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Incorporating Unemployment into the GTAP Model

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This paper documents the development of a labor module that incorporates job-search frictions, to introduce unemployment into the standard GTAP model. In this approach, unemployed individuals must search for a job opening and firms that want to hire must search for a worker to fill the job. To illustrate the potential value of a GTAP model with frictional unemployment, the impacts of a 25 percent increase in U.S. tariffs on metal products (e.g., ferrous and non-ferrous metals) are simulated. While employment of skilled and unskilled labor increases in the U.S. metals sector, employment of both types of labor declines in U.S. manufacturing and services sectors. These decreases in employment offset the increase in the metals sector, leading to a 0.8 percent increase in the unemployment of unskilled labor and a 1.5 percent in the unemployment of skilled labor. These increases would translate to a 0.1 percent point increase in the unemployment rate in the U.S. labor market. A potential barrier to wider use of a the GTAP model with unemployment is the availability of job separation or turnover rate data in regions other than the United States. In the example simulation, job turnover rates, and thus the initial levels of matched labor in the non-U.S. regions are assumed to be the same as for United States.

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1. Introduction

Many applied general equilibrium (AGE) models, such as GTAP (Corong, et al. (2017)), have been designed to assess the impacts of policy changes, such as trade liberalization and climate change, or technological change in the medium to long-run where the time period is long enough for labor markets to return to a fixed or full-employment equilibrium following the policy or technological change. As such, these models assume that the labor supply is fixed and a uniform, flexible wage rate balances labor supply and labor demand. As noted by Boeters and Savard (2013), researchers must go beyond this basic labor market specification if they are interested in assessing the impacts of a specific change in labor market

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institutions or if they are interested in the labor market impacts of a policy change that does not directly impact labor markets, such as trade liberalization. Given recent concerns regarding the impacts of trade agreements, such as the North American Free Trade Agreement (NAFTA), on manufacturing and total employment in the U.S., the latter will be the focus of this paper.

To move beyond the basic labor market specification, there are numerous choices an AGE modeler can make within the three components of the labor market: labor supply, labor demand, and market coordination.[1] For example, for labor supply, one choice is whether to use a representative household or microsimulation approach. For labor demand, the choices center on the degree of substitution or complementarity between different types of labor (e.g., skilled versus unskilled) in production. Finally, for market coordination, modelers are faced with the choice of perfectly or imperfectly competitive labor markets. In addition to these three labor market components, Boeters and Savard (2013) also identify two other key directions of model development: introducing more complex labor market mechanism such as endogenous unemployment and collective bargaining, and disaggregation of units (e.g., types of labor, households, occupations). These different dimensions and labor market components will be used to help organize the discussion on modeling choices made in this paper and the potential benefits and drawbacks of these choices.

Because the main objective of this paper is to extend the labor market specification in the standard GTAP model to enable the model to assess the impacts of policy changes on employment (and hence unemployment), only labor market issues that can be modeled using static or recursively dynamic models are considered. For example, trade agreements that reduce employment of unskilled labor in manufacturing could cause a change in education choice, increasing the level of skilled versus unskilled labor. This type of life cycle decision would require a dynamic model with forward-looking agents. In addition, labor mobility across countries will not be considered as this goes beyond the purview of models based on the standard GTAP data base (Aguiar, et al. 2019).

Several earlier AGE models have assumed more complex labor market coordination than perfect competition within a static or recursively-dynamic model. Kehoe and Serra-Puche (1983) assume that the real wage of urban consumers in Mexico is downwardly rigid, due to the presence of a government minimum wage policy and labor unions, but where wages are updated. Similarly, in the MONASH model of Australia, Dixon and Rimmer (2002) assume that institutions such as labor unions cause wages to be "sticky" in the short-run, leading to the possibility of unemployment. While the assumption of wage rigidity may be appropriate in some countries, it would not be for other countries

[1] See Boeters and Savard (2013) for a recent review of alternative labor market specifications in AGE models.

such as the United States where the membership in labor unions has been decreasing and real wages have experienced significant fluctuations since 1979 (see Figure 1).

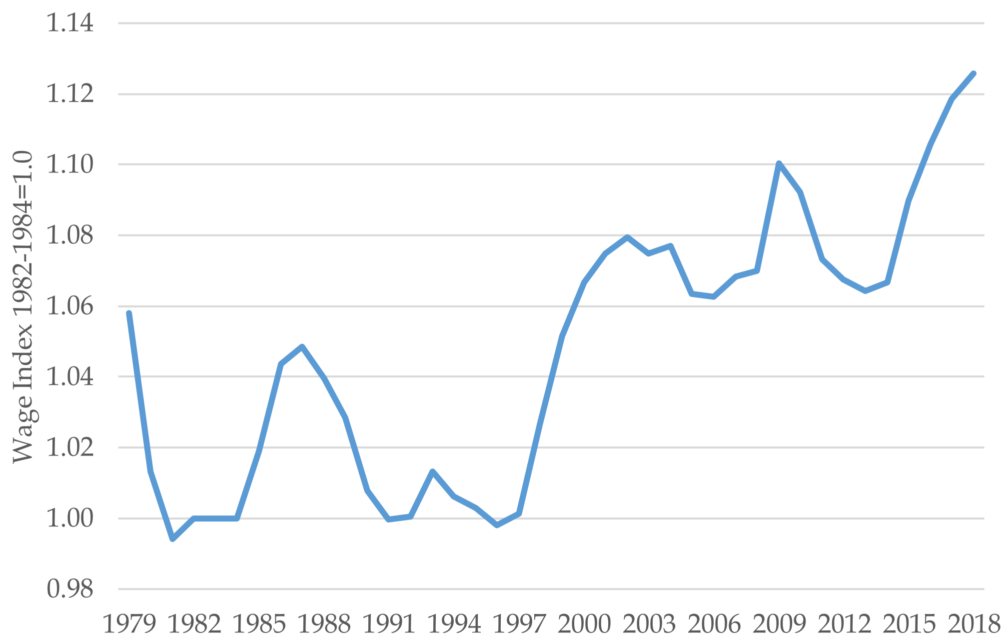

Figure 1. U.S. median weekly real earnings, employed full time, wage and salary workers, 16 years and over

Source: Federal Reserve Economic Data (Available at https://fred.stlouisfed.org)

A recent alternative to wage rigidity is the emerging literature introducing job-search frictions into AGE models, such as Hafstead and Williams (2018). In this approach, unemployed individuals must search for a job opening and firms that want to hire must search for workers to fill the job. The number of "matches" or new hires in an industry is determined by a matching function that depends on the recruiting effort in each industry and the level of unemployment (see Shimer, 2010). The greater the own recruiting effort or the greater the level of unemployment, the larger the number of matches. Conversely, the greater the recruiting effort in other industries, the smaller the number of matches in a given industry. This approach has two key advantages: it is based on consistent microeconomic foundations, and it can replicate key stylized facts about labor markets, such as the substantial rate of job turnover observed in the U.S. economy.

The remainder of this paper is organized as follows. The next section discusses the specification of labor supply in the model, including modifications to the existing GTAP preference structure to incorporate a labor-leisure decision by the representative household in each region. This section also discusses the calibration of the labor disutility parameters to ensure that the preference structure is compatible with observed labor supply in the GTAP data base. The third and fourth sections describe the matching process and the modifications to the production structure of the GTAP model to incorporate existing and matched labor. The fifth section describes the equations in the new labor module and the required modifications in the GTAP data base. The last section compares the results of an experiment where the U.S. increases its existing ad-valorem tariff on metal products by 25 percent using the standard GTAP model and the new GTAP Labor model (GTAP-LAB). This section also includes a sensitivity analysis of the new parameters in the GTAP-LAB model to highlight which endogenous variables are most affected by alternative values. The section concludes by considering a "short-run" scenario wherein capital is sluggish between sectors within a region.

2. Labor supply

When moving away from the assumption of fixed labor supply, one must recognize that the supply of labor can be flexible in both the number of hours worked (intensive margin) as well as labor market participation (extensive margin). Thus, there are three key aggregate labor supply elasticities: the elasticity of hours worked with respect to the wage rate, the elasticity of hours worked with respect to non-wage income, and the elasticity of participation with respect to the wage rate.[2]

To determine the number of hours worked (or labor supplied), the representative household[3] will maximize a utility function that includes leisure as a separate good, giving rise to disutility of supply, labor subject to budget and time constraint. Consider the following general specification that abstracts from taxes and treats consumption as a single aggregate good:

$$max\ U\ (c, l)\ \text{s.t.}\ p_c c = wh + K \text{ and } T = h + l \tag{1}$$

where c is consumption, l is leisure, p_c is the aggregate price of consumption, h is hours worked, K is non-wage income, and T is the time constraint. Using the time constraint, we substitute h out of the budget constraint and have the following "full-income" constraint:

$$p_c c + wl = wT + K \tag{2}$$

where the wage rate times the hours of leisure represents the opportunity cost of leisure. Note that because of the linear time constraint, choosing the hours of leisure or the hours of work will be equivalent.

[2] The level of non-wage income is typically assumed not to affect participation.

[3] Because the GTAP database assumes a single representative household in each region, this assumption will be maintained throughout this paper.

If the utility function in equation (1) is represented by a Constant Elasticity of Substitution (CES) or Linear Expenditure System (LES), commonly used functional forms in AGE models, then the preference structure for the representative household is separable between consumption and the number of hours worked (or leisure).[4] This implies that the marginal utility of consumption does not depend on the number of hours worked. There are several advantages to this assumption. First, it will eliminate the need to disaggregate the regional household into employed and unemployed households and keep track of how their employment status might change following a policy shock. Second, it maintains a preference structure that is parsimonious in the number of unknown parameters that must be supplied by the modeler. This is an important consideration in multi-regional models.

If the utility function in equation (1) is CES, then the income elasticity of demand for leisure will equal 1, since the CES function is homothetic. If the time constraint T is constant, then any change in the hours of leisure demanded will have an equal and opposite effect on the hours of labor supplied. Consider a change in non-wage income:

$$\frac{\partial l}{\partial K}\frac{K}{l} = 1 = -\frac{\partial h}{\partial K}\frac{K}{l}\frac{h}{h} = -\eta_h\frac{h}{l} \tag{3}$$

where η_h is the elasticity of hours works with respect to non-wage income. Bargain et al. (2014) find that the elasticity of hours with respect to non-wage income is very small, with an absolute value of the point estimate being of less than 0.05, and often negative across 25 representative micro datasets. This result was consistent across married men and women, and single men and women. If η_h in equation (3) is small, then number of hours of leisure is also small relative to the number of hours worked. If η_h equals -0.05 and h equals 40, then l must equal 2 and T would equal 42.

