} is the observed ratio of export

[1] Identification further requires that these conditional expectations be non-linear functions of their arguments and/or that they condition on additional arguments that do not appear in equation (A3.2). Note that the dependence of $\ln \ell_{it}$ on ϵ_{it} does not prevent us from obtaining consistent estimates of these parameters because the coefficient on $\ln \ell_{it}$ can be inferred from the coefficients on $\ln \ell_{it-1}$ and $\ln r_{it-1}$.

revenues to total sales (which we treat as a noisy measure of true export intensity).

This estimation strategy requires that we calculate $E\left[\epsilon_{it}|\mathcal{I}_{it}^{c}=1,\ln r_{it-1},\ln \ell_{it-1},\mathcal{I}_{it-1}^{x}\right]$. To this end, recall that there is a threshold productivity level above which all firms with beginning-of-period employment level ℓ_{it-1} will continue operating. Denoting this threshold productivity level $g^{*}(\ell_{it-1})$, the continuation condition is $\ln z_{it}=\rho\ln z_{it-1}+\epsilon_{it}>g^{*}(\ell_{it-1})$. Or, since $\ln z_{it-1}=\frac{\sigma}{\sigma-1}\left[\ln r_{it-1}-(d_H+\mathcal{I}_{it-1}^{x}d_F)\right]-\alpha\ln l_{it-1}$ (by equation 3.27), continuation occurs when $\frac{\epsilon_{it}}{\sigma_\epsilon}>\frac{g^{*}(\ell_{it-1})-\rho\ln z_{it-1}}{\sigma_\epsilon}\overset{def}{=}g(r_{it-1},l_{it-1},\mathcal{I}_{it-1}^{x})$, and the probability of continuation can be calculated as

$$p_{it}^{C}=1-\Phi\left[g(\ln r_{it-1},\ln l_{it-1},\mathcal{I}_{it-1}^{x})\right], \tag{A3.3}$$

where $\epsilon_{it}\sim N(0,\sigma_\epsilon^2)$ and $\Phi()$ is the standard normal cumulative distribution. Treating $g(\cdot)$ as a flexible function of its arguments, it follows that p_{it}^{C} values can be imputed from estimates of the probit function (A3.3), and the object of interest can be calculated using well-known properties of the normal distribution (e.g., Maddala, 1983):[2]

$$\begin{aligned}
E\left[\epsilon_{it}|\mathcal{I}_{it}^{c}=1,\ln r_{it-1},\ln \ell_{it-1},\mathcal{I}_{it-1}^{x}\right] &= \sigma_\epsilon\cdot M_{it},\\
var\left[\epsilon_{it}|\mathcal{I}_{it}^{c}=1,\ln r_{it-1},\ln \ell_{it-1},\mathcal{I}_{it-1}^{x}\right] &= \sigma_\epsilon^2\cdot\left(1-M_{it}\left[M_{it}-\Phi^{-1}(p_{it}^{C})\right]\right),
\end{aligned}$$

where $M_{it}=\frac{\phi(\Phi^{-1}(p_{it}^{C}))}{p_{it}^{C}}$ is the relevant Mills ratio and $\phi()=\Phi'(\ )$.

Our estimation strategy also requires that we calculate $E\left[\mathcal{I}_{it}^{x}|\mathcal{I}_{it}^{c}=1,\ln r_{it-1},\ln \ell_{it-1},\mathcal{I}_{it-1}^{x}\right]$. For this, note that firms above some threshold productivity level will choose to export, given (l_{it-1},z_{it-1}). Thus, once again exploiting the normality of ϵ_{it}, we can write

$$E\left[\mathcal{I}_{it}^{x}|\mathcal{I}_{it}^{c}=1,\ln r_{it-1},\ln \ell_{it-1},\mathcal{I}_{it-1}^{x}\right]=p_{it}^{X}=1-\Phi\left[h(\ln r_{it-1},\ln l_{it-1},\mathcal{I}_{it-1}^{x})\right], \tag{A3.4}$$

where p_{it}^{X} is the probability that firm i exports in period t and $h(r_{it-1},l_{it-1},\mathcal{I}_{it-1}^{x})$ is a flexible function of its arguments.[3] Hence $E\left[\mathcal{I}_{it}^{x}|\mathcal{I}_{it}^{c}=1,...\right]$ can be calculated by estimating

[2] When estimating this probit, we use a flexible (translog) functional form for $g(r_{it-1},l_{it-1},I_{it-1}^{X})$.

