Adjusting to Trade Liberalization: Reallocation and Labor Market Policies*

A. Kerem Coşar†

University of Chicago Booth School of Business

January 25, 2013

Abstract

Labor market responses to trade liberalization typically exhibit a slow reallocation of labor across industries, large costs for displaced workers, and a disproportionate adjustment burden for older workers. To explain these features and analyze alternative policies, I develop a two-sector small open economy model with overlapping generations, frictional labor markets, and sector-specific human capital. Calibrated to Brazilian data, the quantitative model shows that search frictions alone cannot explain the sluggishness of adjustment. The model also helps to compare the distributional and efficiency effects of alternative worker-assistance programs and contributes to a better understanding of trade-induced transitional dynamics.

Keywords: Trade Liberalization; Labor Reallocation; Sector-specific Human Capital.
JEL Classification Numbers: E24, F16, J38.

*The financial support of Human Capital Foundation and partial support by the National Science Foundation (Grant No.SES-0617888) are gratefully acknowledged. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. All errors are mine.

†Address: 5807 S.Woodlawn Avenue, Chicago IL, 60637; e-mail: kerem.cosar@chicagobooth.edu

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 relatively little attention to formally modeling and rigorously quantifying the short to medium-term dynamics that derive from trade liberalization.[2] 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.

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

[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)), and pro-competitive effects (Melitz and Ottaviano (2008)).

[2]Exceptions are Mayer (1974), Leamer (1980), Mussa (1984), and Davidson and Matusz (2004). Kambourov (2009), Artuç et al. (2010) and Dix-Carneiro (2011) are recent quantitative contributions.

slow net reallocation towards industries with comparative advantage.[3] Using industry-level panel data, Wacziarg and Wallack (2004) find that trade liberalization leads to little or no inter-industry worker reallocation, depending on the level of aggregation. Using a linked employer-employee dataset from Brazil, Menezes-Filho and Muendler (2011) find that workers were displaced from previously protected industries, but comparative advantage industries failed to absorb them for years. I provide further industry-level evidence on the lack of labor reallocation in Brazil after trade liberalization in Section 3.1.

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 U.S. workers who change sectors have longer unemployment spells than 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. For Mexico, Krebs et al. (2008) show that liberalization led to a short-run increase in income risk. Using U.S. 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.

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. According to Kletzer (2001), displaced U.S. workers below 45 years old are 11 percentage points more likely to be reemployed

[3] 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.

within two years than workers 45 years or older at the time of displacement. In the case of Brazil, Gonzaga et al. (2003) document that 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. The decomposition of changes in youth employment by Pagés et al. (2009) shows that sectoral reallocation increased demand for young workers in Brazil between 1990 and 2003 (See page 137).[4] Finally, in a survey of transition countries undergoing structural change from a formerly planned economy to a market-oriented one, Boeri and Terrell (2002) summarize the cross-country evidence that older workers 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.

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 in an undirected fashion and randomly match with firms. Depending on 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.

The key outcome of the model is an externality between workers and future employers generated by sector-specificity of skills in the presence of rent sharing in frictional labor markets. The mechanism is similar to Acemoglu (1997): part of the productivity improvement due to skill formation is cap-

[4] 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.

tured 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, particularly binding for an economy subject to skill mismatch during the transition, could help explain why post-liberalization labor reallocation takes so long. Moreover, 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 the pre-reform age-earning profiles and labor market flows (as well as various macro variables) in Brazil. I then consider a decline in the tariff rate that matches the observed increase in trade 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 issues. First, I compare the transition path of the complete model with that of a nested model without human capital. The insight from this exercise is that search frictions alone cannot account for the sluggishness of the transition. Sector-specific human capital is a big impediment to mobility. Second, I investigate the distributional and aggregate effects of labor market policies observed in Brazil and elsewhere. I first consider an unemployment insurance program that mimics the policy introduced in Brazil just before the liberalization of trade. A counterfactual experiment is a revenue neutral, targeted employment subsidy paid to the initial old employed in the previously protected industry conditional on working in the export-oriented industry.[5] My model is especially suitable for

[5]This policy is inspired by the wage insurance program under the 2002 U.S. 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."

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.

The unemployment insurance (actual policy) leads to an output loss during the transition by hampering what the economy needs most: reallocation and skill formation in the expanding sector. In contrast, 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 to build human capital 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 (1990b) apply a two-sector model with search frictions to a small open economy in order to study the validity of conventional trade theorems. Using a two-country two-sector model of trade, Helpman and Itskhoki (2010) 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 in which old workers prefer nonemployment 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. This last point resonates with Feenstra and Lewis (1994) who show that when all factors of production are imperfectly immobile, Dixit-Norman type commodity taxation needs to be augmented by policies that give factors an incentive to move in order to restore the Pareto efficiency of free trade.

Finally, my paper is most closely related to several papers that study the transition under barriers to mobility. Two recent papers by Artuç et al. (2010) and Dix-Carneiro (2011) conduct structural estimation of inter-industry mobility costs for workers in the U.S. and Brazil, respectively. Both models feature competitive labor markets. Given the low level of mobility, estimated mobility costs are large. Lacking micro-foundations for these costs, however, it is not possible to pin down the sources of inertia and possible policy effects from these models. Falvey et al. (2010) analyze distributional and policy-related issues in a Heckscher-Ohlin model with an education sector and skill upgrading. 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. Ritter (2012) uses a similar model to study the distributional impact of offshoring in the U.S. The main difference between my model and related search-based models is in the policy implications. In Kambourov (2009) and Ritter (2012), workers search for jobs in a directed fashion across islands of sectors or occupations. Since labor markets are competitive within each island, there is no rent-sharing. My model highlights the importance of rent-sharing which leads to a suboptimally slow transition even when there are no institutional barriers. As a result, there is a potential efficiency role for policies that encourage workers with different levels of sectoral experience to switch industries.

2 The Model

2.1 The Environment

Demographics are governed by a stochastic overlapping-generations structure. Workers have finite lives with two stages, young and old. 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. When old, each worker faces a constant probability $\delta_m \in (0, 1)$ of death. There is no population growth, and total population is normalized to one. Preferences are defined by a momentary utility function linear in consumption. Agents discount the future at rate $\beta \in (0, 1)$ and 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,

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

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

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

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

$$q_i(z, h) \;=\; A_i z h_i, \tag{3}$$

where A_i is sectoral aggregate productivity, and z is a productivity level idiosyncratic to the match. Relative productivity across sectors, $A_1 \;/\; A_2$, is the only source of comparative advantage in the model. I assume that $(p_1 A_1) \;/\; (p_2 A_2)$ is sufficiently large so that the country is a net exporter of good 1 and a net importer of good 2 in equilibrium. Note that an analysis of employment reallocation across sectors necessitates a diversified economy (i.e. both goods being produced in equilibrium) to begin with. The modeling of firms' sectorial entry decision will ensure that this is the case.

Labor Markets Unemployed workers search for jobs in an undirected fashion taking the match probability ϕ_w as given. On the other side of the market, there is a measure one of value-maximizing firms owned by workers.[6] Some of these firms are already matched with a worker. 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 which sector to enter. The economy-wide measure of new matches is

$$m(U, V) \;=\; \frac{UV}{(U^\lambda + V^\lambda)^{1/\lambda}}, \tag{4}$$

where U is the measure of unemployed workers, and V is the measure of total vacancies.[7] Matching probabilities for workers and firms are thus defined as

[6] Since firms constitute a scarce factor, they earn profits redistributed to workers as dividend income d.

[7] 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.