Given the very small empirical estimates of η_h, one could consider an alternative, additive preference structure where non-wage income does not directly affect the number of hours worked. This would have the advantage of not requiring T to be calibrated for each representative household in the model. Following Hafstead and Williams (2018), consider the following additive utility function with both skilled and unskilled labor:

$$U(c,h) = log\, c - \psi_u\frac{h_u^{1+\rho_u}}{1+\rho_u} - \psi_s\frac{h_s^{1+\rho_s}}{1+\rho_s} \tag{4}$$

where c is level of consumption, h is the units of labor for unskilled (u) and skilled (s) labor, ψ represents the disutility from work parameter, and $1/\rho$ is the Frisch

[4] The same is true for any utility function this is additive in consumption and the number of hours worked. For a utility function that is non-separable in consumption and hours worked, see Shimer (2009) and Yedid-Levi (2016).

elasticity of labor supply. To derive the labor supply from equation (4), consider the Lagrangian for the constrained utility maximization problem:

$$L = log\, c - \psi_u \frac{h_u^{1+\rho_u}}{1+\rho_u} - \psi_s \frac{h_s^{1+\rho_s}}{1+\rho_s} + \lambda[w_u h_u + w_s h_s + K - p_c c] \quad (5)$$

where w is the wage rate, K is non-labor income, p_c is the consumption price index, and λ is the Lagrange multiplier. The first-order conditions (FOC) for total consumption, labor supplied, and the Lagrange multiplier are:

$$\frac{\partial L}{\partial c} = \frac{1}{c} - \lambda p_c = 0 \quad (6)$$

$$\frac{\partial L}{\partial h_u} = -\psi_u h_u^{\rho_u} + \lambda w_u = 0 \quad (7)$$

$$\frac{\partial L}{\partial h_s} = -\psi_s h_s^{\rho_s} + \lambda w_s = 0 \quad (8)$$

$$\frac{\partial L}{\partial \lambda} = w_u h_u + w_s h_s + K - p_c c = 0 \quad (9)$$

Using the FOC for skilled and unskilled labor:

$$w_l = \frac{\psi_l h_l^{\rho_l}}{\lambda} \; \forall l = s, u \quad (10)$$

then equation (10) are the inverse labor supply functions. If one expresses h as a function of the wage rate, the labor supply elasticities are:

$$h_l = \left[\frac{\lambda w_l}{\psi_l}\right]^{\frac{1}{\rho_l}} \rightarrow \varepsilon_l = \frac{\partial h_l}{\partial w_l}\frac{w_l}{h_l} = \frac{1}{\rho_l} \; \forall l = s, u \quad (11)$$

Thus, in this model, the labor supply elasticities for skilled and unskilled labor are constant.[5]

Because the utility function in equation (4) is separable between consumption and the number of hours worked, instead of *log c* for consumption, one could substitute the current GTAP preference structure for private consumption, government consumption and savings. Thus, the new GTAP preference structure can be expressed as:

$$U = Q_P^{\alpha} Q_G^{\beta} Q_S^{\delta} - \psi_u \frac{h_u^{1+\rho_u}}{1+\rho_u} - \psi_s \frac{h_s^{1+\rho_s}}{1+\rho_s} \quad (12)$$

where Q_P is the aggregate quantity of private consumption, Q_G is the aggregate quantity of government consumption, and Q_S is the quantity of savings. Because of the assumption of separability, no changes are required in the existing GTAP product demand equations. The resulting labor supply function will be included in the new labor module for GTAP-LAB.

[5] Note that non-wage income (K) will indirectly affect the number of hours worked through λ.

2.1 Labor supply elasticities

Bargin, et al. (2014) state that, while the consensus in the existing literature on labor supply is that the elasticity of hours worked with respect to the wage rate is largest for married women and smallest for men, there is a large variation in the magnitude of the estimated elasticities of labor supply. For married women, Blundell and MaCurdy (1999) report wage elasticities ranging from -0.01 to 2.03 while Evers, et al. (2008) report elasticities ranging from 0.03 to 2.79. However, Evers, et al. (2008) report much lower variation in the wage elasticities for men. In Bargin, et al. (2014), uncompensated elasticity of total hours, reflecting both the intensive and extensive margins with respect to the wage rate, range from 0.15 to 0.7 for single and married women, from 0.1 to 0.7 for single men, and from 0.05 to 0.2 for married men. Hall and Milgrom (2008) use a Frisch elasticity of labor supply of one, which they suggest represents an approximate average between the elasticity found for middle-age men (0.7) and higher elasticities found for women and young men. Yedid-Levi (2016), using a more complex preference structure that includes unemployment benefits and is non-separable in consumption and hours of work, calibrate the value of the Frisch elasticity of labor supply to equal one. In this paper, we follow Hall and Milgrom (2008), Yedid-Levi (2016), and Hafstead and Williams (2018) and set the initial value of the Frisch elasticity of labor supply to equal one, but recognize that this parameter is highly uncertain and therefore undertake a systematic sensitivity analysis with respect to its value.

2.2 Calibrating labor disutility

To determine the change in utility from a shock to an exogenous variable, such as a tax rate, in the GTAP model, values of the parameters ψ and ρ must be determined. The value of ρ is determined by the choice of the labor supply elasticity. However, ψ must be calibrated such that it is consistent with the units of labor supplied in the initial equilibrium of the GTAP data base year. To do so, start by using equation (6) to solve for λ:

$$\lambda = \frac{1}{p_c c} \tag{13}$$

or λ is equal to the reciprocal of total expenditure (consumption and savings in GTAP-LAB). Substituting equation (13) into equation (10):

$$w_l = \frac{\psi_l h_l^{\rho_l}}{\lambda} = \frac{\psi_l h_l^{\rho_l}}{p_c c} \rightarrow \psi_l = \frac{p_c c w_l}{h_l^{\rho_l}} \ \forall l = s, u \tag{14}$$

If the initial wage rate is equal to $1 and the labor supply elasticity is also 1, then ψ is equal to initial total expenditure divided by the initial units of labor supplied. The top half of Table 1 shows the initial values of the key factors in equation (14) and the calibrated values of ψ for the three regions that are used in the illustrative experiment discussed below: the U.S., EU, and Rest of the World (ROW). Note that the choice of the units of labor, defined as the amount of labor that can be rented for $1 in the initial equilibrium, is purely arbitrary. If data are available on wages rates across countries and sectors, one could define the units of labor as the total expenditure on labor divided by the wage rate.

Table 1. Calibrated value of labor disutility parameter

	USA	EU	ROW
Units of unskilled labor	3652802	2549144	8814360
Total expenditure	13611061	15300026	33127073
Wage rate	1.0	1.0	1.0
Labor supply elasticity	1.0	1.0	1.0
ψ	6.002024	3.758307	3.726197
Units of skilled labor	5355975	3668960	7219569
Total expenditure	13611061	15300026	33127073
Wage rate	1.0	1.0	1.0
Labor supply elasticity	1.0	1.0	1.0
ψ	4.170126	4.588511	2.541285
Initial consumption utility (U_c)	1.0	1.0	1.0
Initial unskilled labor disutility	-0.134185	-0.083305	-0.133039
Initial skilled labor disutility	-0.196751	-0.119900	-0.108968
Initial total utility	0.6690641	0.796794	0.757994

Source: Author calculation`s.

2.3 Change in total utility

Instead of just being composed of aggregate consumption, total utility is now a function of aggregate consumption and labor disutility:

$$U = U_c - \psi_u \frac{h_u^{1+\rho_u}}{1+\rho_u} - \psi_s \frac{h_s^{1+\rho_s}}{1+\rho_s} \tag{15}$$

where U_c is the level of utility from consumption and savings, or the current level of utility in the GTAP model. Because preferences are ordinal, and following the current practice in the GTAP model, the level of U_c is normalized to equal one. From equation (13), if the initial level of p_c equals to $1, then c is equal to initial total expenditure. Thus, normalizing the value of U_c to equal one implies that h_u and h_s in equation (15) also be rescaled by initial total expenditure.[6] The bottom half of Table 1 shows the initial values of U_c, the disutility of labor, and total utility from each region. The change in utility can be derived by taking the first-order differential of equation (15):

$$U\frac{du}{U} = U_c \frac{du_c}{U_c} - \psi_u h_u^{1+\rho_u} \frac{dh_u}{h_u} - \psi_s h_s^{1+\rho_s} \frac{dh_s}{h_s} \tag{16}$$

[6] This would also apply to h_u and h_s in equation (15) when calibrating the values of ψ.

3. Matching process

The current literature on frictional unemployment utilizes a search model where unemployed workers must search for job openings. To hire new workers, firms must utilize some labor to "match" the unemployed workers with job openings in their firm (or sector). Following Shimer (2010), Hafstead and Williams (2018) specify a matching function that exhibits constant-returns-to-scale in its main arguments: the level of aggregate unemployment and recruiting effort in each sector.[7] Their matching function is given below:

$$m_j = \mu_j(1-\bar{n})^{\gamma_j} v_j h_j \left(\textstyle\sum_k v_k h_k\right)^{-\gamma_j} \tag{17}$$

where m_j is the number of matches in sector j, v_j is the number of recruiters in sector j, h_j is the number of hours worked by a recruiter in sector j, $(1-\bar{n})$ is the unemployment rate,[8] k is indexed over all sectors, and μ_j and γ_j are matching efficiency and matching elasticity parameters in sector j. In this specification, the number of matches in a given sector increases as the unemployment rate increases, as the recruiting effort in that sector increases, and as the recruiting effort in other sectors decrease (less competition for unemployed workers).

Rather than revise the labor data in the GTAP model to the number of hours worked, equation (17) can be based on the number of "units" of labor.[9] Thus, one can rewrite equation (17) as follows:

$$m_j = \mu_j(1-\bar{n})^{\gamma_j} R_j \left(\textstyle\sum_k R_k\right)^{-\gamma_j} \tag{18}$$

where R_j is the units of recruiter labor used in sector j.

4. Classes of labor and production structure

To ensure that adjustments in the labor market occur through the hiring of unemployed labor, three classes of labor are identified: existing, matched (newly hired) labor, and recruiters for both skilled and unskilled labor. The quantity of existing labor is assumed to be fixed in each sector. As will be discussed later in this section, because the annual job turnover rate is relatively large in all sectors, any increase or decrease in labor employment can accomplished through the level of matched labor hired. This eliminates the need for the model to determine when involuntary unemployment of existing labor occurs. In addition, it is not necessary for the model to determine when or if an existing worker decides to voluntarily switch to employment in a different sector.

[7] The model in Hafstead and Williams (2018) is based on earlier work on search models in Pissarides (1985), Mortensen and Pissarides (1994), and Shimer (2010).

[8] Hafstead and Williams (2018) normalize the total number of workers to equal one.

[9] If the initial wage rate is \$1, then the number of units of labor is equal to the values of *VFM* in the GTAP database.