[3] It is interesting that lagged exports help predict current exports here, even though we have assumed

the probit (A3.4) and retrieving the imputed p_{it}^X values. Clearly, identification here comes from the non-linear form of the probit function.[4]

B.3.3 The Moment Conditions

To summarize, our GMM estimator is based on the moment conditions:

$$\begin{aligned} E[\xi_{it} \ln r_{it-1}] &= 0,\ E[\xi_{it} \ln \ell_{it-1}] = 0,\ E[\xi_{it} M_{it}] = 0,\ E[\xi_{it} \mathcal{I}_{it-1}^x] = 0, \\ E[\xi_{it} p_{it}^X] &= 0,\ E[\xi_{it}] = 0, E[\nu_{it}^\epsilon] = 0,\ E[\nu_{it}^x] = 0. \end{aligned}$$

where:

$$\begin{aligned} \xi_{it} &= \frac{\sigma}{\sigma - 1}\left[\ln r_{it} - d_H(1-\rho) - d_F(\mathcal{I}_{it}^x - \rho \mathcal{I}_{it-1}^x) - \rho \ln r_{it-1}\right] + \alpha\rho \ln \ell_{it-1} - \alpha \ln \ell_{it} - \sigma_\epsilon \cdot M_{it}, \\ \nu_{it}^\epsilon &= \xi_{it}^2 - \sigma_\epsilon^2 \cdot \left(1 - M_{it}\left[M_{it} - \Phi^{-1}(p_{it})\right]\right), \\ \nu_{it}^x &= \mathcal{I}_{it}^x(1 - e^{-d_X}) - x_{it}. \end{aligned}$$

In principle, these conditions identify ρ, α, σ_ϵ^2, d_X, d_H, $\frac{\sigma-1}{\sigma}$. In practice, while ρ, $\alpha, \sigma_\epsilon^2, d_X$, and d_H can be estimated with some precision using this estimator, $\frac{\sigma-1}{\sigma}$ is poorly identified. We therefore fix $\frac{\sigma-1}{\sigma}$ at several alternative values taken from the existing literature, and generate corresponding sets of estimates for the remaining parameters. (Refer to Table 1 in the text.) Our results proved not to be sensitive to the inclusion of time dummies in A1.1. Accordingly, since our theoretical model presumes that the macro environment is stable, we focus our attention on the case in which they are omitted.

away sunk entry costs. The reason is that, by (3.27), lagged exports help to explain lagged productivity.

[4]Olley and Pakes (1996) develop a related strategy that posits a determinstic linkage between productivity shocks and investment levels. This allows them to get away from functional form as a basis for identification, but it is not an available option in the present setting.

B.3.4 Numerical Solution Algorithm

The following steps describe the solution algorithm. Since we provide the detailed description of workers and firms problems for the closed economy case, we refer to these equations below with an understanding that the revenue functions (and as a result hiring and firing ages as well as all the value functions) will be adjusted appropriately for the open economy case (3.7).

- Take τ, τ^m and D_F as given.
- Set $J^o = 1/r$.

1. Start with guesses for D_H, $w_f(z,l), \eta$ and ϕ_f. Given D_H, D_F and η, calculate $w_h(z,l)$ using equation (3.23).
2. Given D_H, $w_f(z,l), \eta$, ϕ_f and $w_h(z,l)$ calculate the value function for the firm, $\mathcal{V}(z,l)$, using equation (3.10) and find the associated decision rules for exit, hiring and exporting. Calculate the expected value of entry, $\mathcal{V}_e$, using equation (3.15). Compare $\mathcal{V}_e$ with c_e. If $\mathcal{V}_e > c_e$, decrease D_H (to make entry less valuable) and if $\mathcal{V}_e < c_e$, increase D_H (to make entry more valuable). Go back to Step 1 with the updated value of D_H and repeat until D_H converges.
3. Given $w_f(z,l), \eta$, ϕ_f and the converged value of D_H from step 2, update $w_f(z,l)$. To do this, first calculate $J^e(z',l')$ using equations (3.19) and (3.22), and imposing the equilibrium condition $J^u = J^o$. Given $J^e(z,l)$, update firing wage schedule using equation (3.24). Compare the updated firing wage schedule with the initial guess. If they are not close enough go back to Step 1 with the new firing wage schedule and repeat Steps 1 to 3 until w_f converges. Note that if firing wages are too high, then $J^e(z,l)$, the value of being in a firm at the start of a period, is high, since the firm is less likely to fire workers. A high value of $J^e(z,l)$, however, lower firing wages. Similarly, if the firing wages are too low, then J^e is low, which pushed firing wages up.

4. Given ϕ_f, the converged value of D_H step 2, the converged value of $w_f(z,l)$ from step 3, calculate the trade balance. In order to do this:

   (a) Given firms decisions, calculate $f(z,l)$ and $\widetilde{f}(z,l)$, the stationary probability distributions over (z,l) at the end and interim states, respectively.

   (b) Given $\widetilde{f}(z,l)$, calculate average number of vacancies and the average employment in differentiated goods sector using equations (B.4) and (B.3).