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

$$\phi_w = (\theta^{-\lambda} + 1)^{-1/\lambda}, \tag{5}$$

$$\phi_f = (\theta^{\lambda} + 1)^{-1/\lambda}. \tag{6}$$

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 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 1 – Timing of Events for Idle Firms

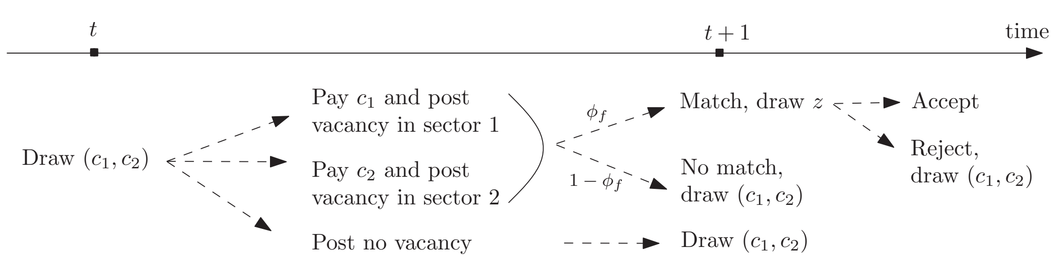


Figure 1 summarizes the sequence of events for idle firms. All such firms are ex-ante homogeneous and cost draws are independent across time. In other words, firms do not carry these costs as a state variable and the outside option has the same value for all matched firms. If an idle firm finds its cost draws for both sectors prohibitively expensive, it remains inactive and redraws next period. If it creates a vacancy, matching uncertainty is resolved at the beginning of next period. Vacancy creation costs are sunk before the matching uncertainty is resolved.[8]

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:

$$h_{it+1} = \begin{cases} h_{it}^{\alpha} H^{1-\alpha} & \text{if employed in sector } i, \\ h_{it} & \text{otherwise,} \end{cases} \tag{7}$$

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. Note that human capital does not depreciate. This assumption is based on Browning et al. (1999) who survey estimates of human capital production function and find no clear evidence for positive depreciation; see Table 2.3 in that paper.

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

[8] 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.

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) where the worker has to divide her time between production and learning, skill formation here is simply a by-product of market work.

State Space At any point in time, a worker is either employed in a sector with match 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. Next, I describe the job formation and vacancy creation problems.

2.2 Job Formation Problem

A firm-worker pair jointly decides to continue or terminate a 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 match in sector-i with productivity z. If the job involves an old worker ($g = o$) with human capital h_t, its value is

$$\Pi_{it}(z, h_t, o) = p_{idt}q_i(z, h_t) + \beta(1-\delta^o_{JD})(1-\delta_m)\mathcal{I}^a_{it+1}(z, h_{t+1}, o)\Pi_{it+1}(z, h_{t+1}, o), \tag{8}$$

where human capital level h_{t+1} evolves according to the law of motion (7).[9] The term $\mathcal{I}^a_{it+1}(\cdot)$ is the job formation policy to be defined below, and equals one if the worker-firm pair decides to continue. A match with a young worker

[9]Note that this is the total value of a productive match. Its continuation value in the case of separation is thus zero. Value functions for employed workers and matched firms will be defined below and take into account continuation values.

$(g = y)$ has value:

$$\Pi_{it}(z, h_t, y) \ = \ p_{idt} q_i(z, h_t) + \beta(1 - \delta_{JD}^y) \Big[\delta_a \mathcal{I}_{it+1}^a(z, h_{t+1}, o) \Pi_{it+1}(z, h_{t+1}, o) + (1 - \delta_a) \mathcal{I}_{it+1}^a(z, h_{t+1}, y) \Pi_{it+1}(z, h_{t+1}, y) \Big]. \tag{9}$$

Although match-specific productivity is fixed after the initial draw, endogenous separations are still possible. Because of the complementarity between the productivity term z and human capital h_i in the production function (3), a worker may accept a match, accumulate human capital and endogenously separate in order to search for a more productive job. Having $\mathcal{I}_{it+1}^a(\cdot)$ in the job value functions captures this possibility.

The continuation values in equations (8) and (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_{ut} respectively (see Appendix B for the derivation of these expressions). An accepted job yields a surplus over the sum of worker's and firm's outside opportunities:

$$\Delta_{it}(z, h, g) \ = \Pi_{it}(z, h, g) \ - \ \big[W_t(\ell_u, h, g) \ + \ J_{ut} \big]. \tag{10}$$

If a match is formed, the parties split the surplus by Nash bargaining with a worker share $\sigma \in [0, 1)$. Both parties would accept the match is their share of the surplus is non-negative. 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 sectoral job formation policy $\mathcal{I}^a_{it}(z,h,g)$ is then defined by the following indicator function:

$$\mathcal{I}^a_{it}(z,h,g) \;=\; \begin{cases} 1 & \text{if } \Delta_{it}(z,h,g) \geq 0, \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

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.[10]

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 the value of a match to the firm $J_{it}(z,h,g)$ derived in Appendix B , the expected value of the firm conditional on being matched is

$$EJ_{it} \;=\; \sum_{g\in\{y,o\}} \nu_t(g|\ell_u) \int_{\mathcal{H}} \int_0^{\overline{z}} J_{it}(z,h,g)\; dF_z(z)\; d\Psi_t(h|\ell_u,g). \tag{12}$$

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

[10]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.

net gain is greater than the value of starting next period idle:

$$\phi_{ft}\beta\big[EJ_{it+1} - J_{ut+1}\big] \;\geq\; p_{Y_t}c_{it},^{11} \tag{13}$$

and it dominates entry to the other sector:

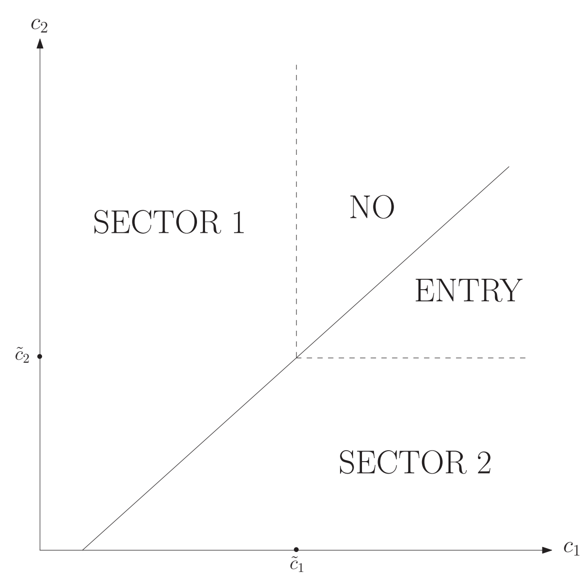
$$\phi_{ft}\beta EJ_{it+1} \;-\; p_{Yt}c_{it} \;\geq\; \phi_{ft}\beta EJ_{jt+1} \;-\; p_{Y_t}c_{jt}. \tag{14}$$

These conditions define the vacancy creation policy for a sector:

$$\mathcal{I}^v_{it}(c_{1t}, c_{2t}) \;=\; \begin{cases} 1 & \text{if (13) and (14) hold,} \\ 0 & \text{otherwise.} \end{cases} \tag{15}$$

Figure 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 $\tilde{c}_{it} = \phi_{ft}\beta(EJ_{it+1} - J_{ut+1})/p_{Y_t}$ defined by (13).

Figure 2 – Sectoral Entry Decision of an Idle Firm



[11] Note that (13) is obtained by rearranging the condition that the expected value of posting a vacancy, $\phi_{ft}\beta EJ_{it+1} + (1 - \phi_{ft})\beta J_{ut+1} - p_{Y_t}c_{it}$, is greater than the value of spending the period inactive and entering next period as an idle firm.