Unmatched labor, from which matched labor and recruiters are drawn, is available to all sectors.[10] Thus, there will be a single wage rate for matched labor and recruiters across all sectors for each labor type. For simplicity, each labor type is used to recruit its own type of labor – e.g., skilled labor is used to recruit skilled labor and unskilled labor is used to recruit unskilled labor. A more complicated possibility would be for skilled labor (e.g., personnel in human resources) to recruit all the different labor types. However, this might make it difficult to have a generic model specification that could accommodate both a single aggregate type of labor as well as skilled and unskilled labor. In addition, because recruiters comprise a small share of the total labor force, the composition of skilled and unskilled labor in recruitment is not likely to have a large impact on the general equilibrium results.

Because matched and existing labor may differ in characteristics, a new CES nest is added to the GTAP value-added production structure, as shown in Figure 2. For each labor type, e.g., skilled and unskilled labor, firms can substitute between existing and matched labor. The elasticities of substitution, denoted as σ_{LU} for unskilled and σ_{LS} for skilled labor, vary by labor type and sector, but not across regions in the current specification. This is similar to the assumption about the elasticity of substitution in the value-added nest in the standard GTAP model. Because existing labor is specific to each industry, the wage rates for existing labor will vary across industries and will be determined by changes in the demand for skilled or unskilled labor (e.g., *qfe*). The wage rate for matched labor and recruiters will be determined by labor supply functions in equation (10). Because the labor supply function has a constant elasticity, the level of labor supplied will not affect the supply elasticity. Thus, changes in the level of matched labor and recruiters across all sectors will result in a change in the wage rate for these labor classes.

[10] An alternative would be to assume that recruiters are part of the existing labor in each sector. However, attempts to implement this specification were not successful, possibly due to the assumption that existing labor is homogeneous, whether used in production or recruitment.

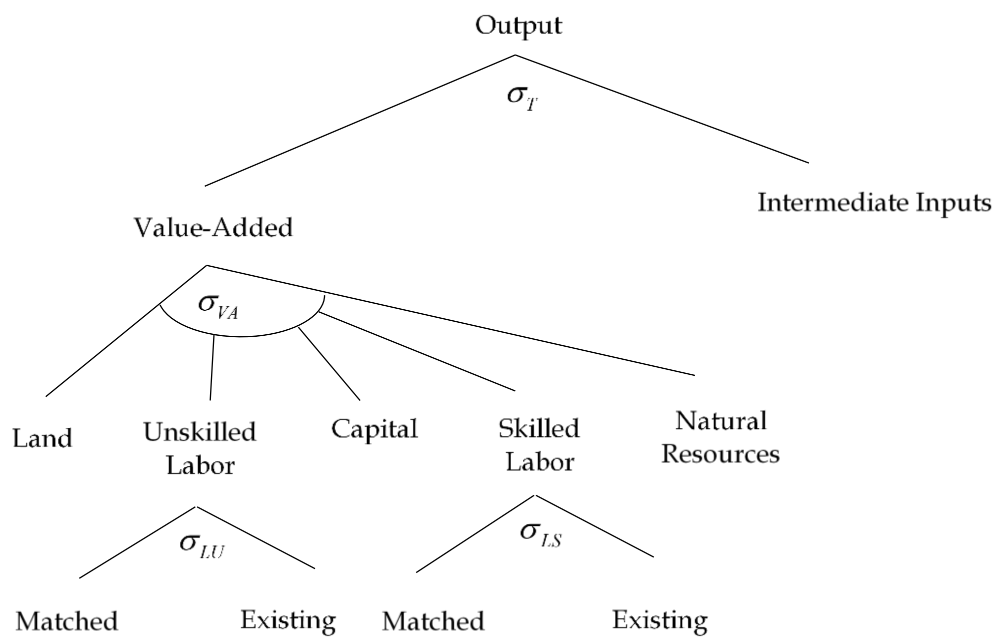

Figure 2. CES production structure

Because newly hired workers must be recruited, the "cost" of matched labor for firms includes not only the wages and input taxes paid on labor, but also the cost of recruiting the new workers. Thus, the cost of the labor composite *qfe*, will include the cost of existing, matched, and recruitment labor. This has the added benefit of requiring no changes to the existing zero profit condition in the model code.

One potential problem for this specification could occur for sectors where production decreases substantially. Because the level of existing labor is fixed in each sector, then labor employment cannot decrease below that level. Whether this problem arises in practice will depend on the level of labor turnover in each sector.

For the U.S., the level of labor turnover can be determined from the Job Openings and Labor Turnover Survey (JOLTS) from the U.S. Bureau of Labor Statistics (BLS). Table 2 shows the total U.S. non-farm separations, which includes individuals that were laid off or discharged, individuals that resigned, and other separations, on a monthly basis from 2001 through 2017. Total separations ranged from a low of approximately 48 million in 2010 and 2011, just after the Great

Table 2. Total separations: US nonfarm

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Thousands												
2001	6,066	5,383	5,655	5,545	5,439	5,252	5,303	5,142	5,169	5,501	5,053	4,783	64,291
2002	5,202	4,953	4,609	5,027	4,979	4,793	5,119	4,860	4,890	4,805	4,761	4,918	58,916
2003	5,015	4,779	4,586	4,781	4,671	4,783	4,750	4,747	4,752	4,789	4,611	4,732	56,996
2004	4,795	4,571	4,874	4,900	4,654	4,881	4,885	4,985	4,807	4,781	5,098	4,991	58,222
2005	5,177	5,006	5,071	4,970	5,105	5,074	4,917	5,220	5,305	4,960	4,949	4,945	60,699
2006	5,043	4,983	5,037	5,012	5,417	5,136	5,183	5,001	5,007	5,171	5,291	5,108	61,389
2007	5,144	5,094	5,123	5,138	5,080	5,065	5,118	5,105	5,031	5,129	5,031	4,926	60,984
2008	5,005	5,010	4,762	5,121	4,728	4,900	4,713	4,815	4,751	4,895	4,605	4,814	58,119
2009	4,974	4,674	4,536	4,655	4,146	4,192	4,297	4,060	4,084	3,951	3,873	3,989	51,431
2010	3,894	3,830	3,949	3,892	3,831	4,223	4,278	4,009	4,026	3,784	3,843	4,026	47,585
2011	3,907	3,838	3,980	3,924	4,035	4,093	4,082	4,113	4,114	4,010	4,000	3,993	48,089
2012	4,013	4,175	4,133	4,260	4,336	4,366	4,141	4,359	4,058	4,193	4,170	4,037	50,241
2013	4,297	4,174	4,114	4,370	4,357	4,298	4,391	4,530	4,513	4,296	4,270	4,297	51,907
2014	4,456	4,427	4,465	4,517	4,548	4,559	4,789	4,640	4,861	4,937	4,610	4,774	55,583
2015	4,844	4,710	4,997	4,894	4,784	5,011	4,862	5,003	5,053	4,988	4,978	5,172	59,296
2016	5,045	5,181	5,036	5,117	5,128	5,032	5,052	5,190	4,989	5,072	5,041	5,021	60,904
2017	5,222	5,030	5,171	5,110	5,265	5,294	5,406	5,345	5,346	5,272	5,253	5,314	63,028

Source: Job Openings and Labor Turnover Survey, Bureau of Labor Statistics.

Table 3. Total separations by industry

	Year									
Industry	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Thousands									
Mining and logging	6,066	5,383	5,655	5,545	5,439	5,252	5,303	5,142	5,169	5,501
Construction	5,202	4,953	4,609	5,027	4,979	4,793	5,119	4,860	4,890	4,805
Durable goods manufacture	5,015	4,779	4,586	4,781	4,671	4,783	4,750	4,747	4,752	4,789
Nondurable goods manufacture	4,795	4,571	4,874	4,900	4,654	4,881	4,885	4,985	4,807	4,781
Wholesale trade	5,177	5,006	5,071	4,970	5,105	5,074	4,917	5,220	5,305	4,960
Retail trade	5,043	4,983	5,037	5,012	5,417	5,136	5,183	5,001	5,007	5,171
Transport, utilities	5,144	5,094	5,123	5,138	5,080	5,065	5,118	5,105	5,031	5,129
Information	5,005	5,010	4,762	5,121	4,728	4,900	4,713	4,815	4,751	4,895
Finance, insurance	4,974	4,674	4,536	4,655	4,146	4,192	4,297	4,060	4,084	3,951
Real estate	3,894	3,830	3,949	3,892	3,831	4,223	4,278	4,009	4,026	3,784
Professional, business services	3,907	3,838	3,980	3,924	4,035	4,093	4,082	4,113	4,114	4,010
Educational services	4,013	4,175	4,133	4,260	4,336	4,366	4,141	4,359	4,058	4,193
Health and social services	4,297	4,174	4,114	4,370	4,357	4,298	4,391	4,530	4,513	4,296
Arts, entertainment, recreation	4,456	4,427	4,465	4,517	4,548	4,559	4,789	4,640	4,861	4,937
Accommodation, food services	4,844	4,710	4,997	4,894	4,784	5,011	4,862	5,003	5,053	4,988
Other services	5,045	5,181	5,036	5,117	5,128	5,032	5,052	5,190	4,989	5,072
Government	5,222	5,030	5,171	5,110	5,265	5,294	5,406	5,345	5,346	5,272
Total	58,123	51,427	47,584	48,090	50,239	51,902	55,586	59,289	60,904	63,028

Source: Job Openings and Labor Turnover Survey, Bureau of Labor Statistics.