   (c) Take a guess for N_H. Given N_H and $\overline{v}$, calculate the mass of unemployed L_u in differentiated goods sector from

   $$\phi_f(V, L_u) = \frac{M(V, L_u)}{V} = \frac{L_u}{((vN_H)^\theta + L_u^\theta)^{1/\theta}},$$

   which is one equation in one unknown. Given $N_H, \bar{l}$ and L_u , calculate the size of the workforce in the Q-sector is L_Q from

   $$N_H \bar{l} = L_Q - L_u.$$

   Given N_H, $L_S = 1 - L_Q$, M (mass of entrants), and I (aggregate income), check if supply and demand is equal in the service sector

   $$\underbrace{L_S + b(\mu_u L_u)}_{\text{supply}} = \underbrace{(1-\gamma)\, I + N_H \overline{c} + N_H c_f + M c_e}_{\text{demand}},$$

   If the supply is greater than the demand, decrease N_H and if supply is less than demand, increase N_H. Repeat until N_H converges. Repeat Step 4c until N_H converges.

   (d) Given the value of N_H from Step 4c, calculate exports and imports. If exports are larger than imports, lower η and if exports are less than imports, increase η. Go back to Step 1 with the updated value of η, and repeat until convergence.

5. Given the converged value of D_H step 2, the converged value of $w_f(z,l)$ from step 2, and the converged value of η from step 4, update ϕ_f. In order to do that, first

calculate EJ_h^e using (3.19). Then find ϕ_w from

$$\phi_w = (1 - \phi_f^\theta)^{1/\theta}.$$

Given EJ_h^e and ϕ_w, calculate J^u using (3.17). If $J^o > J^u$, increase ϕ_f (to attract workers to differentiated goods sector) and if $J^o < J^u$, we lower ϕ_f (to make the differentiated goods sector less attractive). Go back to Step 1, and repeat until ϕ_f converges.

B.3.5 Estimation Code

The above algorithm solves the model for a given set of exogenous parameter values, including the cost of entry c_e. When we estimate the benchmark model to obtain parameter estimates: i) we use the empirical value of η, ii) take the value of D_H estimated in the first stage where we estimate revenue function parameters, iii) set c_e such that free entry holds. This enables us to skip loops 2 and 4 in the calibration. When we do policy experiments by varying the parameters related to trade costs, the values of D_H and η change endogenously, so we use the complete algorithm to solve the model.

Appendix C

C.1 Steady State Equilibrium

In this section, I show the existence of an equilibrium along a balanced growth path (BGP) so that all variables grow at the same rate under certain parameter restrictions. There are two dynamic decisions in this economy: capital accumulation undertaken by households and skilled labor employment decision given by intermediate good producers. I solve these problems to characterize the equilibrium interest rate, rental price of capital and the wage premium along the proposed BGP. To find the equilibrium quantities and prices, I impose equilibrium conditions to the first order necessary conditions of these problems and check the sufficiency conditions. I derive the necessary restrictions on parameters to ensure the existence of the proposed BGP. The stability conditions are trivial since the technology adoption function approaches its steady state level monotonically, and capital accumulation dynamics are the same as in the neoclassical growth model.

Household Problem

The household problem is rather standard. Since households are identical, there will be no trade in shares and bonds in equilibrium. I suppress the bond market and consider the investment decisions for physical capital and shares. By a no-arbitrage condition, the interest rate r_t on bonds will be equal to the rate of return on shares. Since household members equally split the total consumption, the relevant part of the objective function (2.18) is to maximize C_t. Household takes rental rate of capital R_t, dividends and share

prices (D_t, q_t), total wages W_t and transfers z_t as given and solves,

$$\max_{\{C_t\},\{\mathrm{N}_t\},\{S_t\}} \int_{t=0}^{\infty} e^{-(\rho-g_\ell)t} \ \ln(C_t)\ dt,$$

subject to K_0 and

$$C_t + (1+\theta)\mathrm{N}_t + q_t S_t = W_t + R_t \mathrm{K}_t + D_t a_t + z_t,$$
$$\dot{K}_t = \mathrm{N}_t - \delta \mathrm{K}_t,$$
$$\dot{a}_t = S_t.$$

Along a BGP, household level variables $\{C_t, \mathrm{N}_t, W_t, \mathrm{K}_t, D_t, z_t\}$ grow at the same rate λ as the output. By the absence of trade in shares in equilibrium, share prices should also increase at the same rate. Suppressing the time subscripts, the Hamiltonian is

$$J = \ e^{-(\rho-g_\ell)t} \ \ln(C) + \mu_{\mathrm{K}} \cdot (\mathrm{N} - \delta \mathrm{K}) + \mu_a \cdot S$$