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:

$$\tilde{\mu}_{it} = \int_{\mathbb{R}_+} \int_{\mathbb{R}_+} \mathcal{I}_{it}^v(c_i, c_j) dF_c(c_i) dF_c(c_j). \tag{16}$$

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

$$\mu_{it} = \frac{\tilde{\mu}_{it}}{\tilde{\mu}_{it} + \tilde{\mu}_{jt}}. \tag{17}$$

Note that unlike workers, idle firms do not have any sector-specific capital. Also, since they draw independent vacancy posting costs, they are more flexible in switching sectors in response to relative price changes. While it is a big abstraction to leave out adjustment frictions related to firms and physical capital, this modeling choice is driven by the necessity to make the computational analysis feasible as well as the desire to find the extent to which frictions related to labor markets and human capital specificity alone can explain sluggish adjustments. As discussed in the introduction, the role of physical capital specificity has been extensively studied by previous work.

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 we only need to keep track of workers 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 C, 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 a sequence $\{x_t\}_{t=0}^{\infty}$.

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:

a) 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 formation and vacancy creation problems described in Sections 2.2 and 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

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

b) Vacancy posting decisions define sectoral composition of entry $\{\tilde{\mu}_{1t}, \tilde{\mu}_{2t}\}$ and that of vacancies $\{\mu_{1t}, \mu_{2t}\}$ as in (16) and (17).

c) Matching probabilities are defined by (5) and (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 2.3. This defines market tightness as $\theta_t = V_t/U_t = \tilde{\mu}_{1t} + \tilde{\mu}_{2t}$.

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

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

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.

e) Tariff revenue on good 2 imports, $R_t = \max\{\tau_t p_{2t}(Q^d_{2t} - Q^s_{2t}), 0\}$, is rebated in a lump-sum fashion, and aggregate income is

$$I_t = p_{1dt} Q^s_{1t} + p_{2dt} Q^s_{2t} + R_t. \tag{18}$$

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

$$Q^d_{1t} = \frac{\gamma I}{p_{1dt}}, \qquad Q^d_{2t} = \frac{(1-\gamma) I_t}{p_{2dt}}. \tag{19}$$

f) Final goods market clears with the price determined competitively by (2),

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

g) 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 job formation decisions, exogenous and endogenous job separations, new matches with productivity draws, the law of motion for human capital accumulation (7), and demographic shocks.

h) 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 (18) and (19), 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 3.2, the steady state equilibrium concept will help us to calibrate the model to the pre-reform data from Brazil. In Section 3.4, I will characterize the equilibrium transition path after an unexpected and permanent change in trade policy parameter τ.

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 (1990b) and Helpman and Itskhoki (2010)). Under either interpretation, directed search implies an extreme selectivity where agents receive no information about jobs in the other 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.

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 $\overline{z}$ (the upper bound on productivity draws) 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, Kambourov and Manovskii (2009) argue that human capital is more occupational than sectoral. Entertaining such a view of human capital does not require a drastic change in the model: one could rewrite the production functions of the two sectors as using two occupational inputs with different intensities; for example, electronics are more intensive in engineers and food products are more intensive in bakers and butchers). Trade liberalization would still lead to shifts in relative returns to occupational human capital. If sectoral intensities are different enough, returns to experience in an occupation would be very low in the sector which is not intensive in that occupation, making the model essentially identical to one presented here. This would also generalize the model to account for some transferability of experience between sectors. The quantitative results presented in the next section should thus be interpreted as an upper bound for the role of sector specific human capital.

3 Quantitative Analysis

This section calibrates the steady state of the model to Brazilian data in 1980s in order to analyze the transition to a new steady state following trade liberalization. Having implemented extensive trade and labor market reforms between 1988 and 1991, Brazil is a suitable environment for a quantitative application of the model. I start with a brief background on policy changes and document a lack of sectoral reallocation during the period under focus.

3.1 Brazilian Reforms and Lack of Reallocation

Trade Reforms After years of pursuing an import-substitution policy, Brazil underwent a big trade liberalization between 1988 and 1991. As Figure 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 Collor Plan.[12] The year 1991 also coincides with the beginning of a strong positive terms-of-trade (ToT) shock to the Brazilian economy (see Figure 3).

Unilateral liberalization was not the only change in the external trade regime during this period. In 1991, Brazil signed a treaty with Argentina, Paraguay and Uruguay to establish a common market (Mercosur). Bilateral tariffs were gradually eliminated by the end of 1994. Moreover, other countries in the region implemented trade reforms—such as Mexico in 1987, and Colombia in 1991—which opened new markets for Brazilian exports. All these factors, together with other forces that spurred world trade throughout period, contributed to the steady increase in the Brazilian trade-gdp ratio in the post-1991 period (see Figure 3).

Reforms also changed the structure of tariffs across industries. Figure 4 plots input and output tariff rates for sixty mining and manufacturing industries before and after liberalization. The high variation in the pre-reform period and the subsequent harmonization indicate a big change in relative domestic prices across industries. Moreover, Figure 5 provides evidence that the initial tariff structure granted higher protection to industries where Brazil had low comparative advantage. All else equal, this would imply an artificially

[12] According to Menezes-Filho and Muendler (2011), 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.

high level of output and employment in those industries before trade reforms.

Given these changes, i.e. reduced protection to import-competing industries and increased ToT for export-oriented industries, one would expect a substantial reallocation of resources across tradable industries. Figures 6 and 7 show that this was not the case. The composition of manufacturing workforce was quite persistent throughout the period: within-manufacturing employment shares in 1990, 1995 and 2007 show only minor deviations from what was observed in the pre-reform year 1985 (top right and bottom sub-figures in Figure 6). Figure 7 plots the total within-manufacturing employment share of export-oriented industries (grouped by their trade balance or by their revealed comparative advantage being greater or less than one) over an extended period of time. While it is hard to evaluate the level of short-run activity without knowing the new long-run equilibrium, these figures also show limited level of reallocation. The employment share of comparative advantage industries (left panel) is virtually stable between 1986-1995, while there is an increase of several percentages after 2000 (right panel). One of the objectives of the paper is to explain this inertia.[13]

The top left quadrant in Figure 6 shows that the absence of structural change within manufacturing is not a general characteristic of the Brazilian economy. There were large shifts between industries over a comparably long period of time before the reforms (from 1963 to 1985). Also, Figure 8 provides evidence on sectoral shifts at an aggregate level. While the share of manufacturing in male employment remained constant between 1980-2009, there was a trending shift from agriculture to services. The paper abstracts from this structural change and focuses on reallocations within the manufacturing sector.

Labor Market Reforms The country legislated a series of labor market reforms between 1986-1988 that increased workers' individual and collective rights,[14] and introduced an extensive unemployment insurance system. There

[13] Brazil is not a unique example in that regard. The evidence presented here is consistent with the results of Wacziarg and Wallack (2004).

[14] These changes include a tighter cap on maximum working hours per week, an increase in

were also small scale programs such as an employment subsidy, training, and job search assistance for the unemployed.

One of the goals of the paper is to evaluate the impact that various labor market policies have during the transition following a relative price change. Among the set of possible policies, and among those that Brazil implemented, I focus on two only: unemployment insurance and employment subsidies. Without a doubt, firing costs and unionization affect labor market outcomes both in steady state and during the transition. In particular, firing costs penalize some potentially efficient separations and make the transition more costly. These effects have been studied by Kambourov (2009). My goal here is to focus on the incentives of workers to switch sectors and on the policies that directly affect these incentives. Therefore, I abstract from labor market policies other than unemployment insurance and employment subsidies. Next, I describe some institutional details of these policies that will be relevant for the quantitative analysis.

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.[15] 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 de Barros et al. (2006), 5% of the workforce was receiving this wage supplement in 1997.