Table 4. Average monthly separation rate by industry

Industry	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Percent									
Mining and logging	3.5	3.5	2.5	2.6	3.5	3.3	3.4	4.6	4.9	4.0
Construction	6.0	6.7	6.3	6.1	5.8	5.2	4.6	4.7	4.8	5.1
Durable goods manufacture	2.7	2.8	2.0	1.8	1.8	1.9	1.8	2.0	2.2	2.3
Nondurable goods manufacture	3.0	3.0	2.6	2.4	2.2	2.1	2.3	2.3	2.5	3.0
Wholesale trade	2.8	2.5	2.2	2.1	2.2	2.0	2.4	2.4	2.3	2.3
Retail trade	4.7	4.0	3.7	3.7	3.9	4.1	4.7	4.7	4.5	4.4
Transport, utilities	3.1	3.3	2.5	2.7	3.0	3.0	3.1	3.3	3.3	3.3
Information	2.4	2.5	2.2	2.3	2.4	2.5	2.7	2.8	2.7	2.9
Finance, insurance	2.4	2.0	2.0	1.7	1.9	2.2	2.0	2.0	1.9	2.0
Real estate	3.8	3.9	3.0	2.9	3.2	3.3	3.1	3.0	2.9	3.1
Professional, business services	5.0	4.5	4.4	4.7	4.7	4.7	5.0	5.1	5.3	5.3
Educational services	2.2	2.2	2.1	2.1	2.1	2.2	2.2	2.3	2.4	2.3
Health and social services	2.6	2.5	2.4	2.3	2.4	2.5	2.5	2.6	2.6	2.8
Arts, entertainment, recreation	6.0	5.5	5.7	6.2	6.3	6.0	6.8	6.6	6.7	6.7
Accommodation, food services	6.2	5.1	4.7	4.9	5.1	5.2	5.6	6.0	6.2	6.0
Other services	3.4	3.6	3.1	3.4	3.4	3.3	3.3	3.6	3.2	3.7
Government	1.3	1.3	1.5	1.3	1.3	1.3	1.3	1.5	1.5	1.5
Total	3.5	3.3	3.0	3.0	3.1	3.2	3.3	3.5	3.5	3.6

Source: Job Openings and Labor Turnover Survey, Bureau of Labor Statistic

Recession, to between 63 and 64 million in 2001 and 2017. However, as shown in Tables 3 and 4, the number of total separations, as well as and the separation rate, varies greatly across sectors in the United States. Professional and business services, accommodation and food services, retail trade, health and social services, and construction have the largest number of total separations during the period 2008-2017. These five broad sectors accounted are approximately two-thirds of the total separations. In addition, these sectors also have relatively high separation rates (total separations divided by employment). The average monthly separation rates range between 5 and 6 percent for these sectors, except for health and social services, which averages closer to 2.5 percent. This compares to an average monthly separation rate of between 3 and 3.5 percent across all non-farm sectors in the United States. The arts, entertainment and recreation sector also have a very high separation rate of greater than 6 percent in most years. Conversely, government employment, information, finance, wholesale trade, and manufacturing have relatively low average monthly separation rates, less than 3 percent for most years.

To determine the level of matched labor, the annual turnover rate, defined as total separations divided by total employment, is computed for each sector. Note that total employment can be determined by dividing the total number of separations each month by the separation rate. Then the total monthly separations are summed and divided by the average annual level of employment in each industry. Table 5 gives the annual turnover rate for the 17 sector groups between 2008 and 2017. Professional and business services; accommodation and food service; retail trade; arts, entertainment, and recreation; mining and logging; and construction have the highest turnover rates, with some rates exceeding 70 percent. For example, the turnover rate in construction was equal to or exceeded 70 percent from 2008 through 2012. This implies that at least 70 percent of the labor employed in construction would be considered a new "match" during those years. The lowest turnover rates occur in manufacturing, finance, information, wholesale trade, and government. While the turnover rate for the government ranged between 15 and 20 percent, this would not represent the lowest level of matched labor when applied to the GTAP database because government activities (e.g., public administration and defense) are only a part of the GTAP sector Public Administration, Defense, Education, Health (osg). This sector also includes education and health and social work, where turnover rates are mostly between 25 and 30 percent. Otherwise, the lowest turnover rates are in the finance and insurance sector, ranging from approximately 20 to 29 percent between 2008 and 2017. Thus, at a minimum, matched labor would represent about 20 percent of the total employment in this sector. This implies that employment would have to fall by approximately 20 percent before reaching the fixed level of existing labor. It would be very unlikely for this to occur for most policy experiments undertaken

Table 1. Annual labor turnover rate by industry

Industry	Year									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Percent									
Mining and logging	41.6	42.6	30.2	31.0	42.2	39.2	40.6	55.4	59.0	47.8
Construction	71.9	80.7	75.8	72.8	69.2	62.6	55.0	56.2	57.7	60.6
Durable goods manufacture	31.7	34.4	23.6	21.2	22.1	22.2	21.7	24.1	26.0	27.3
Nondurable goods manufacture	35.7	35.4	30.9	29.0	25.9	25.2	27.7	27.8	29.7	35.5
Wholesale trade	33.5	30.2	25.8	25.1	26.2	23.6	28.8	28.3	27.8	27.3
Retail trade	55.8	47.6	44.8	44.2	46.2	49.3	55.9	56.4	53.6	53.2
Transport, utilities	37.4	39.6	30.5	32.6	35.4	36.5	37.7	39.3	39.9	39.9
Information	28.8	29.9	26.4	27.4	28.6	30.0	32.4	33.6	32.5	35.2
Finance, insurance	29.0	24.1	23.5	20.2	23.3	26.1	24.4	24.5	23.2	24.4
Real estate	45.3	46.7	36.4	35.2	38.3	39.6	36.8	35.4	34.7	36.6
Professional, business services	60.3	54.5	52.8	56.5	56.3	56.5	60.0	61.6	64.0	64.0
Educational services	26.6	26.0	25.3	25.3	25.7	25.9	26.6	28.1	28.3	27.4
Health and social services	31.7	29.7	28.2	27.0	28.3	29.9	30.3	31.2	31.7	33.0
Arts, entertainment, recreation	72.6	65.8	68.8	73.9	75.4	71.8	81.0	79.0	80.4	80.8
Accommodation, food services	74.5	61.4	56.3	58.6	60.8	62.6	66.8	72.2	73.8	72.4
Other services	40.4	42.6	36.6	40.5	40.6	39.9	39.2	43.0	38.1	44.1
Government	15.0	15.1	18.3	15.5	16.1	15.9	16.1	18.0	18.3	18.3
Total	42.3	39.2	36.5	36.4	37.4	38.1	40.0	41.8	42.2	43.0

Source: Job Openings and Labor Turnover Survey, Bureau of Labor Statistics with the GTAP model. If this were a problem for a smaller sector, one could implement a negative shock to the level of existing labor for that sector.

5. Labor module

In this section, the equations in the new "labor module" that will determine the changes in level of matches and recruitment labor, the demand for existing and matched labor, and various price and quantity indices are presented. All new equations and share definitions will be presented in algebraic form.

The new labor module is a mix of mostly linear equations, but a few levels equations, with the choice between linear and levels equations being a matter of convenience and ease of interpretation.[11] The levels equations are for the number of matches, the level of unemployment, and the level of matched and recruitment labor. [12] There are 14 new endogenous variables and 2 new exogenous variables in the labor module, with four of the endogenous variables being "levels" variable. The new levels variables are:

1) *M_L*(*e*,*j*,*r*): the level of matches of labor type *e* used in sector *j* in region *r*,
2) *QFE_LR*(*e*,*j*,*r*): level of recruitment labor type *e* in sector *j*, region *r*,
3) *UNEMP*(*e*,*r*): level of unemployment of labor type *e* in region *r*, and
4) *MT_L*(*e*,*r*): level of matched and recruitment labor type *e* in region *r*.

Note that *e* is indexed to include both skilled and unskilled labor and *j* is indexed over *TRAD_COMM* to avoid having levels equations that are always equal to zero, as would be the case for the *CGDS* sector. The ten new endogenous linear variables, representing percentage changes in underlying levels, are:

1) *qlab_e*(*e*,*j*,*r*): demand for existing labor type *e* in sector *j* in region *r*,
2) *qlab_m*(*e*,*j*,*r*): demand for matched labor type *e* in sector *j* in region *r*,
3) *plab_e*(*e*,*j*,*r*): firm price of existing labor type *e* in sector *j* in region *r*,
4) *plab_m*(*e*,*j*,*r*): firm price of matched and recruitment labor type *e* in sector *j* in region *r*,

[11] Hertel, et al. (1992) show that both the levels and linearized versions of a non-linear AGE model provide accurate solutions to the non-linear equilibrium problem, with the levels representation being a more natural way to express accounting conditions while behavioral relationships are more easily expressed in a linearized representation. Harrison, et al (1994) discuss the advantages to modelers from using a mixture of levels and linear equations.

[12] This choice was made to eventually allow for a lower bound on unemployment that would correspond to "full employment" to be incorporated into the model.

5) *pm_labe*(*e,j,r*): market price of existing labor type *e* in sector *j* in region *r*,
6) *pm_labm*(*e,r*): market price of matched and recruitment labor type *e* in region *r*,
7) *ps_labe*(*e,j,r*): agent price of existing labor type *e* in sector *j* in region *r*,
8) *ps_labm*(*e,r*): agent price of matched and recruitment labor type *e* in region *r*,
9) *pm_lab*(*e,j,r*): composite market price of labor type *e* in sector *j* in region *r*, and
10) *uc_m*(*e,j,r*): unit cost of matched labor type *e* in sector *j* in region *r*.

Finally, there is one levels variable that is exogenous, *QUNMATCH*(*e,r*), the level of unmatched labor type *e* in region *r*, and one linear exogenous variable, *qoel*(*e,j,r*), the supply of existing labor type *e* to sector *j* in region *r*.

There are three new levels equations in the labor module. The first levels equation is the number of matches from equation (18), using the above nomenclature:

$$M\_L(e,j,r) = \mu(e,j,r) * UNEMP(e,r)^{\gamma(e.j.r)} * QFE\_LR(e,j,r) * \left[\sum_k QFE\_LR(e,k,r)\right]^{-\gamma(e.j.r)} \tag{19}$$

where k is indexed over *TRAD_COMM*. The new two levels equations determine the level of matched and recruitment labor and the level of unemployment:

$$MT\_L(e,r) = \textstyle\sum_k [M\_L(e,k,r) + QFE\_LR(e,k,r)] \tag{20}$$

$$UNEMP(e,r) = QUNMATCH(e,r) - MT\_L(e,r) \tag{21}$$

To link the level of matches in equation (19) to the demand for matched labor, the following linear equation is specified:

$$qlab\_m(e,j,r) = p\_M\_L(e,j,r). \tag{22}$$

The next set of linear equations relate to the use of existing and matched labor by firms. Given the nested CES structure for existing and matched labor discussed above, the demand equations for these labor types are:

$$qlab\_e(e,j,r) = qfe(e,j,r) - \sigma_{Lj}[plab\_e(e,j,r) - pfe(e,j,r)] \text{ and} \tag{23}$$

$$qlab\_e(e,j,r) = qfe(e,j,r) - \sigma_{Lj}[plab\_e(e,j,r) - pfe(e,j,r)], \tag{24}$$

where σ_{Lj} is the elasticity of substitution between existing and matched labor in sector j. Note that similar to the elasticity of substitution within the value-added nest, this value is allowed to vary across sector but not across regions. The market clearing condition for existing labor is:

$$qlab\_e(e,j,r) = qoel(e,j,r). \tag{25}$$

Since *qoel* is an exogenous variable, this will fix the level of existing labor in each sector. One could apply a negative shock to *qoel* to include some additional job destruction. Note that this market clearing condition will pin down the wage rate for existing labor in the model.