Necessary and sufficient conditions for the optimum read as

$$\frac{\partial J}{\partial \mathrm{N}} = 0 \quad \Rightarrow \quad \mu_{\mathrm{K}} = e^{-(\rho-g_\ell)t}\ \frac{1+\theta}{C}, \tag{C.1}$$

$$\frac{\partial J}{\partial S} = 0 \quad \Rightarrow \quad \mu_a = e^{-(\rho-g_\ell)t}\ \frac{q}{C}, \tag{C.2}$$

$$\frac{\partial J}{\partial \mathrm{K}} + \dot{\mu}_{\mathrm{K}} = 0 \quad \Rightarrow \quad \dot{\mu}_{\mathrm{K}} = -e^{-(\rho-g_\ell)t}\ \frac{R}{C} + \delta \mu_{\mathrm{K}}, \tag{C.3}$$

$$\frac{\partial J}{\partial a} + \dot{\mu}_a = 0 \quad \Rightarrow \quad \dot{\mu}_a = -e^{-(\rho-g_\ell)t}\ \frac{D}{C}, \tag{C.4}$$

$$\lim_{t\to\infty} [\mu_{\mathrm{K}}(t)\mathrm{K}(t)] = 0. \tag{C.5}$$

$$\lim_{t\to\infty}[\mu_a(t)a(t)] = 0. \tag{C.6}$$

First divide (C.4) by (C.2) to get:

$$\frac{\dot{\mu}_a}{\mu_a} = -\frac{D}{q}.$$

Then I take the logarithm of (C.2) and differentiate the resulting expression with respect to t. In a BGP, total consumption C_t grows at a rate equal to $\lambda + g_\ell$. Using $\frac{\dot{C}}{C} = \lambda + g_\ell$,

$$\frac{\dot{\mu}_a}{\mu_a} = -(\rho+\lambda) + \frac{\dot{q}}{q},$$

which implies

$$\frac{D+\dot{q}}{q} = \rho + \lambda.$$

This is the net rate of return to shares which is the sum of dividend and capital gains.

The rental rate of capital is obtained by differentiating (C.1) with respect to t to obtain

$$\frac{\dot{\mu}_{\mathrm{K}}}{\mu_{\mathrm{K}}} = -(\rho+\lambda),$$

and dividing (C.3) by this expression,

$$R_{ss} = (\rho+\lambda+\delta)(1+\theta).$$

The net interest rate in the bond market is equal to the rate of return to shares by a no-arbitrage condition:

$$r_{ss} = \rho + \lambda.$$

Since μ_{K} is decreasing at a rate $\rho+\lambda$, and household capital stock K_t is growing by $\lambda + g_\ell$, the assumption $\rho > g_\ell$ makes sure that the transversality condition (C.5) is satisfied. Since μ_a is decreasing by a rate ρ, and a_t is constant, the second transversality condition (C.6) is also satisfied.

Intermediate Good Producer's Problem

Henceforth I will refer the representative intermediate good producer as 'the firm'. The firm enjoys monopoly rents. Hence its net profit after rental payments is positive. Skilled labor is paid out of this rent. Now I solve firm's dynamic problem of skilled labor demand. I will derive the parameter restriction needed to ensure that the firm has enough rents to cover the decentralized wage rate along the proposed BGP.

Given $w_{s,t}$, when the firm employs a measure of $\ell_{s,t}$ skilled, its profit and resulting change in its technology are given by

$$\Pi_t = A_t x_t^{\alpha} \ell_u^{1-\alpha} - w_{s,t}\ell_{s,t} \ , \tag{C.7}$$

$$\dot{A}_t = \ \ell_{s,t}^{\beta} \left(\frac{T_t}{A_t}\right)^{\eta} A_t, \quad \beta \in (0,1), \quad \eta \in (0,1). \tag{C.8}$$

I restrict attention to the constant interest rate r_{ss} along the BGP. The firm with an initial technology level A_0 solves the following problem:

$$V(A_0) \ = \ \max_{\{\ell_{s,t}\}} \int_{t=0}^{\infty} \ e^{-r_{ss}\cdot t} \ \Pi_t \ dt, \tag{C.9}$$

subject to (C.7) and (C.8).

Note that $x_t = x = k_t/A_t$ is constant along the BGP. Since wages grow by λ, I normalize wages and productivity by T_t. Let $\tilde{w}$ denote the stationary wage level. As in the text, $g = A_t/T_t$ is the gap between a country's productivity and the frontier. The problem in (C.9) can be rewritten as

$$\begin{aligned} V(A_0) \ &= \ \max_{\{\ell_{s,t}\}} \int_{t=0}^{\infty} \ e^{-r_{ss}\cdot t} \ T_t \ \frac{\Pi_t}{T_t} \ dt \\ &= \ \max_{\{\ell_{s,t}\}} \int_{t=0}^{\infty} \ e^{-\rho\cdot t} \cdot [g_t \ x^{\alpha} \ell_u^{1-\alpha} - \tilde{w}_s \ell_s] \ dt, \end{aligned}$$