These programs were financed by a special 0.65% tax levied on firms' revenues (*FAT: Fundo de Amparo ao Trabalhador*; Workers Protection Fund). Ac-

minimum overtime pay, increased maternity leave and paid vacations, a substantial increase in dismissal penalties, and higher freedom and autonomy to unions. For a summary of these reforms, see de Barros and Corseuil (2004).

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

cording to Berg et al. (2006), total cost of the new social safety net amounted to around 1% of GDP in 1995. Unemployment insurance payments and employment subsidies constituted roughly 70% and 15% of expenditures respectively, with the rest going to training programs. Because of the dominant role of unemployment insurance, I will consider the actual policy change to be a simultaneous lowering of tariffs and introduction of unemployment insurance in the quantitative section that follows. Of particular interest will be the comparison of the transition after the actual policy change with the outcomes of counterfactual labor market policies accompanying trade liberalization.

To sum up, the timing of these reforms justify the treatment of the pre-reform decade as the initial steady state of the Brazilian economy. Labor market reforms became effective in late 1980s and early 1990s. Trade liberalization took place between 1988-1991 with the most decisive steps taken in 1991. In terms of macroeconomic performance, 1980s is considered a "lost decade" for Brazil due to the stagnation following the Latin American debt crisis. Yet, key economic indicators such as terms of trade, trade-to-gdp ratio, per capita real income, and unemployment rate were relatively stable and comparable between the beginning and the end of the decade.[16]

3.2 Calibration

In mapping the model to data, I focus on the formal manufacturing sector in Brazil. As noted by Cosar et al. (2011), complications arise when using the flow approach to modeling labor markets in developing countries where informality (salaried or self-employed) is pervasive. In the case of Brazil, informal employment is almost exclusively a service sector phenomenon. According to Goldberg and Pavcnik (2003), informal workers make up only 10% of Brazilian manufacturing employment between 1987-1990. Although this fraction has increased to 20% by 1998, empirical studies suggest that this was driven by new

[16] Although income growth rates were somewhat volatile, PPP converted income per equivalent adult at constant prices was $7978 in 1988 compared to $7940 in 1981 (series rgdpeqa in Penn World Table 7.1). Unemployment rates in 1981 and 1988 were 4.3% and 3.8%, respectively (ILO (2011)).

labor market regulations (i.e. increased unionization and firing costs) that I abstract from. Using sectoral employment data, Goldberg and Pavcnik (2003) find no evidence that trade liberalization contributed to the increased informality in manufacturing during 1990s. Using a different empirical methodology and household data, Bosch et al. (2012) reach the same conclusion. Moreover, the former paper documents that the increase in informality happened mostly within industries,[17] justifying the decision to keep informality out of the picture when studying compositional changes between industries. Thus, I only consider flows between unemployment and the formal sector in the quantitative analysis.

The calibration proceeds in two stages. First, I set the parameters that do not require the model to be solved. Some of these have direct empirical counterparts while some others are normalized. I then pin down the remaining parameters by matching model-generated moments to their empirical counterparts. The algorithm used to solve for the steady state is described in Appendix D.

Parameters Chosen Without Solving the Model Table 1 summarizes the first stage calibration. The model period is a quarter. Bosch and Maloney (2007) report an average unemployment duration of 5.76 months (their Table 3b and Figure 2), so a quarterly frequency is enough to capture the transitions in the Brazilian labor market.

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

[17] 88% of the increase was within industries, see table 3c in their paper.

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 $(\underline{h}_1, \underline{h}_2) = (1, 1)$. Workers and firms are assumed to split the rents equally which implies $\sigma = 0.5$.

Newborn workers have an expected life span of 40 years which is equally split between young and old-age. This implies $\delta_a = \delta_m = 1/80$. The calibration thus abstracts from population growth which has been on a downward trend in Brazil since mid-1960s.[18] Note that in the model, newborns have no sectoral attachment which makes them more mobile. Declining population growth, however, implies an aging workforce which is a factor toward slower adjustment. Hence, abstracting from population growth does not bias the results in the favor of finding a lengthy transition period.

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 (2.3), 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 $[\alpha, H, A_1, \lambda, C_{sd}, \delta^y_{JD}, \delta^o_{JD}]$. The first two parameters are the curvature and the upper bound for the skill formation process (7) respectively. A_1 is the aggregate productivity of the comparative advantage sector. λ is the elasticity parameter in the matching function (4). The last two parameters are exogenous separation probabilities for young and old workers, respectively.

Calibrated values and empirical targets are summarized in Table 2. The two parameters governing the accumulation of human capital are calibrated to match two moments of the age-earning profile in 1990 reported by Menezes-Filho et al. (2008). Male workers with 5 years of labor market experience earn

[18] Heston et al. (2012) population series displays a secular decline from 2.4% annual growth in 1980 to 1.6% in 1991, and 1.18% in 2010.

41% more than their starting wages on average. 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 (2006). 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—see Figure 4a, bottom panel in their paper. In the model, this is equal to $a\phi_w$ where a is the job formation 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 $C_{sd} = 1.49$.

Bosch and Maloney (2007) report job duration in the formal manufacturing sector as 4.48 years for the time period under study. This figure is calculated from monthly transitions in the Monthly Employment Survey (PME) and implies a quarterly separation rate of $1/(4 * 4.48) = 0.055$. They also report that 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 $40 - 60$. This information helps to set the targets for job separation probability for young and old workers as $(0.063, 0.042)$, respectively. Exogenous separation rates $(\delta^y_{JD}, \delta^o_{JD})$ are calibrated to match these targets. Although not restricted, the calibrated model does not feature endogenous separations in steady state so that exogenous parameters exactly equal the targets.

3.3 Steady State Outcomes

In this section, I report and discuss relevant labor market outcomes that were not targeted in the calibration, and compare the magnitudes with empirical counterparts to the extent possible.

In the 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. The model thus generates the well-known decline in sectoral mobility over the life-cycle. Kambourov and Manovskii (2008) 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. For the age group 47-61, the probability falls to 4.8%. Although there is no empirical study of age-related mobility in Brazil, we can expect it to be qualitatively similar.

A related outcome is the difference in the unemployment rates across 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 formation 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 matches. On the other hand, they are less specialized and have less human capital than the old which implies a higher job acceptance rate for either sector with the purpose of gaining experience. 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. For comparison, unemployment rate among 15-24 old males was 2.9 times higher than among males with age 25 and above between 1985-1990 in Brazil (ILO (2011)).

Turning to post-separation wage changes, 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 23% (Panel A, Column 8 in Table 1). This figure, however, is not controlling for selection based on worker characteristics which could affect the probability of involuntarily separations, and thus should be considered as an upper bound on the isolated effect of the human capital.

In short, the model is constructed and quantified to capture some salient features of steady state labor market outcomes such as life-cycle mobility and unemployment. The next section investigates the transitional dynamics of a trade reform using the calibrated model.

3.4 Policy Experiments

This section first replicates the actual policy package in Brazil: simultaneous reduction in tariffs and introduction of unemployment insurance. Two counterfactual policy experiments follow. First, I liberalize trade but do not implement any income support program. 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. This counterfactual 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. The second counterfactual scenario 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 D.

3.4.1 Trade Liberalization with and without Unemployment Insurance

Let the economy initially be in the steady state which it is calibrated in Section 3.2 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.[19] 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

[19]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 and the real value of a match will be the same as when the intermediate good sector is taxed.

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. Note that in a small economy model, this change captures the relative price effect of both the tariff reduction and the terms-of-trade improvement documented in Figure 3.