As shown in Figure 2, the total labor employed in production (e.g., the variable *qfe* in the standard GTAP model) is a composite of existing and matched labor, but not recruitment labor. However, the cost of matched labor to firms will include the cost of recruitment. Because the matching function exhibits a diminishing number of matches from increases in the number of recruiters a sector employs, all else constant, the cost of recruiting per match (e.g., the unit cost) will increase with the number matches. The unit cost of matched labor is derived by first defining the total cost of matched labor to equal the wage rate for matched labor times the sum of the number of matches plus the number of recruiters:

$$\begin{aligned} TC\_M(e,j,r) = {} & PLAB\_ML(e,j,r) \\ & * [M\_L(e,j,r) + QFE\_LR(e,j,r)]. \end{aligned} \tag{26}$$

where TC_M is the total cost of matched labor and $PLAB\_ML$ is the level of the wage rate for matched labor. Then, the unit cost of matched labor, UC_M, is defined as the total cost divided by the number of matches, or:

$$UC\_M(e,j,r) = PLAB\_ML(e,j,r) * \left[1 + \frac{QFE\_LR(e,j,r)}{M\_L(e,j,r)}\right] \tag{27}$$

Note that even if the market wage for matched labor is equal to \$1, the unit cost of matched labor will be greater than \$1. Totally differentiating equation (27) gives the linear equation:

$$\begin{aligned} uc\_m(e,j,r) = {} & plab\_m(e,j,r) + \\ & VSHRCT(e,j,r) * \left[p\_QFE\_LR(e,j,r) - p\_M\_L(e,j,r) \right] \end{aligned} \tag{28}$$

where *VSHRCT* is the cost share of recruitment labor in matched labor for labor type e in sector j in region r. Note that *VSHRCT* is equal to *PLAB_ML***QFE_LR* divided by *TC_M*.

The wage rate for matched and recruitment labor is determined by the inverse supply of these two labor classes using a linear version of equation (10):

$$ps\_labm(e,r) = \eta(e,r) * qo(e,r) \tag{29}$$

where η is the inverse labor supply elasticity. Note that the labor supply elasticity is allowed to vary by labor types, skilled versus and unskilled, and across regions. Also note that this equation is linked to the levels equation for total labor supplied.

The next set of equations in the labor module are the price linkage equations and the expressions for several composite prices. The price linkage equations for existing and matched labor (including recruitment labor) are:

$$plab\_e(e,j,r) = tf(e,j,r) + pm\_labe(e,j,r), \tag{30}$$

$$plab\_m(e,j,r) = tf(e,j,r) + pm\_labm(e,r), \tag{31}$$

$$ps\_labe(e,j,r) = to(e,r) + pm\_labe(e,j,r), \text{ and} \tag{32}$$

$$ps\_labm(e,r) = to(e,r) + pm\_labm(e,r). \tag{33}$$

where *tf* is the tax on labor type *e* used by sector *j* in region *r*, and *to* is output (income) tax on labor type *e* in region *r*, which are both exogenous variables. Next, is the equation for the composite price of existing, matched, and recruiting labor in each sector:

$$\begin{aligned} pfe(e,j,r) = {} & SHRLP(e,j,r) * plab\_e(e,j,r) \\ & + [1 - SHRLP(e,j,r)]uc\_m(e,j,r) \end{aligned} \tag{34}$$

where *SHRLP* is the share of existing labor *e* used by sector *j* in region *r*. Again, note that the unit cost of matched labor is used as the "price" for matched labor in this composite.

To update the value of producer expenditure at market prices, denoted as *VFM* in the GTAP model, a composite market price of existing, matched, and recruitment labor for each labor type is computed for each sector in all regions. Using index theory, the value of producer expenditure on labor at market prices, which is defined as *VFM* in the standard GTAP model, can be expressed as the level of the price index for labor, evaluated at market prices, *PM_LAB_L*, times the level of the quantity index of labor used in production, which is defined as *QFE_L*. Then:

$$\begin{aligned} PM\_LAB\_L(e,j,r) &= \frac{VFM(e,j,r)}{QFE\_L(e,j,r)} \\ &= \Big[PM\_LABE\_L(e,j,r) * QLAB\_E(e,j,r) + \\ &\quad PM\_LABM\_L(e,j,r) * \big[M\_L(e,j,r) + QFE\_LR(e,j,r) \big] \Big] \Big/ QFE\_L(e,j,r) \end{aligned} \tag{35}$$

where *PM_LABE_L* is the level of the market price for existing labor, *QLAB_E* is the level of existing labor, and *PM_LABM_L* is the level of the market price for matched and recruitment labor. Totally differentiating equation (35):

$$\begin{aligned} pm\_lab(e,j,r) = {} & SHRLPE(e,j,r) * \left[pm\_labe(e,j,r) + qlab\_e(e,j,r) \right] + \\ & \left[1 - SHRLPE(e,j,r) \right] pm\_labm(e,r) + \\ & SHRLPM(e,j,r) * p\_M\_L(e,j,r) + \\ & SHRLPR(e,j,r) * p\_QFE\_LR(e,j,r) - qfe(e,j,r) \end{aligned} \tag{36}$$

where *SHRLPE* is the share of existing labor in the total cost of labor, *SHRLPM* is the share of matched labor in the total cost of labor, and *SHRLPR* is the share of recruitment labor in the total cost of labor, all evaluated at their respective market prices. Note that *qfe* is the percentage change in the demand for labor, as defined in the standard GTAP model.

With three classes of labor, it may be useful for reporting purposes to compute a composite market price of labor (*pm*) for each labor type. The change in this composite price will be a share weighted sum of the price of existing labor and matched labor, at market prices:

$$\begin{aligned} pm(e,r) = \sum_{k \in TRAD} [& REVSHR\_E(e,k,r) pm\_labe(e,k,r) \\ & + REVSHR\_M(e,k,r) pm\_lab(e,r)] \end{aligned} \tag{37}$$

where *REVSHR_E* is the share of existing labor type *e* across all sectors in *r* and *REVSHR_M* is the share of matched and recruitment labor type *e* across all sectors in *r*.

The last equation in the labor module defines the total supply of labor, including existing, matched, and recruitment labor. The total level of labor supplied, *QO_L*, is defined as the sum of the level of production labor, *QFE_L*, plus the sum of recruitment labor, *QFE_LR*, across all sectors. Note that *QFE_L* is the quantity index of existing and matched labor. The corresponding linear equation is:

$$qo(e,r) = \sum_{k \in TRAD} [QFESHR(e,k,r) qfe(e,k,r) + QFESHR(e,k,r) p\_QFE\_LR(e,k,r)] \tag{38}$$

where *QFESHR* is the quantity share of production or recruitment labor type *e* used in sector *k* in region *r*.

5.1 Other model modifications

Other than the modifications to the change in utility discussed above, there are a few other changes needed to incorporate a matching function and an endogenous labor supply. The main modification is to the computation of factor income at market prices, net of depreciation (*fincome*). First, the coefficient *FY*, is redefined as:

$$FY(r) = \sum_{e \in ENDWL} \sum_{j \in TRAD} \Big[VEXLBM(e,j,r) + VRCTM(e,j,r) + VMATM(e,j,r) \Big] + \sum_{i \in ENDNL} VOM(i,r) - VDEP(r) \quad (39)$$

where *VELBM* is the value of existing labor type *e*, in sector *j* and region *r*, at market prices; *VRCTM* is the value of recruitment labor type *e*, in sector *j* and region *r*, at market prices; and *VMATM* is the value of matched labor type *e*, in sector *j* and region *r*, at market prices. Note that the index *ENDNL_COMM* includes all non-labor primary factors. Using equation (39), the equation *FACTORINCOME* is modified to:

$$\begin{aligned} FY(r)\,fincome(r) = & \sum_{e \in ENDWL} \sum_{j \in TRAD} VEXLBM(e,j,r)\big[pm\_labe(e,j,r) + qlab\_e(e,j,r)\big] + \\ & \sum_{e \in ENDWL} \sum_{j \in TRAD} VRCTM(e,j,r)\big[pm\_labm(e,j,r) + p\_QFE\_LR(e,j,r)\big] + \\ & \sum_{e \in ENDWL} \sum_{j \in TRAD} VMATM(e,j,r)\big[pm\_labm(e,j,r) + p\_M\_L(e,j,r)\big] + \\ & \sum_{i \in ENDNL} VOM(i,r)\big[pm(i,r) + qo(i,r)\big] - VDEP(r)\big[pcgds(r) + kb(r)\big] \end{aligned} \quad (40)$$

The new treatment of labor also necessitates the modification of equation TFURATIO, which computes the change in ratio of tax payments on factor usage to regional income. The new equation, expressed in GEMPACK code is:

```
100.0 * INCOME(r) * del_taxrfu(r) + TFU(r) * y(r)
= sum(i,ENDWM_COMM, sum(j,PROD_COMM,
VFA(i,j,r) * tf(i,j,r) + ETAX(i,j,r) * [pm(i,r) + qfe(i,j,r)]))
+ sum(i,ENDWS_COMM, sum(j,PROD_COMM,
VFA(i,j,r) * tf(i,j,r) + ETAX(i,j,r) * [pmes(i,j,r) + qfe(i,j,r)]))
+ sum(i,ENDWL_COMM, sum(j,PROD_COMM,
VFA(i,j,r)*tf(i,j,r) + ETAX(i,j,r)*[pm_lab(i,j,r) + qfe(i,j,r)]));
```

Finally, two initial levels in the original GEMPACK code require modification. First, the level of *qfe* is set equal to *VFM* in the standard GTAP model, because all market prices are initially set equal to one. However, because the cost of recruitment is included in the market price of matched labor, the market price of labor will be greater than one. A new coefficient is defined in the labor module, *QFE_L*, which is defined as the level of composite labor used in production.[13] This also necessitates that the initial level of the market price of labor also be revised. Instead of all market prices being set equal to one, they are set to a new coefficient *PM_L*, which provides the initial market price of labor that includes the unit cost of recruitment, with all other market prices being set equal to one.

[13] Note that this coefficient is updated by changes in *qfe* and is used to compute the quantity shares in equation (25).

6. Modification of GTAP labor data and calibration

This section details how the labor data in the existing GTAP Data base are modified, key assumptions, and how the parameters of the matching function are calibrated. In this paper, version 9 of the GTAP Data base (Aguiar, et al. 2016) using the base year of 2011 is used. To aid in this discussion, the modification of the labor data for the commodity aggregation used in the example in the next section for a single region, the United States, will be highlighted. In the example, there are six sectors: food and agriculture, extraction industries, metals (ferrous and nonferrous), manufacturing, trade and transportation, and services. Both skilled and unskilled labor are included in the example.

Following the earlier discussion on calibrating the labor disutility parameters, one unit of labor is defined to equal to $1 worth of labor. Then the initial value of *VFM* in the GTAP Data base will equal the initial units of each labor type in each sector. The top portion of Table 6 shows the values of *VFM* for skilled and unskilled labor for the six sectors in the United States. These values are then allocated to existing labor, matched labor, and the number of recruiters in each sector. Because data availability on the number of recruiters in specific industries is not available, it is assumed that 1 percent of the total quantity of labor employed in each sector are recruiters.[14] The upper right-hand portion of Table 6 shows the number of recruiters for both skilled and unskilled labor by sector.