subject to

$$\dot{g}_t = \ell_s^{\beta} \ g_t^{1-\eta} - \lambda g_t.$$

We present the Hamiltonian and the first order necessary conditions. Imposing equilibrium properties, we derive the wage premium. Lastly, we check that the sufficiency condition and transversality condition are satisfied. Suppressing the time subscripts,

$$H(g, \ell_s,) \;=\; e^{-\rho \cdot t} \cdot [\; g\; x^{\alpha} \ell_u^{1-\alpha} - \tilde{w}_s \ell_s \;] + \mu \cdot [\; \ell_s^{\beta}\; g^{1-\eta} - \lambda g \;],$$

$$\frac{\partial H}{\partial \ell_s} = 0 \quad \Rightarrow \quad e^{-\rho \cdot t}\; \tilde{w}_s = \mu\; \beta\; \ell_s^{\beta-1} g_{.}^{1-\eta} \tag{C.10}$$

$$\frac{\partial H}{\partial g} + \dot{\mu} = 0 \quad \Rightarrow \quad \dot{\mu} \;=\; -e^{-\rho \cdot t} x^{\alpha} \ell_u^{1-\alpha} + \mu [\; \ell_s^{\beta} (\eta - 1) g^{-\eta} + \lambda \;]. \tag{C.11}$$

Rearrange (C.10) to get

$$\mu = \frac{e^{-\rho \cdot t}\; \tilde{w}_s}{\beta \ell_s^{\beta-1} g^{1-\eta}}, \tag{C.12}$$

and divide (C.11) by (C.12),

$$\frac{\dot{\mu}}{\mu} \;=\; -\frac{x^{\alpha} \ell_u^{1-\alpha}}{\tilde{w}_s}\; \beta\; \ell_s^{\beta-1} g^{1-\eta} + \ell_s^{\beta} (\eta - 1) g^{-\eta} + \lambda. \tag{C.13}$$

Taking the logarithm of (C.12) and differentiating with respect to t, and using the steady state condition $\dot{g} = 0$, I get

$$\frac{\dot{\mu}}{\mu} \;=\; -\rho. \tag{C.14}$$

Letting (C.13) and (C.14) equal, I obtain an expression for skilled wages: Imposing the equilibrium condition $\ell_s = s$, these two equations read as;

$$\tilde{w}_s \;=\; x^{\alpha} \ell_u^{1-\alpha}\; \frac{\beta\; \ell_s^{\beta-1}\; g^{1-\eta}}{\ell_s^{\beta}\; (\eta - 1)\; g^{-\eta} + \lambda + \rho}.$$

Total payments to skilled labor are given by

$$\tilde{w}_s \cdot \ell_s \;=\; g x^{\alpha} \ell_u^{1-\alpha}\; \frac{\beta\; \ell_s^{\beta}\; g^{-\eta}}{\ell_s^{\beta}\; (\eta - 1)\; g^{-\eta} + \lambda + \rho}. \tag{C.15}$$

Under some additional conditions, the sufficiency of necessary conditions is guaranteed

by Arrow-Kurz sufficiency theorem for dynamic control. The maximized Hamiltonian $H^o(g)$ is obtained when one solves (C.10) for optimal $\ell_s(g)$ and inserts this back into $H(\ell_s, g)$. Arrow-Kurz's sufficiency condition is the concavity of H^o in g. [1] The maximized Hamiltonian of this problem is

$$H^o(g) \;=\; g^{\frac{1-\eta}{1-\beta}} \left(\beta^{\frac{\beta}{1-\beta}} - \beta^{\frac{1}{1-\beta}} \right).$$

One can check that $\frac{\partial^2 H^o}{\partial g^2} \leq 0$ is satisfied if either of the following restrictions hold:

i. $\beta \in (0,1)$ and $\eta \in [\beta, 1]$, or

ii. $\beta > 1$, $\eta > 0$ and $\eta \notin (1, \beta)$.

In the text, I assume that the former condition holds. The restriction on β ensures that demand for skilled human capital is finite. As to η, if this parameter is larger than 1, it is optimal for the firm to delay investment in technology adoption, to let T_t/A_t increase over time such that the returns to hiring skilled labor is infinite in an indefinite future period.

The firm has enough rents to pay skilled labor if

$$g x^{\alpha} \ell_u^{1-\alpha} - \tilde{w}_s \, \ell_s \geq 0.$$

Substituting the steady state gap $g = \lambda^{-\eta} \ell_s^{\beta/\eta}$ in (C.15), one can check that this condition is satisfied for

$$\rho \;>\; (\beta - \eta)\lambda. \tag{C.16}$$

This parameter restriction is needed to assure that the firm has enough resources to support technology investment in form of skilled labor hiring in a decentralized economy. Note that (C.16) holds under the assumption $\eta \geq \beta$ already assumed above.