How does the economy respond to these changes in the short- and long-run? And how does it compare to the counterfactual case when trade is liberalized without the introduction of unemployment insurance? Figure 9 compares the net output path during the transition in response to such counterfactual policy with the path under the actual policy solved above. Several results emerge. In the actual policy path, there is an initial dip in net output in line with the overshooting in unemployment which we do not see in the counterfactual scenario with no unemployment insurance. In the latter case, the flows in and out of employment are enough to accommodate the necessary reallocation in the short run. The message is similar to Ljungqvist and Sargent (1998) who analyze the impact of the welfare state under structural change: unemployment compensation hinders the adjustment of an economy to large shocks. Second, unemployment insurance eats away the gains from trade liberalization. The initial drop in output is followed by convergence to a lower steady state level. Finally, transition takes a long time under both scenarios. The skill stock of the economy adjusts as more members of newborn cohorts accumulate human capital in the export-oriented sector. In the counterfactual experiment, 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 further explore the quantitatively dominant mechanism behind the sluggishness of adjustment, 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 10 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. In the complete model with both components, the half-life is 34 years which is almost a generation's career length. 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 (2011) that search frictions alone cannot explain unemployment arising from inter-industry shifts in U.S. data without assuming an unreasonably large cost of moving. Sector-specific human capital acts a barrier to mobility since it increases the opportunity cost of switching sectors for workers.

3.4.2 Counterfactual: 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 declines linearly from 1% to zero in 80 periods.[20] Again, the government runs a balanced budget every period. The policy thus redistributes income from the beneficiaries of trade (those with experience in sector 1) to losers of trade (workers experienced in sector 2).

Figure 11 plots the net output path under the targeted employment subsidy (red dashed line) together with the path when there is no income support program (blue solid line, which is the same as in Figure 9 representing trade liberalization without unemployment insurance). After six quarters, net output with employment subsidy exceeds the alternative path 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 make the transition path more concave with faster initial adjustment. The discounted value of net output stream with employment subsidy is 4.17% higher than its value under the actual policy with unemployment insurance, and 0.61% higher than under the counterfactual scenario with no income support. By encouraging inter-sectoral mobility,

[20] 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.

this policy strengthens the feedback loop between skill formation by workers and entry by firms, and thus speeds up reallocation.

The source of inefficiency that calls for a public policy is a learning externality between workers and future employers similar to Acemoglu (1997). A combination 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 underinvest in learning. 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—through rent-sharing—will benefit from their recent learning. 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.[21] During the transition, workers displaced from the import-competing sector underinvest in skill formation by rejecting some matches in the expanding sector with low starting wages but learning prospects. The employment subsidy is essentially a subsidy for investment in human capital. 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.

Could unemployment insurance ever be welfare improving in this economy? The risk-neutrality of agents assumes away potential gains. Models of optimal unemployment insurance emphasize another source of welfare gains under risk aversion (e.g., Acemoglu and Shimer (1999)). 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

[21] Note standard search externalities are also present: entry and exit of workers and vacancies into the matching process affect matching probabilities of the other participants. The Hosios condition which ensures efficiency in search models (Hosios (1990a)) does not hold here because the elasticity of the matching function (4) is not constant. As a result, there might be deviations from optimality resulting from search externalities.

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 underinvesting in searching for more productive jobs under some parameter values because of rent-sharing. On the other hand, the moral hazard effect is present. Here, it not only reduces employment but the stock of skills as well. The overall effect is thus ambiguous. Also note that I do not claim that the above employment subsidy scheme is the optimal policy. Finding the optimal policy for this environment is beyond the focus of this paper, but it is an interesting open question. The main point of my exercise is to demonstrate the potentially beneficial role for employment subsidies in an economy suffering from skill mismatches while adjusting to a major reallocative shock.

4 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. Model calibration using aggregate and micro moments of pre-reform Brazilian economy helps to simulate the effect of trade and labor market reforms. These simulations show that labor market adjustment to a reallocation shock can indeed take a very long time. This long transition is due to a combination of labor market frictions, workers having finite lives and sector-specific human capital.

I then investigate the quantitative role of these components in accounting for the slow pace of labor reallocation. A comparison of transition paths with and without human capital suggests that human capital is a much bigger barrier to mobility than 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 logical question that follows is what kind of policies could help overcome the sluggish adjustment, if there is a role for policy at all. 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 losses, but also increases total net output throughout the transition. The market failure behind this result is underinvestment in human capital of the comparative advantage sector. Because of search frictions and rent sharing, workers are not full claimants of their "investment" when changing sectors. As a result, transition is sub-optimally slow. A policy that rewards work and mobility mitigates this market failure. Compensation policies such as the wage insurance under the U.S. Alternative Trade Adjustment Assistance (ATAA) and Reemployment Trade Adjustment Assistance (RTAA) 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/RTAA are 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.

Finally, the model can be applied to study other instances of sectoral price shifts, 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.

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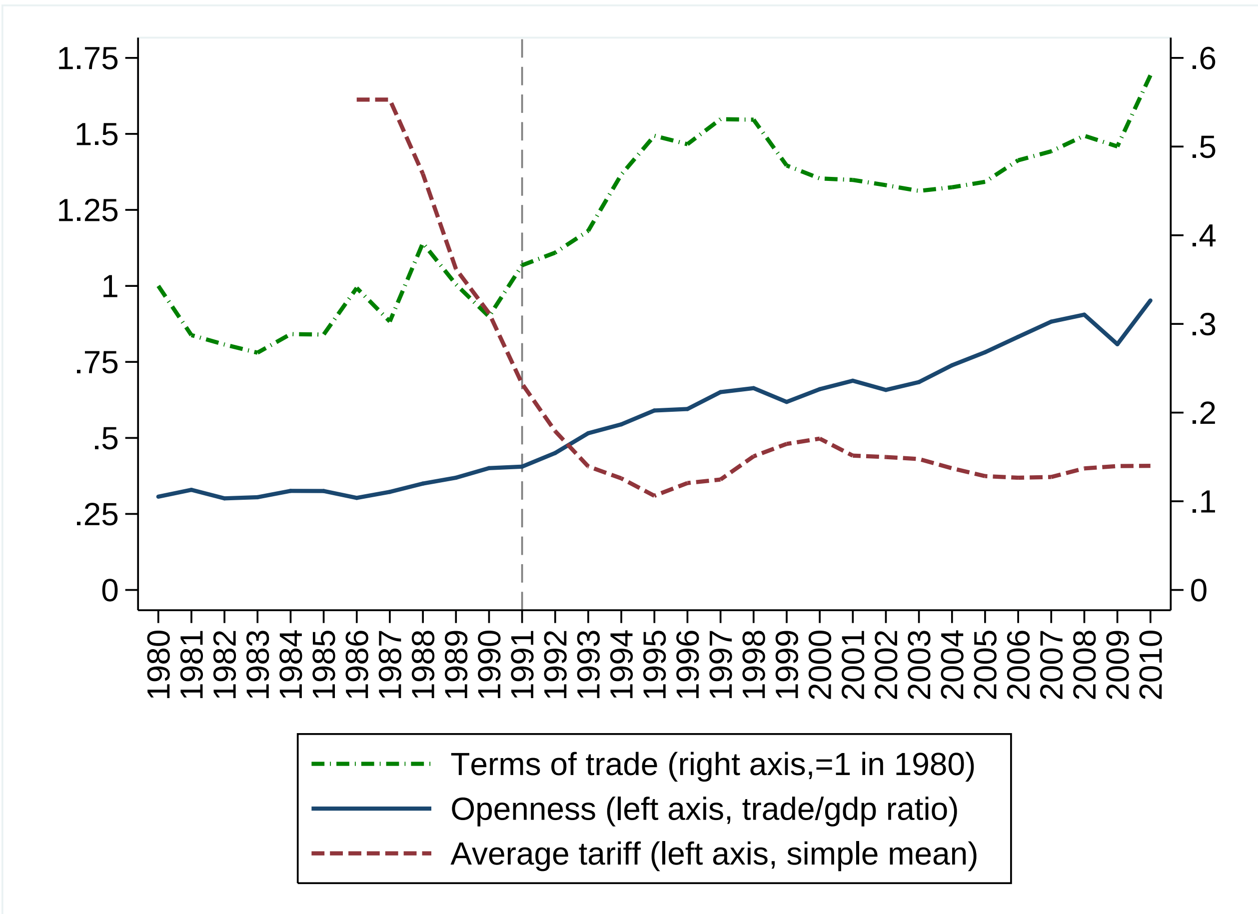
Appendices