The level of matched labor is determined by the turnover rate in each sector, based on the data from the JOTLS data given in Tables 2-5. For metals, the turnover rate is set equal to the rate for durable manufacturing. Given this rate, the turnover rate for the manufacturing sector is determined such that the turnover rate for metals and manufacturing is equal to the average for all manufacturing. The turnover rates by sector are given in the middle of Table 6.[15] With no information on turnover rates by labor type, the rates for skilled and unskilled labor are assumed to be equal. Note that the initial level of matched labor, and thus turnover rate, for services is treated as a residual to ensure that the total level of matched labor, determined by the aggregate turnover rate for the United States, equals the sum of the initial level of matched labor across all sectors. Then, the level of existing labor is determined by subtracting the initial level of

[14] Hafstead and Williams (2018) assume that 0.5 percent of workers are engaged in recruitment in each sector of their model. To avoid the potential of the number of recruiters being driven to zero in a shrinking sector, the disaggregation of each labor type initially assumes that 1 percent of all workers are engaged in recruiting.

[15] The U.S. turnover rates are applied to all regions in this example. Data on job tenure intervals are available from the Organisation for Economic Co-operation and Development (OECD) (https://stats.oecd.org/Index.aspx?DatasetCode=STLABOUR), but are not disaggregated by industry.

matched labor and recruiters from the initial total labor type employed in each sector. These values are shown in the bottom of Table 6.

To calibrate the matching function in equation (19) requires data on the level of unemployment for each labor type in each region. The overall level of unemployment can be readily obtained from many regions from data sources such as the Bureau of Labor Statistics (BLS) in the United States.[16] For the base year of 2011, BLS data from the Current Population Survey (CPS) show that the U.S. unemployment rate was approximately between 9.0 percent. The overall unemployment rates for the EU and the ROW are assumed to be 9.5 percent and 10 percent respectively.

Table 6. Modifying labor data in GTAP data base for United States

	Unskilled	Skilled	Unskilled	Skilled
	VFM[a]		Number of recruiters	
Food and agriculture	100,369.25	102,297.05	1,003.69	1,022.97
Extraction	24,086.68	28,041.44	240.87	280.41
Metals	46,158.81	28,976.54	461.59	289.77
Manufacturing	783,565.88	491,889.47	7,835.66	4,918.89
Trade and transportation	814,913.50	681,488.81	8,149.14	6,814.89
Services	1,883,707.88	4,023,282.00	18,837.08	40,232.82
Total	3,652,801.99	5,355,975.30	36,528.02	53,559.75
	Separation/turnover rates		Initial number of matches	
Food and agriculture	0.3	0.3	30,110.78	30,689.12
Extraction	0.31	0.31	7,466.87	8,692.85
Metals	0.21	0.21	9,693.35	6,085.07
Manufacturing	0.2418	0.2418	189,440.57	118,922.77
Trade and transportation	0.375	0.375	305,592.56	255,558.30
Services	0.4199	0.3815	790,968.59	1,534,982.88
Total	0.365	0.365	1,333,272.73	1,954,930.99
	Existing labor		Level of *QFE*	
Food and agriculture	69,254.78	70,584.97	99,365.56	101,274.08
Extraction	16,378.94	19,068.18	23,845.81	27,761.02
Metals	36,003.87	22,601.71	45,697.22	28,686.78
Manufacturing	586,289.64	368,047.81	775,730.22	486,970.57
Trade and transportation	501,171.80	419,115.62	806,764.37	674,673.92
Services	1,073,902.20	2,448,066.30	1,864,870.80	3,983,049.18
Total	2,283,001.25	3,347,484.57	3,616,273.97	5,302,415.55

Notes: [a] All units, except for the turnover rates, are in millions. The units of labor are defined as $1 worth of labor.

Source: Author calculation`s.

[16] Other sources of employment data across countries include the World Bank Database on Employment, the OECD Employment Database and ILOSTAT from the International Labour Organization.

BLS data on unemployment rates by education level are utilized to determine the unemployment for skilled and skilled labor for the United States. While using educational levels to define skilled versus unskilled labor are not a perfect mapping, they provide some evidence on the differential rates of unemployment across these two labor types. In the base year of 2011, the average unemployment rates in the U.S. were: 14.1 percent for individuals without a high school diploma, 9.4 percent for high school graduates, 8.0 percent for individual with an associate's degree or some college, and 4.3 percent for those individuals with a Bachelor's degree or higher. Without a means to weight these different unemployment rates and assuming that most skilled labor have at least an associate's degree, the unemployment rate for skilled labor in the U.S. is assumed to by 7.0 percent. This implies that the initial unemployment for unskilled labor equals 11.8 percent for the overall U.S. unemployment rate to equal 9.0 percent. In the example simulation, the unemployment rates in the EU are 7.5 and 12.2 percent for skilled and unskilled labor and 8.0 and 11.6 percent for skilled and unskilled labor in the ROW.

As discussed in Hafstead and Williams (2018), empirical estimates of vary from between 0.3-0.5 (Petrongolo and Pissarides, 2001) to 0.75 (Hall 2005; Shimer 2005). Hafstead and Williams (2018), as well as Hall and Milgrom (2008) use a value 0.5 for all sectors as an "average" estimate. This will also be the initial value of γ used for all sectors, labor types, and regions, as shown in Table 7. However, a sensitivity analysis will be conducted for alternative values of γ to assess the sensitivity of the model results to alternative values. Given the values of the initial number of matches, the number of recruiters, the level of unemployment, and the parameter γ, it is possible to solve for μ in equation (19). The calibrated values of μ for each sector and labor type for the U.S. are shown in Table 7.

Table 7. Calibrated matching function parameters for the United States

	Unskilled	Skilled	Unskilled	Skilled
	γ		μ	
Food and agriculture	0.5	0.5	8.209101	10.934872
Extraction	0.5	0.5	8.482738	11.299368
Metals	0.5	0.5	6.567281	8.747898
Manufacturing	0.5	0.5	10.261376	13.668590
Trade and transportation	0.5	0.5	11.490000	13.906426
Services	0.5	0.5	8.209101	10.934872

Source: Author calculation`s.

7. Results

This section will focus on an experiment where the U.S. increases its existing ad-valorem tariff on metal products by 25%, going from approximately 1.0% to

26.2% for the EU, and 0.3% to 25.4% for the ROW. The results of the experiment will be compared for the standard GTAP model and the new GTAP-LAB model. A sensitivity analysis with respect to the key labor parameters in the GTAP-LAB model is then presented. Finally, this experiment is conducted using a "short-run" version of the GTAP-LAB model where capital is treated as a sluggish endowment.

In all model specifications, there are six sectors: food and agriculture, extraction industries, metals, manufacturing, trade and transportation, and services. The primary factors of production in the GTAP Data base are not aggregated to focus on skilled and unskilled labor. Three regions are included in the experiment: the U.S., the EU, and the rest of the world (ROW). All common parameters in the standard GTAP and GTAP-LAB models are set to their default values. The elasticity of substitution between existing and matched labor is set equal to 2.5 in all sectors and regions. In the "short-run" scenario, the elasticity of transformation of capital between sectors is set equal to -0.1 in all regions.

7.1 Comparison between standard GTAP and GTAP-LAB models

The economic intuition of the impact of the tariff increase is that imported metal products become more expensive, causing U.S. firms to substitute domestic metal products for imported metal products. This increase in domestic intermediate demand leads to an increase in the price of U.S. metal products, and therefore increases the cost of production in U.S. sectors, mainly manufacturing. This increase in production costs for U.S. manufacturers leads to a reduction in domestic demand and exports as U.S. manufactured goods become relatively more expensive than manufactured good from the EU and the ROW. Output of U.S. metals products also increases, although the increase in domestic demand is tempered by reductions in U.S. exports as U.S. metal products become relatively more expensive than metal products from the EU and ROW.

While the increase in U.S. metals production will increase its demand for skilled and unskilled labor, the reduction in U.S. manufacturing production will have the opposite effect.[17] Because the U.S. manufacturing sector is larger and employs more labor, the reduction in labor demand by U.S. manufacturing will more the offset the increase in labor demand by the U.S. metals sector. In the standard GTAP model, with fixed labor use, a decrease in demand would lead to a reduction in the wage rates. In this simulation, U.S. wage rates fall by 0.11 and 0.1 percent for unskilled and skilled labor (see Table 8). While the composite U.S. wage rates also fall in the GTAP-LAB model, the different structure of labor use gives rise to quite different impacts on wages of existing and matched labor as well as total employment of labor.

Because existing skilled and unskilled labor are assumed to be sector specific, as long existing labor is not a perfect substitute with matched labor, and labor is

[17] In both cases, the expansion effect is main driver of labor use.

an imperfect substitute for land and capital, wage rates for existing labor will move in the same direction as sectoral output. In the U.S. metals sector, the expansion of production and resulting increase in the demand for existing skilled and unskilled labor increases the wage rates by 9.5 percent. Thus, the overall composite price of skilled and unskilled labor (*pfe*) paid by the U.S metals sector,

Table 8. Comparison of results for standard GTAP and GTAP-LAB models for 25% increase in U.S. tariffs on metal products

	Standard GTAP			GTAP-LAB		
Sector/market	USA	EU28	ROW	USA	EU28	ROW
Change in market price -pm			percent change			
Land	-0.03	0.03	0.04	-0.07	0.06	0.05
Unskilled labor	-0.10	0.07	0.04	-0.18	0.09	0.05
Skilled labor	-0.11	0.08	0.04	-0.21	0.09	0.06
Capital	-0.12	0.08	0.02	-0.30	0.13	0.07
Natural Resources	-0.76	-0.80	-0.57	-0.26	-0.53	-0.37
Food and agriculture	-0.01	0.07	0.03	-0.10	0.09	0.05
Extraction	-0.13	-0.08	-0.10	-0.09	-0.02	-0.04
Metals	2.25	0.07	0.02	4.25	0.08	0.02
Manufacturing	0.30	0.06	0.02	0.20	0.10	0.07
Trade and transportation	-0.02	0.07	0.03	-0.13	0.10	0.06
Services	-0.04	0.07	0.03	-0.16	0.11	0.06
CGDS	0.07	0.07	0.03	-0.03	0.10	0.07
Change in output qo						
Land	0	0	0	0	0	0
Unskilled labor	0	0	0	-0.11	0.05	0.03
Skilled labor	0	0	0	-0.12	0.05	0.03
Capital	0	0	0	0	0	0
Natural Resources	0	0	0	0	0	0
Food and agriculture	0.04	-0.03	0.01	0.07	-0.02	0.00
Extraction	-0.09	-0.13	-0.08	0.00	-0.09	-0.06
Metals	11.83	-0.74	-1.05	7.83	-0.27	-0.67
Manufacturing	-0.65	0.04	0.15	-0.46	0.02	0.10
Trade and transportation	0.04	-0.03	-0.01	-0.05	-0.02	0.01
Services	-0.01	0.01	0.01	-0.10	0.04	0.03
CGDS	-0.54	0.17	0.08	-0.82	0.29	0.14

Source: Author calculation`s.

which include both existing and matched labor, increases by 7.2 percent, compare with a 0.1 percent decrease in the standard GTAP model (see Table 9).[18] The larger increase in labor cost leads to a larger increase in the price of U.S. metals: a 4.25 percent price increase versus a 2.25 percent increase in the standard GTAP model (see Table 8). The increase in labor cost accounts for about 80 percent of the two percent point larger price increase.