Lastly, the transversality condition is given by

$$\lim_{t \to \infty} \; \mu_t \cdot g_t = 0, \tag{C.17}$$

and it is satisfied since g is constant in steady state and μ, as one can see in (C.10), is

[1] The reader can refer to Barro and Sala-i Martin (2004), page 610.

declining at the rate ρ.

Capital-Output Ratio

To find the steady state capital-output ratio, start rearranging term in (4.5), the demand function for capital by intermediate good producers:

$$\left(\frac{x}{\ell_u}\right)^{1-\alpha} = \frac{\alpha}{1-\alpha}\,\frac{1}{R_{ss}}.$$

The contribution of each producer to nation output is given by: $y = A\frac{x^{\alpha}\ell_u^{1-\alpha}}{\alpha(1-\alpha)}$. Using the production function for $x = \frac{k}{A}$, I obtain:

$$\frac{k}{y} = \alpha(1-\alpha)\left(\frac{x}{\ell_u}\right)^{1-\alpha}.$$

Inserting $(x/\ell_u)^{1-\alpha}$ from above, the capital-output ratio for the representative intermediate good producer reads as;

$$\frac{k}{y} = \frac{\alpha^2}{(r_{ss}+\delta)(1+\theta)}. \tag{C.18}$$

The aggregate capital-output ratio is the same since $K = kM$, and $Y = yM$.

Wage Premium

The final good producer pays unskilled labor according to its marginal contribution in production. Total payments to unskilled labor (in efficiency units) amount to

$$w_{u,t}L_{u,t} = \frac{A_t}{\alpha}\,(x_tM_t)^{\alpha}L_{u,t}^{1-\alpha}.$$

In order to derive the wage premium, I divide both sides of this expression by M_t, normalize by T_t and find the payment to unskilled labor per variety:

$$\tilde{w}_u\ell_u = \frac{g}{\alpha}\,x^{\alpha}\ell_u^{1-\alpha}. \tag{C.19}$$

Dividing (C.15) by (C.19),

$$\frac{\tilde{w}_s}{\tilde{w}_u} = \frac{\alpha\ \beta\ \ell_s^{\beta-1}\ g^{-\eta}}{\ell_s^{\beta}(\eta-1)g^{-\eta}+\lambda+\rho}\ \ell_u.$$

Substituting the steady state g, I get

$$\frac{\tilde{w}_s}{\tilde{w}_u} = \frac{\alpha\beta\lambda}{\eta\lambda+\rho}\ \frac{\ell_u}{\ell_s}. \tag{C.20}$$

In equilibrium, $\ell_u = (1-s)u$ and $\ell_s = s$ which yields (4.29) in the text.

Rate of Convergence

In steady state, a constant fraction $\sigma \in (0,1)$ of household income will be saved. We can write the law of motion for per-capita capital normalized with respect to T_t as

$$\frac{\dot{k}}{k} = f^1(k,g) = vg^{1-\alpha}k^{\alpha-1} - (g_\ell + \delta + \lambda) \tag{C.21}$$

where $v = \sigma/(\alpha(1-\alpha))$. The steady state value of k is given by

$$k^* = \left[\frac{v}{g_\ell+\delta+\lambda}\right]^{\frac{1}{1-\alpha}} g^*. \tag{C.22}$$

The law of motion for the technological gap is

$$\frac{\dot{g}}{g} = f^2(g) = \ell_s^{\beta} g^{-\eta} - \lambda, \tag{C.23}$$

and its steady state value is

$$g^* = \ell_s^{\frac{\beta}{\eta}} \lambda^{-\frac{1}{\eta}}. \tag{C.24}$$

Log-linearizing $f^1(k,g)$ and $f^2(g)$ around the steady state yields

$$\begin{aligned}\tilde{f}^1(k,g) &= (1-\alpha)(g_\ell+\delta+\lambda)\left[\frac{g}{g^*}-\frac{k}{k^*}\right],\\ \tilde{f}^2(g) &= \eta\lambda\left[1-\frac{g}{g^*}\right].\end{aligned}$$

The system of differential equations around the steady state can be written as

$$\begin{bmatrix}\dot{k}/k\\ \dot{g}/g\end{bmatrix} = \begin{bmatrix}-(1-\alpha)(g_\ell+\delta+\lambda) & (1-\alpha)(g_\ell+\delta+\lambda)\\ 0 & -\eta\lambda\end{bmatrix}\cdot\begin{bmatrix}k-k^*\\ g-g^*\end{bmatrix} \tag{C.25}$$

which has two roots $\epsilon_1 = (1-\alpha)(g_\ell+\delta+\lambda)$ and $\epsilon_2 = \eta\lambda$. Plugging in the calibrated parameter values for (α,λ,δ) and using the population growth rate $g_\ell = 1.5\%$, the first root is $\epsilon_1 = 0.0475$. Since this is much larger than the empirical estimates of the rate of convergence, I assume that ϵ_2 is the smaller root and hence the rate of convergence.