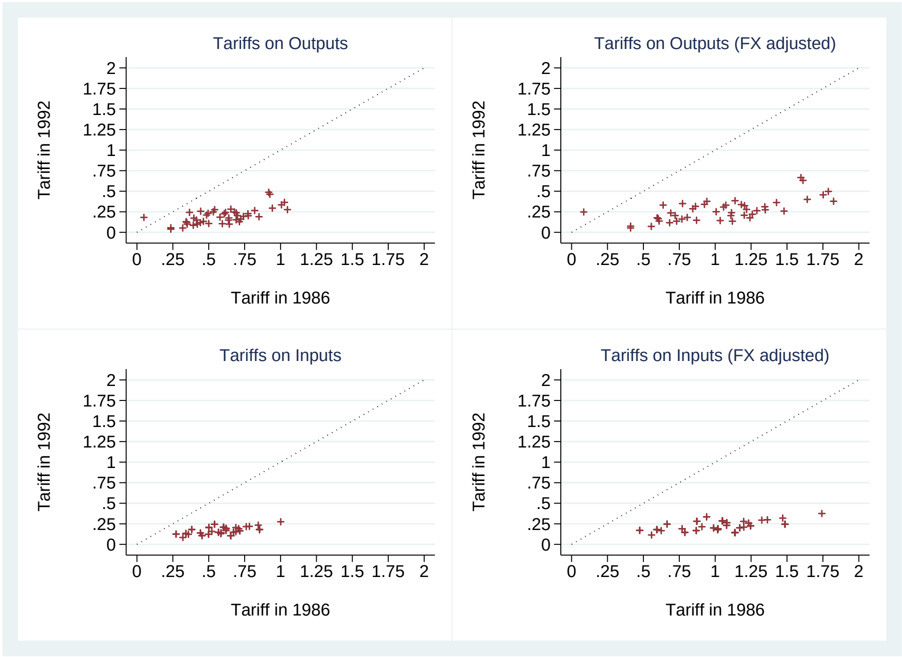
A Figures and Tables

Figure 3 – Tariffs, Terms of Trade and Openness In Brazil



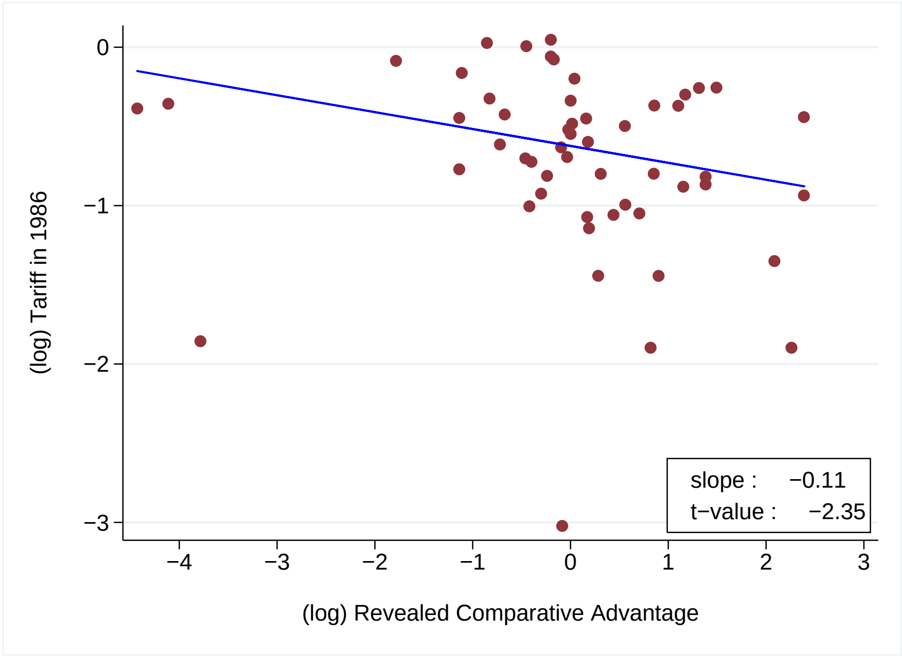
Notes: Openness: total trade as a percentage of GDP at 2005 constant prices (series openk in Penn World Tables 7.1); Terms of trade: net barter terms of trade index (1980 = 1, indicator TT.PRI.MRCH.XD.WD in http://data.worldbank.org); Average tariff: simple mean of applied tariff rates on manufactured products (series TM.TAX.MANF.SM.AR.ZS in http://data.worldbank.org)

Figure 4 – Industry Level Tariff Rates Before and After Trade Reforms



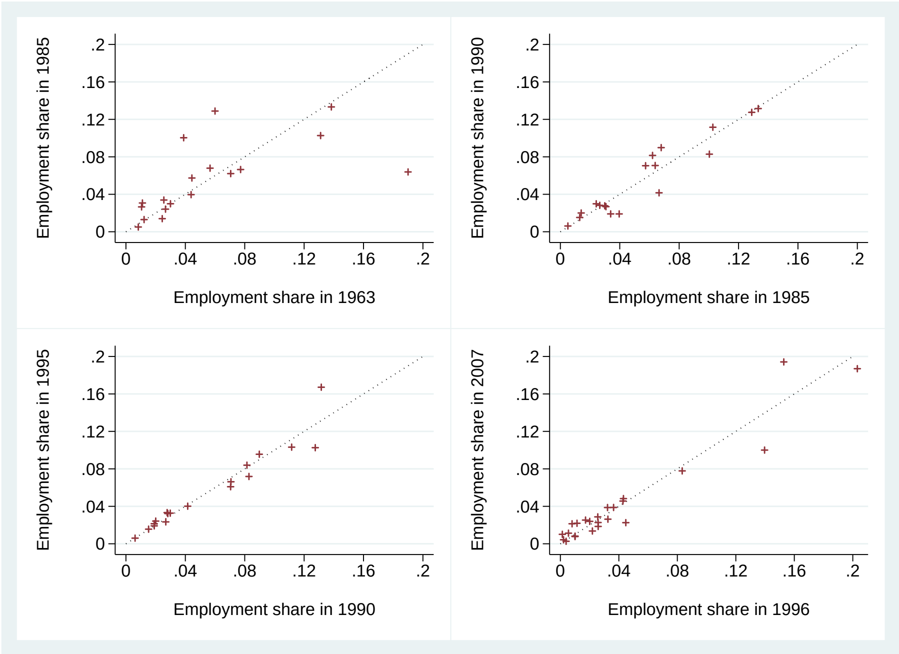
Notes: Industry level (Brazilian classification *Nivel 80*) tariff rates compiled by Marc Muendler. Top panel is tariffs on final products, bottom panel is average tariff rate on inputs used by each industry calculated using Brazilian IO tables. All series are available in http://www.econ.ucsd.edu/muendler/html/brazil.html