Table 9. Comparison of labor market impacts for standard GTAP and GTAP-LAB models for 25% increase in U.S. tariffs on metal products

	Standard GTAP			GTAP-LAB		
Sector/market	USA	EU28	ROW	USA	EU28	ROW
qfe – unskilled labor			percent change			
Food and agriculture	0.04	-0.03	0.00	0.03	0.00	0.00
Extraction	-0.13	-0.17	-0.12	-0.02	-0.10	-0.07
Metals	11.82	-0.74	-1.06	5.54	-0.14	-0.32
Manufacturing	-0.66	0.04	0.14	-0.37	0.03	0.07
Trade and transportation	0.03	-0.03	-0.02	-0.09	0.02	0.02
Services	-0.03	0.02	0.00	-0.14	0.07	0.04
qfe – skilled labor						
Food and agriculture	0.05	-0.03	0.00	0.04	-0.01	0.00
Extraction	-0.13	-0.18	-0.12	-0.02	-0.10	-0.07
Metals	11.84	-0.74	-1.06	5.55	-0.15	-0.32
Manufacturing	-0.65	0.04	0.14	-0.35	0.03	0.06
Trade and transportation	0.04	-0.04	-0.02	-0.08	0.02	0.02
Services	-0.01	0.01	0.00	-0.12	0.06	0.03
pfe – unskilled labor						
Food and agriculture	-0.10	0.07	0.04	-0.12	0.06	0.04
Extraction	-0.10	0.07	0.04	-0.16	-0.02	-0.02
Metals	-0.10	0.07	0.04	7.21	-0.13	-0.41
Manufacturing	-0.10	0.07	0.04	-0.59	0.11	0.12
Trade and transportation	-0.10	0.07	0.04	-0.20	0.08	0.05
Services	-0.10	0.07	0.04	-0.21	0.10	0.05
pfe – skilled labor						
Food and agriculture	-0.11	0.08	0.04	-0.14	0.07	0.05
Extraction	-0.11	0.08	0.04	-0.18	-0.01	-0.01
Metals	-0.11	0.08	0.04	7.20	-0.12	-0.41
Manufacturing	-0.11	0.08	0.04	-0.61	0.12	0.12
Trade and transportation	-0.11	0.08	0.04	-0.21	0.08	0.05
Services	-0.11	0.08	0.04	-0.23	0.10	0.06

Source: Author calculation`s.

[18] Because matched labor is mobile between all sectors, a decrease in the total use of matched labor will lead to decrease in its wage rate. As will be discussed later, total use of matched labor in the U.S. decreases in this simulation.

The larger price increase of U.S. metal products leads to a smaller production increase of 7.8 percent compared with an 11.8 percent increase in the standard GTAP model (see Table 8). This occurs for several reasons. First, the larger price increase causes exports of the U.S. metal products to decrease by 2.2 percentage points more than in the standard GTAP model. The reduction in exports also reduces the own-use of metal products, further reducing the output of U.S. metal products. Finally, the larger increase in the price of U.S. metal products reduces price differential to imported metal products, thereby reducing the substitution effect in domestic intermediate demand compared to the standard GTAP model. Domestic intermediate use of U.S. metal products is about 1.9 percentage points lower than in the standard GTAP model, with about 75 percent of that decrease due to the reduction in own-use.

For U.S. manufacturing, the assumption of sector-specific existing labor has the opposite effect. The wage rates for existing skilled and unskilled labor decrease by approximately 0.75 percent with the overall composite price (*pfe*) decreasing by 0.6 percent, again compared with the 0.1 percent decrease in the standard GTAP model. The lower labor costs, although partially offset by the higher cost of U.S. metals intermediate inputs, leads to a 0.1 percentage point lower increase in the price of U.S. manufactured products than in the standard GTAP model. The lower price increase in turn leads to a 0.2 percentage point smaller decrease in U.S. manufacturing production, mainly due to a smaller reduction in U.S. exports.

While the different structure of labor demand in the GTAP-LAB model affects the level of production, or the expansion effect, it also affects the substitution effect. In the standard GTAP model, the increase in the tariff has only a small impact on the capital rental rate, implying that the substitution effect for labor demand is very small in the U.S. metals and manufacturing sectors. However, in the GTAP-LAB model, the relatively large changes in the wage rates for existing labor lead to more substantial substitution effects. In the U.S. metals sector, the increases in the wage rates for existing labor cause the composite price of skilled and unskilled labor to increase relative to capital. Thus while U.S. metals production increases by 7.8 percent, the demand for skilled and unskilled labor only increases by 5.5 percent. Thus, the gains in employment in the U.S. metals sector is even smaller, compared to the standard GTAP model. Conversely, the reduction in the wage rates for existing skilled and unskilled labor in U.S. manufacturing, relative to the capital rental rate, lead to a positive substitution effect. While the production on U.S. manufacturing drops by 0.46 percent, labor use only drops by about 0.35 percent. Thus, the contraction of employment in U.S. manufacturing is not as large as in the standard GTAP model.

Given the relative size of the U.S. trade and transport, and services sector, there are also some small, but important differences in the level of output and labor demand between the GTAP-LAB and standard GTAP model. For services, production was unchanged in the standard GTAP model, but decreases by 0.1

percent in the GTAP-LAB model. This difference is mainly driven by changes in investment use (e.g., use in the CGDS sector). As will be more fully discussed shortly, the reduction in employment in the GTAP-LAB model leads to slightly larger decrease in U.S. income and therefore a larger reduction in savings (*qsave*). For U.S. trade and transport, output decreases by 0.05 percent, compared to a 0.04 percent increase in the standard GTAP model, due to smaller increase in intermediate use in the U.S. metals sector along with reductions in own-use and investment use. While the wage rates for existing skilled and unskilled labor in these sectors decrease from the reduction in output, it the composite price of skilled and unskilled labor decreases less than the decrease in the capital rental rate, leading to an additional decrease in employment in these sectors. As will be shown shortly, these decreases in labor use, particularly in services, will have important impacts on overall labor employment.

Another implication of existing labor being sector specific is that any change in labor use must be achieved through a change in the level of matched labor. For the U.S. metals sector, the relatively low turnover rate implies that this sector has a low initial level of matched labor. Thus, the 5.5 percent increase in the use of skilled and unskilled labor by the U.S. metals sector requires a relatively large increase in matched labor, which increases by approximately 26 percent for skilled and unskilled labor (see Table 10). In order to hire more labor, more recruiters must also be employed. The number of recruiters for unskilled labor increases by 24.8 percent while the number of recruiters for skilled labor increases by 24.0 percent.[19] Conversely, the reduction in labor use in U.S. manufacturing leads to a 1.4 and 1.46 percent reduction in the use of skilled and unskilled matched labor. Because fewer matches are required, the number of recruiters in U.S. manufacturing also decrease by 3.1 percent for skilled labor and 2.5 percent for unskilled. labor. Finally, as shown in Table 10, the level of matched labor decreases by 0.20 to 0.24 percent in trade and transport and 0.30 to 0.33 percent in services. The number of recruiters for unskilled labor decrease by 1.27 and 1.36 percent in trade and transport and services, and by 1.93 and 2.03 percent for skilled labor.

Given the changes in the use of matched labor and the number of recruiters across sectors in the U.S., it is possible to determine the impact on overall employment. The bottom half of Table 10 shows the change in the units of matched labor employed in each U.S. sector as well as the number of recruiters for skilled and unskilled labor. The increase in employment of skilled and unskilled labor in the U.S. metals sector is more than offset by reductions in employment in

[19] Note that with an equal percentage of recruiters, the same value of γ across all sectors (and regions) and the lowest labor turnover rate, the metals sector has the smallest value of μ in the matching function. This implies that more recruiters are needed in metals to achieve a given number of matches than other sectors.

the U.S. manufacturing and services sectors. Employment of skilled and unskilled matched labor in the U.S. decreases by 0.26 and 0.27 percent. With fewer matches required, the number of recruiters for skilled and unskilled labor decreases by 1.97 and 1.23 percent as well. Overall, the level of unemployed skilled and unskilled labor increases by 1.53 and 0.83 percent while the level of employed skilled and unskilled labor (*qo*) decreases by 0.12 and 0.11 percent in the United States. This translates into a 0.1 percentage point increase in the U.S. unemployment rate for both skilled and unskilled labor.

Table 10. Impacts on matched labor and number of recruiters for 25% increase in U.S. tariffs on metal products

	Unskilled labor			Skilled labor		
Sector/market	USA	EU28	ROW	USA	EU28	ROW
Number of recruiters			percent change			
Food and agriculture	-0.92	0.47	0.30	-1.60	0.73	0.44
Extraction	-1.09	0.15	0.07	-1.78	0.42	0.21
Metals	24.82	-0.18	-1.16	24.01	0.07	-1.04
Manufacturing	-2.47	0.61	0.55	-3.11	0.86	0.68
Trade and transportation	-1.27	0.53	0.34	-1.93	0.79	0.47
Services	-1.36	0.63	0.37	-2.03	0.89	0.51
Matched labor						
Food and agriculture	0.11	-0.01	0.01	0.14	-0.02	0.01
Extraction	-0.06	-0.32	-0.22	-0.05	-0.32	-0.22
Metals	26.11	-0.64	-1.44	26.20	-0.67	-1.46
Manufacturing	-1.46	0.14	0.26	-1.40	0.11	0.25
Trade and transportation	-0.24	0.06	0.06	-0.20	0.04	0.04
Services	-0.33	0.16	0.09	-0.30	0.14	0.08
Unemployment level	0.83	-0.36	-0.22	1.53	-0.63	-0.36
Number of recruiters			change in units of labor (millions)[a]			
Food and agriculture	-9.3	8.5	36.2	-16.4	9.0	9.5
Extraction	-2.6	0.3	2.2	-5.0	0.6	2.8
Metals	114.6	-0.6	-21.7	69.6	0.3	-7.9
Manufacturing	-193.7	36.7	97.2	-153.1	55.5	54.5
Trade and transportation	-103.2	18.3	63.3	-131.7	29.6	47.8
Services	-255.5	85.7	127.9	-817.5	221.7	254.6
Total	-449.8	148.8	305.2	-1,054.1	316.6	361.3
Matched labor						
Food and agriculture	31.6	-3.2	54.3	42.8	-7.3	3.4
Extraction	-4.6	-19.1	-220.5	-4.1	-13.1	-89.9
Metals	2,531.1	-48.8	-565.2	1,594.4	-52.0	-234.1
Manufacturing	-2,768.0	201.0	1,137.5	-1,663.0	174.2	480.4
Trade and transportation	-742.9	78.4	391.4	-503.7	59.0	159.8
Services	-2,635.8	912.6	1,419.8	-4,585.4	1,410.8	1,571.1
Total	-3,588.5	1,120.7	2,217.3	-5,119.0	1,571.7	1,890.7

Notes: [a] All labor units are initially defined as $1 worth of labor.