C.2 Data

C.2.1 Human Capital Stocks

I measure s by the share of scientists and engineers in workforce at year 1985. This is computed using two pieces of evidence. Barro-Lee (2001) data provides the college attainment levels of countries. UNESCO (1975) reports the share of majors in total enrollment.

The efficiency level of unskilled human capital is measured using the country-specific Mincerian returns in Psacharopoulos (1994) and average years of schooling in Barro-Lee (2001). Following the standard procedure in the literature, in a country in which the Mincerian return is r and average years of schooling is m, total stock of unskilled labor is equivalent to $\exp(r\cdot m)$ units of efficiency labor.

C.2.2 Measurement of the Wage Premium

I measure the wage premium in two steps. First, I obtain the relative earnings ratio of an average college graduate over a worker with no education (college premium). Next, I use the premium of an engineering major over the average college graduate. Grogger and Eide (1995) provide estimates of major-specific wage premia in the US. Their estimate of engineering premium is 1.2 (over earnings of an average college graduate). Psacharopoulos (1994) reports a similar measure for a limited group of countries. These estimates do not systematically vary with income levels. Thus, I use the US value for other countries in the sample as well.

The measurement of the college premium follows the private rate of return method proposed by Psacharopoulos (1995) and is based on returns to investment in education data in Psacharopoulos (1994) (Table A1). The Mincerian method, used to construct of the human capital stocks u, is based on the assumption that there is a rental price for efficiency units of labor and workers of different skill levels are substitutable in production. Education enables a worker to produce more of the same. This assumption is valid when u is imputed because efficiency units of human capital embedded in unskilled workers with different education levels are substitutable in the model. However, skilled and unskilled labor are not substitutable and paid different the rental rates. The private rate of return method is appropriate to back out the underlying wage premium based on the estimated rates of return.it

Let P stand for life-expectancy in a country. Also, let D indicate the duration of finishing a particular level of education. After finishing the school, the worker earns w_s for the rest of her life whereas the uneducated worker earns w_u. Given a private rate of return r, the discounted life-time gain of obtaining a degree is equal to the opportunity cost plus the direct cost c:

$$\sum_{t=1}^{P-D} \frac{w_s - w_u}{(1+r)^t} \;=\; \sum_{t=1}^{D} (w_u + c)(1+r)^t.$$

From this equation, one can calculate w_s/w_u. We have country specific data on r for

primary, secondary and tertiary education as well as life-expectancy P.[2] The direct cost c is taken as zero for all levels of education in all countries except college education in the US. The case for the calibration target, the US value, is discussed below. I calculate the wage ratio for each education level (college over secondary, secondary over primary and primary over no education.) The college premium is obtained by multiplying these three ratios.

Psacharopoulos (1994) reports only the social rate of return for the US. Most of the higher education expenses in the US are, however, privately financed. In the absence of externalities, the social return will be close to the private return. Thus, I use the 10% rate of return for secondary and 12% rate of return for higher education in the US. I also compute an estimate of the relative direct cost of higher education in terms of the unskilled wage level, c/w_u, in the US for 1975. According to the US Department Education, the total cost of a year of college education was \$2,275 in 1975 in current dollars. [3] In the same year, minimum wage was \$2.1. An unskilled laborer working for 8 hours a day, 5 days a week for 9 months of school time would earn \$3.275 on total. This yields an estimate of $c/w_u = 0.7$. Using this figure, and a life expectancy of $P = 71$ years, the US college wage premium is estimated as 5.1. Using the engineering premium of 1.2, the calibration target is $w_s/w_u = 6.13$.

[2]International Life expectancy data is from US Census Bureau (http://www.census.gov/ipc/www/idb/idbprint.html). I take the 1975 value whenever possible to capture the educational choice of the average workforce in 1985. For many countries, data in this year is available. Otherwise, I choose the date closest to 1975. The results are not sensitive to small changes in life expectancy.