Figure 5 – Industry Level Initial Tariffs and Comparative Advantages



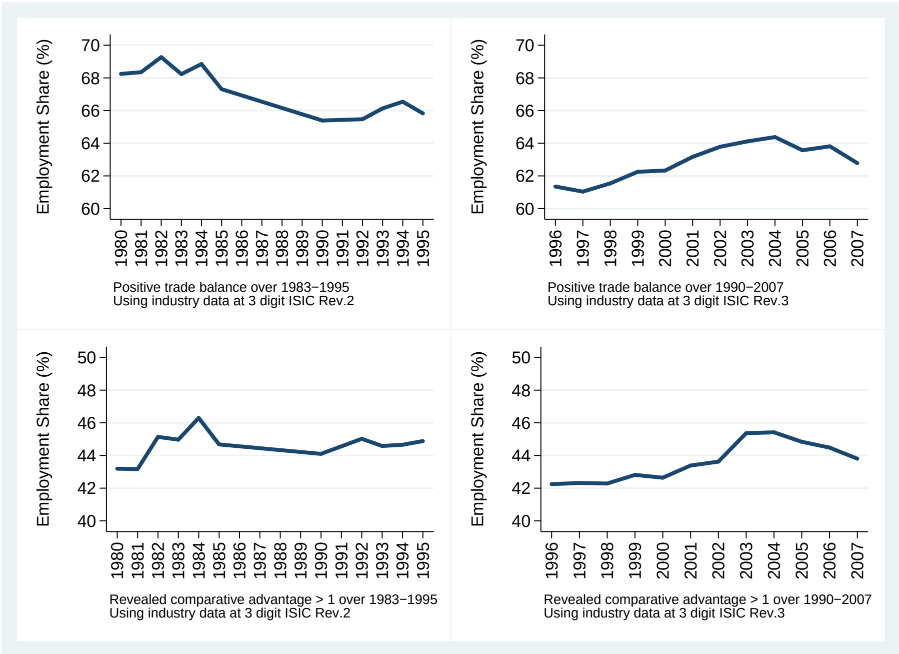
Notes: Logarithm of Brazilian tariff rates on final products in 1986 (see Figure 4 for details) regressed (using a robust-to-outliers method) on a constant and log measure of Balassa comparative advantage. All series are available in http://www.econ.ucsd.edu/muendler/html/brazil.html

Figure 6 – Workforce Composition across Manufacturing Industries



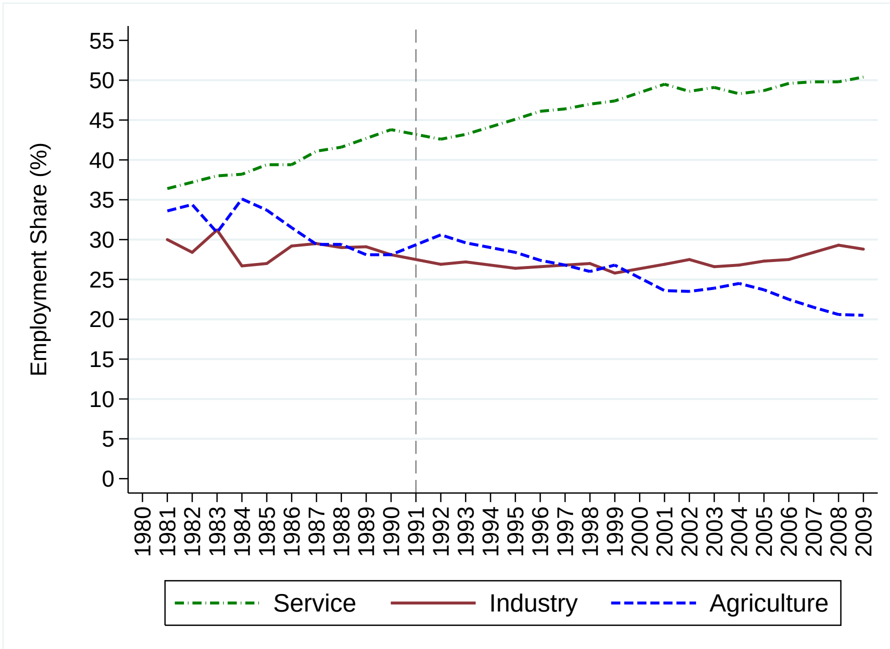
Notes: Within-manufacturing employment share of industries at 3-digit ISIC classification in Brazil. The bottom right panel is based on ISIC Rev. 3 (UNIDO INDSTAT4 2010). All other plots are based on ISIC Rev. 2 (UNIDO INDSTAT3 2006)

Figure 7 – Employment Share of Comparative Advantage Industries



Notes: Total employment share of export-oriented industries in Brazil. In the top panel, export-orientation is defined as a positive trade balance at the industry level over the period for which data is available. In the bottom panel, it is defined as an industry with a Balassa comparative advantage index greater than one using total exports over the period for which data is available. Due to change in industry classification, series are not continuous: left and right panels use industry data in 3 digit ISIC Rev.2 and Rev.3 classifications, respectively (UNIDO IDSB 2006, IDSB 2011, INDSTAT3 2005, INDSTAT4 2010).

Figure 8 – Workforce Composition across Aggregate Sectors



Notes: Employment share (across male workers) of aggregate sectors at 1 digit ISIC classification in Brazil (International Labour Office (ILO), Key Indicator of the Labour Market (KILM) 7th edition)

Figure 9 – Net Output under Unemployment Insurance

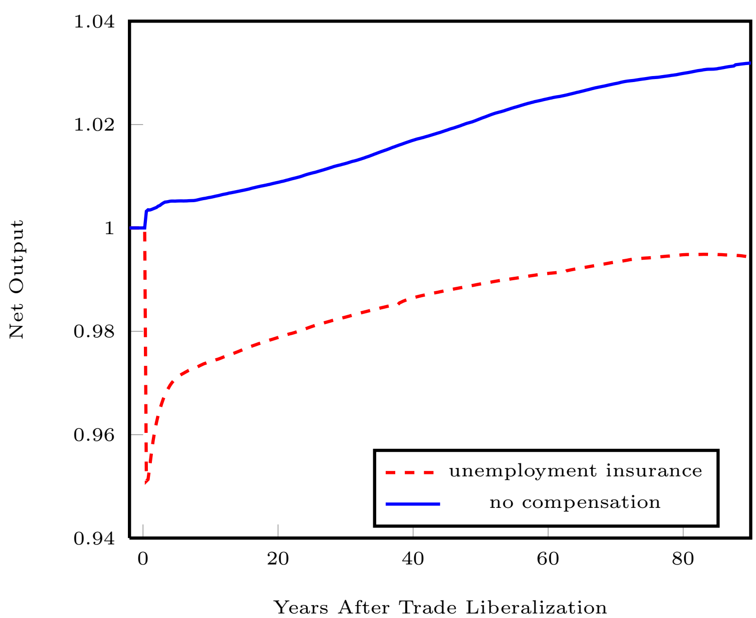
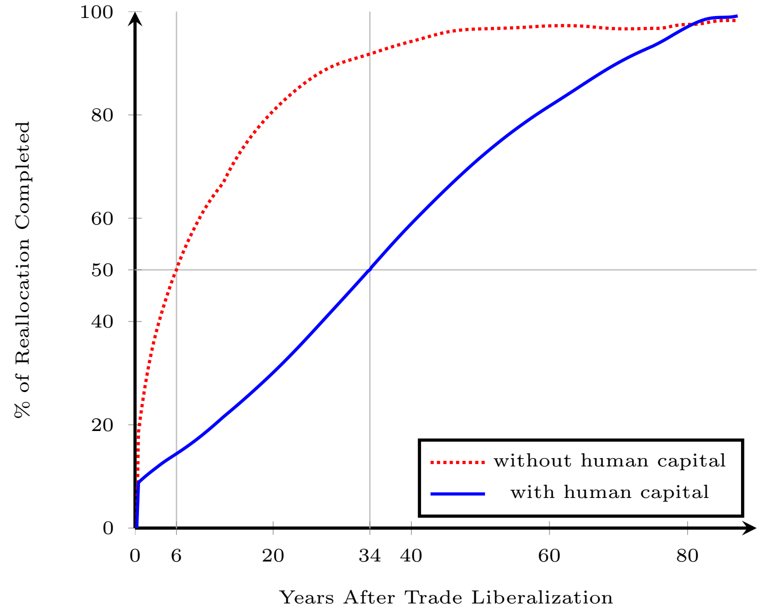
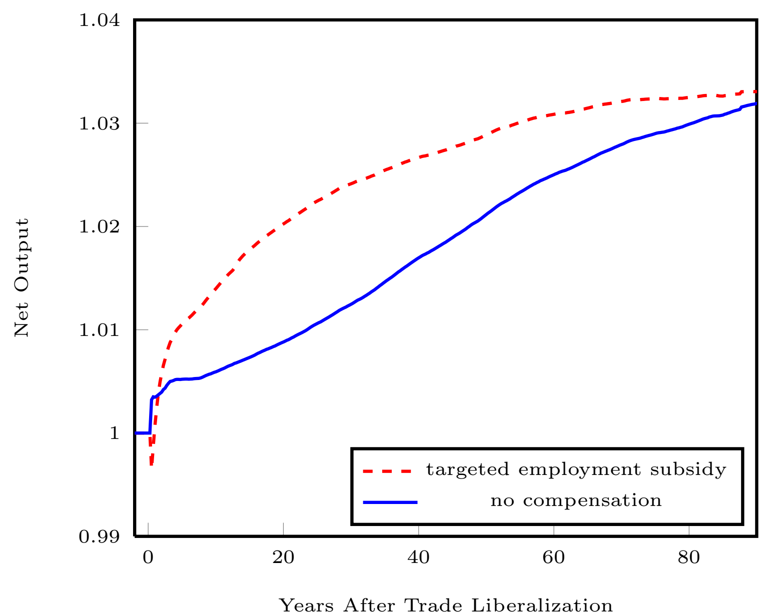