[3]Data on college costs available in http://nces.ed.gov/programs/digest/d06/tables/dt06_319.asp

Country	**Code**	y_i/y_{us}	u_i	s_i	$1+\theta_i$	$\mathbf{log}[(w_s/w_u)_i]$
Argentina	ARG	0.48	2.00	0.009	1.40	2.19
Australia	AUS	0.81	2.24	0.024	1.15	1.64
Austria	AUT	0.86	1.81	0.006	0.95	-
Bolivia	BOL	0.13	1.57	0.008	1.35	2.44
Botswana	BWA	0.18	1.76	0.001	1.89	9.79
Brazil	BRA	0.32	1.61	0.007	0.65	3.51
Canada	CAN	0.80	2.52	0.040	1.02	1.61
Chile	CHL	0.32	2.06	0.009	0.58	2.33
Colombia	COL	0.27	1.79	0.006	1.56	3.39
Costa Rica	CRI	0.34	1.56	0.013	1.75	2.42
Cyprus	CYP	0.45	1.51	0.015	1.06	1.65
Denmark	DNK	0.77	1.53	0.020	0.93	-
Dominican Republic	DOM	0.22	1.43	0.020	2.08	5.58
Ecuador	ECU	0.28	1.92	0.015	0.55	2.63
Egypt	EGY	0.17	1.16	0.005	2.18	-
El Salvador	SLV	0.21	1.30	0.004	2.25	2.46
Finland	FIN	0.69	1.92	0.015	0.69	-
France	FRA	0.86	2.08	0.011	0.95	2.69
Germany	GER	0.76	2.00	0.008	0.80	-
Ghana	GHA	0.04	1.23	0.001	1.55	3.97
Greece	GRC	0.58	1.70	0.010	0.76	1.43
Guatemala	GTM	0.21	1.44	0.004	1.56	3.88
Honduras	HND	0.14	1.39	0.004	1.46	3.72
Hong Kong	HKG	0.65	1.58	0.008	0.90	3.3
India	IND	0.07	1.39	0.004	1.32	2.23
Indonesia	IDN	0.11	1.29	0.001	0.85	-
Iran	IRN	0.35	1.36	0.001	0.65	-
Israel	ISR	0.77	1.78	0.026	0.70	2.31
Italy	ITA	0.83	1.17	0.007	0.83	2.89
Jamaica	JAM	0.16	3.29	0.003	1.2	2.60
Japan	JPN	0.70	3.08	0.017	1.11	1.88
Kenya	KEN	0.05	1.46	0.001	1.86	2.66
Korea (South)	KOR	0.29	2.96	0.013	0.99	2.07
Malaysia	MYS	0.29	1.58	0.002	1.17	5.08
Mexico	MEX	0.41	1.41	0.008	1	3.03
Nepal	NPL	0.04	1.08	0.002	1.19	-
Netherlands	NLD	0.86	1.70	0.015	0.87	1.57
Nicaragua	NIC	0.30	1.47	0.008	2.47	-
Norway	NOR	0.93	1.59	0.014	0.83	-
Pakistan	PAK	0.11	1.32	0.002	1.22	2.75
Panama	PAN	0.35	2.34	0.012	1.03	2.63
Paraguay	PRY	0.27	1.74	0.005		2.85
Peru	PER	0.27	1.57	0.013	0.92	2.89
Philippines	PHL	0.15	2.28	0.020	1.41	2.25
Portugal	PRT	0.42	1.36	0.005	1.14	7.36
Singapore	SGP	0.61	1.80	0.005	0.45	2.88
South Africa	ZAF	0.41	1.24	0.003	2.08	-
Spain	ESP	0.65	1.47	0.008	0.98	-
Sri Lanka	LKA	0.12	1.45	0.002	0.98	2.27
Sweden	SWE	0.76	1.59	0.018	1.02	1.74
Switzerland	CHE	0.99	2.10	0.013	0.95	-
Taiwan	TWN	0.36	1.51	0.012	1.62	4.01
Thailand	THA	0.12	1.73	0.006	0.83	2.3
Tunisia	TUN	0.28	1.22	0.003	1.17	2.77
United Kingdom	GBR	0.70	1.78	0.014	0.97	-
United States	USA	1.00	3.23	0.037	1	1.82
Uruguay	URY	0.33	1.88	0.009	4.34	2.75
Venezuela	VEN	0.43	1.65	0.011	1	3.34

Table C.1: Income and Education Data

Vita

Ahmet Kerem Coşar

Education

Ph.D. Economics, The Pennsylvania State University, August 2010.

M.A. Economics, Boğaziçi University, June 2004.

B.A. Management, Boğaziçi University, June 2002.

Research Fields

Primary : International Trade, Macroeconomics.

Secondary : Labor Economics, Growth and Development.

Research Papers

"Adjusting to Trade Liberalization: Reallocation and Labor Market Policies", (May 2010)

"Firm Dynamics, Job Turnover and Wage Distributions in an Open Economy", with Nezih Guner and James Tybout (May 2010)

"Human Capital, Technology Adoption and Development"(January 2009),

"Necessary and Sufficient Conditions of Dynamic Optimization", with Edward Green (January 2008)

Awards & Grants

National Science Foundation - Graduate Student Award to attend the 2. Lindau Meeting of Nobel Laureates and Students in Economic Sciences in Lindau, Germany, August 2006.

Personal

Date of Birth: 09/06/1979

Place of Birth: Ankara, Turkey

Gender: Male

Languages: Turkish (native), English (fluent), German (fluent)