Figure 10 – Employment Share Reallocation During the Transition



Notes: 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 $100 \cdot (E_t^1 - E_0^1)/(E_T^1 - E_0^1)$.

Figure 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 $[0, 1]$	normalization
γ	Cobb-Douglas share of good 1	0.50	symmetry between sectors
σ	worker's bargaining share	0.50	standard
$\underline{h}_i$	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

Table 1 – Parameters Set Without Solving the Model

Parameter	Value	Target	Source
α	0.98	wage increase after 5 years of initial experience = 1.41	Menezes-Filho et al. (2008)
H	2.60	wage increase after 40 years of experience = 2.43	Menezes-Filho et al. (2008)
A_1	1.71	export / (value added) = 0.26	Pavcnik et al. (2004),OECD (2006)
λ	2.16	elasticity of hiring to unemployment = 0.25	Hoek (2007)
C_{sd}	1.49	transition probability from unemployment to formal employment = 0.38	Bosch et al. (2007)
δ^y_{JD}	0.063	job destruction for young	Bosch and Maloney (2007)
δ^o_{JD}	0.042	job destruction for old	Bosch and Maloney (2007)

Table 2 – Parameters Obtained by Solving the Model

B Value Functions (Not intended for publication)

The value of a match to the worker is

$$W_t[\ell_i(z), h_t, g] \;=\; \max_{\text{accept,reject}} \Big\{ \sigma\Delta_{it}(z, h_t, g) + W_t(\ell_u, h_t, g)\;,\; W_t(\ell_u, h_t, g) \Big\}. \tag{20}$$

Similarly, the value of a match in sector i to the firm is given by

$$J_{it}(z, h, g) \;=\; \max_{\text{accept,reject}} \Big\{ (1-\sigma)\Delta_{it}(z, h_t, g) + J_{ut}\;,\; J_{ut} \Big\}, \tag{21}$$

where the match is with a worker in state (h, g) and the productivity draw is z. The solutions to these two problems agree: only matches with a positive surplus are accepted, giving rise to the job formation policy function (11). I now specify $W_t(\ell_u, h, g)$, the value of unemployment to the worker, and J_{ut}, the value of being idle to the firm.

B.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:

$$\begin{aligned} W_t(\ell_u, h_t, o) \;&= p_{Yt} d_t + \beta(1-\delta_m)\Big[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, o) f_z(z) dz \\ &\qquad + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, o) \Big]. \end{aligned} \tag{22}$$

For a young worker:

$$\begin{aligned} W_t(\ell_u, h_t, y) \;&= p_{Yt} d_t + \beta(1-\delta_a)\Big[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, y) f_z(z) dz \\ &\qquad + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, y) \Big] \\ &\quad + \beta\delta_a \Big[\sum_{i=1}^{2} \phi_{w_i t} \int_0^{\overline{z}} W_{t+1}(\ell_i(z), h_{t+1}, o) f_z(z) dz \\ &\qquad + (1 - \phi_{w_1 t} - \phi_{w_2 t}) W_{t+1}(\ell_u, h_{t+1}, o) \Big] \end{aligned} \tag{23}$$

B.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:

$$\hat{c}_{it} \;=\; \int_{\mathbb{R}_+} \int_{\mathbb{R}_+} c_i \, \mathcal{I}^v_{it}(c_i, c_j) dF(c_i) dF_c(c_j). \tag{24}$$

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

$$J_{ut} \;=\; \sum_{i=1}^{2} \tilde{\mu}_{it}\Big\{\phi_{ft}\beta EJ_{it+1} \;+\; (1-\phi_{ft})\beta J_{ut+1} - p_{Yt}\hat{c}_{it}\Big\} \;+\; (1-\tilde{\mu}_{1t}-\tilde{\mu}_{2t})\beta J_{ut+1}. \tag{25}$$

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.

C 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 (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:

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

D 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.

D.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. Given the curvature of human capital accumulation α that is being iterated on, I construct the grid points in line with the increments implied by the learning function (7).

D.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 $(J_u, \phi_f, \phi_w, \tilde{\mu}_1, \tilde{\mu}_2)$ by simulating a large number of cost draws for firms from the distribution $F_c(c)$, and using expressions (5), (6), (13), (14), (25) and the fact that market tightness θ is equal to $\tilde{\mu}_1 + \tilde{\mu}_2$.

Step 3. Solve for the job formation cutoffs $\tilde{z}_{it}(h, g)$, and the value functions (20) and (21) using the following subroutine:

i. Start with old workers. Assume initial set of values for unemployment $W(\ell_u, h, o)$ and matches $\Pi_i(z, h, o)$ for both sectors. Use (10) to find the job formation cutoffs, and update $\Pi_i(z, h, o)$ using equation (8).

ii. To update $W(\ell_u, h, o)$, use the job formation cutoffs in (22). Iterate until convergence.

iii. Repeat the same steps for young workers, using equation (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 (12), iterate until the distances $|EJ_1^{j+1} - EJ_1^j|$, and $|EJ_2^{j+1} - EJ_2^j|$ are sufficiently small.

D.3 Transition Algorithm

In order to solve for the transition between two steady states, I use an algorithm 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 $\{J_{ut}, \phi_{ft}, \phi_{wt}, \tilde{\mu}_{1t}, \tilde{\mu}_{2t}\}_{t=1}^{t=N}$ by using the same cost draws from $F_c(c)$ as in the steady state solution. Again, we use expressions (5), (6), (13), (14), (25) 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 formation cutoffs backward, using the value functions specified in Section 2.2 and Appendix B. Store the value functions of firms $\{J_{it}(z, h, g)\}_{t=1}^{t=N}$.

Step 4. Starting with $t = 1$, simulate the economy forward for 10,000 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.

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 $\{J_{it}(z, h, g)\}_{t=1}^{t=N}$ in equation (12) 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.