Source: Author calculation`s.

Note that because the level of unemployment increases in the U.S., it becomes easier for firms to find labor matches, thus reducing their recruiting effort for a given level of matches. Therefore, the reduction in the number of recruiters is larger than the reduction in the level of matched labor in U.S. manufacturing, trade and transport, and services. Also, the increase in the number of recruiters in U.S. metals is smaller than the increase in the number of matches. Thus, the decrease in the units of recruiter labor serves to reinforce the decline in overall labor use.

The decrease in the U.S. demand for matched and recruitment labor caused the U.S. wage rates for matched skilled and unskilled labor to decrease by 0.12 and 0.11 percent. The composite wage rate, across all sectors and existing and matched labor, decreases by 0.21 percent for skilled labor and 0.18 percent for unskilled labor in the United States. The capital rental rate also decreases by 0.3 percent, slightly larger than the 0.12 percent decrease in the standard GTAP model due to a reduction in capital use by the U.S. services sector in the GTAP-LAB model. With larger reductions in factor prices (except for natural resources) and less labor employed, U.S. household income decreases by 0.21 percent, compared with only a 0.005 percent decrease in the standard GTAP model (see Table 11). The decrease in regional household income leads to a reduction in total utility of 0.036 percent in the GTAP-LAB model, compared with a 0.0015 percent reduction in the standard GTAP model. For the GTAP-LAB model, the decrease in total utility can be decomposed into a 0.10 percent reduction in the utility from consumption, which is offset from a reduction in the disutility of labor employment of 0.23 and 0.24 percent for skilled and unskilled labor, due to the reduction in labor employment. With a larger decrease in total utility, U.S. equivalent variation (EV) decreases by about $4.9 billion in the GTAP-LAB model as opposed to $202 million in the standard GTAP model.

Table 11. Comparison of changes in household income, equivalent variation, and utility

	Standard GTAP			GTAP-LAB		
Sector/market	USA	EU28	ROW	USA	EU28	ROW
			percent change			
Household Income	-0.0051	0.074	0.015	-0.21	0.14	0.066
Utility						
Consumption	-0.0015	0.0065	-0.017	-0.10	0.038	0.0056
Skilled labor				0.24	-0.10	-0.063
Unskilled labor				0.23	-0.10	-0.058
Total	-0.0015	0.0065	-0.017	-0.036	0.021	-0.012
			$millions			
Equivalent variation	-202.4	990.3	-5,509.4	-4,888.7	3,226.4	-3,946.7

Source: Author calculation`s.

The increase in the U.S. tariffs on imported metals has a positive, but relatively small impact on labor markets in the EU and ROW. While metal production declines in both regions, a small expansion in the production of manufacturing and services, along with labor becoming relatively less expensive than capital, results in an increase in labor use in both sectors in the EU and ROW (see Table 9). This leads to an increase in matched and recruitment labor in both sectors in the EU and ROW. Total employment of skilled and unskilled labor increases by 0.05 percent in the EU and 0.03 percent in the ROW. With more labor employed and higher wage rates, the changes in household income, total utility, and EV are larger than in the standard GTAP model (see Table 11).

7.2 Sensitivity analysis

To provide insight on the sensitivity of the GTAP-LAB model to key labor parameters, an analysis is performed on the labor supply elasticity ($1/\rho$), the elasticity of substitution between existing and matched labor (σ_{LU} and σ_{LS}), and the matching elasticity parameter (γ). Note that matching efficiency parameter (μ) is calibrated, given the value of γ, such that the matching functions replicate the initial level of matches and recruiters. Also note that the labor disutility parameters (ψ) are calibrated given the value of the labor supply elasticity. In the sensitivity analysis, a uniform distribution is assumed with the endpoints at plus/minus 50 percent of the base values. For example, the base labor supply elasticity is equal to one, so the endpoints are 0.5 and 1.5. Since no information is available on how these parameters may vary across regions or sectors, they are varied together. So, the labor supply elasticities for skilled and unskilled labor are varied by the same amount in each region.

Tables 12 and 13 provide the model results key U.S. sectors for the base parameters, and the mean and standard deviation from varying all three labor parameters. The top portion of Table 12 focuses on the sensitivity of the change in aggregate market price and labor supply of skilled and unskilled labor, and the market prices and output levels of the metals, manufacturing, and services sectors in the United States. In most cases, the standard deviation is approximately one tenth the magnitude of the mean or base result. The largest absolute standard deviations are for the market price and output of the U.S. metals sector. For these variables, the elasticity of substitution between existing and matched labor is main driver of model uncertainty. The bottom portion of Table 12 focuses on labor use (*qfe*) and the composite price of labor paid (*pfe*) in the U.S. metals, manufacturing, and services sectors. Relative to the mean or base results, the standard deviations for labor use are larger than for the changes in market price and output. For U.S. metals and manufacturing, the key driver is the elasticity of substitution between existing and matched labor. However, for services, uncertainty in the labor supply elasticities and the matching elasticity account for more of the uncertainty. Both parameters have a larger effect on the standard deviation of total income in the

U.S., which affects the demand for savings and production of investment goods, which were shown earlier to have an important impact on the production of services in the United States. The composite price of labor is most affected by the elasticity of substitution between existing and matched labor.

Table 13 focuses on how changes in the labor parameters affect the use of matched and recruitment labor in the U.S., and the overall impact on the level of unemployment for skilled and unskilled labor. For matched labor, the standard

Table 12. Results of sensitivity analysis for key U.S. sectors

		Sensitivity	
Sector	Base	Mean	Standard deviation
Change in market price - pm		percent change	
Unskilled labor	-0.18	-0.18	0.019
Skilled Labor	-0.21	-0.21	0.021
Metals	4.25	4.30	0.32
Manufacturing	0.20	0.20	0.012
Services	-0.16	-0.17	0.020
Change in output qo			
Unskilled labor	-0.11	-0.11	0.021
Skilled Labor	-0.12	-0.12	0.023
Metals	7.83	7.75	0.60
Manufacturing	-0.46	-0.46	0.030
Services	-0.10	-0.10	0.021
Change in unskilled labor use - qfe			
Metals	5.54	5.41	0.93
Manufacturing	-0.37	-0.36	0.050
Services	-0.14	-0.14	0.028
Change in skilled labor use - qfe			
Metals	5.55	5.43	0.94
Manufacturing	-0.35	-0.34	0.048
Services	-0.12	-0.11	0.028
Composite price of unskilled labor - pfe			
Metals	7.21	7.38	1.18
Manufacturing	-0.59	-0.60	0.072
Services	-0.21	-0.22	0.024
Composite price of skilled labor - pfe			
Metals	7.20	7.37	1.18
Manufacturing	-0.61	-0.62	0.070
Services	-0.23	-0.24	0.022

Source: Author calculation`s.

deviations are relatively small, mainly between one-tenth and one-third the magnitude of the mean values. The main drivers of the uncertainty are the same as for the labor use: the elasticity of substitution between existing and matched labor for metals and manufacturing, but more of a mix for the other sectors. The relative magnitudes of the standard deviations for recruitment labor are somewhat larger, mainly between one-quarter and one-half the value of the mean. Except for the U.S. metal sectors, the key driver of the uncertainty is matching efficiency parameter. For the metals sector, given the large increase in the demand for matched labor in the experiment, the elasticity of substitution between existing and matched labor is the key parameter in the variation in recruitment labor.

Table 13. Results of sensitivity analysis for U.S. matched and recruitment labor

		Sensitivity	
Sector	Base	Mean	Standard deviation
Matched labor - unskilled		percent change	
Food & agriculture	0.11	0.10	0.039
Extraction	-0.06	-0.06	0.032
Metals	26.11	25.52	4.26
Manufacturing	-1.46	-1.43	0.20
Trade & transport	-0.24	-0.24	0.062
Services	-0.33	-0.33	0.064
Matched labor - skilled			
Food & agriculture	0.14	0.14	0.045
Extraction	-0.05	-0.05	0.031
Metals	26.20	25.61	4.28
Manufacturing	-1.40	-1.37	0.19
Trade & transport	-0.20	-0.19	0.068
Services	-0.30	-0.29	0.072
Recruiters - unskilled			
Food & agriculture	-0.92	-1.04	0.53
Extraction	-1.09	-1.20	0.55
Metals	24.82	24.09	4.28
Manufacturing	-2.47	-2.55	0.54
Trade & transport	-1.27	-1.37	0.52
Services	-1.36	-1.46	0.52
Recruiters - skilled			
Food & agriculture	-1.60	-1.77	0.86
Extraction	-1.78	-1.95	0.88
Metals	24.01	23.22	4.35
Manufacturing	-3.11	-3.24	0.84
Trade & transport	-1.93	-2.09	0.85
Services	-2.03	-2.19	0.84
Unemployment			
Unskilled labor	0.83	0.83	0.15
Skilled labor	1.53	1.52	0.29

Source: Author calculation`s.

Finally, the standard deviations for the change in level of skilled and unskilled unemployment is about one-fifth the magnitude of the mean values. These endogenous variables are most sensitive to the labor supply elasticity and the matching efficiency parameters.

Since unmatched labor can be employed in any sector within a given region, as the elasticity of substitution between existing and matched labor increases towards infinity, all labor would become perfectly mobile between sectors. Thus, the results from the GTAP-LAB model should converge towards the results from

Table 14. Sensitivity of elasticity of substitution between existing and matched labor on U.S. market prices and output levels

	Standard	GTAP-LAB, σ_{LS} and σ_{LU} equal to:			
Sector	GTAP	2.5	10.0	30.0	50.0
Change in market price - pm			percent change		
Land	-0.03	-0.07	-0.08	-0.09	-0.09
Unskilled labor	-0.10	-0.18	-0.12	-0.10	-0.10
Skilled labor	-0.11	-0.21	-0.13	-0.11	-0.11
Capital	-0.12	-0.30	-0.22	-0.19	-0.18
Natural resources	-0.76	-0.26	-0.52	-0.62	-0.64
Food & agriculture	-0.01	-0.10	-0.06	-0.04	-0.04
Extraction	-0.13	-0.09	-0.12	-0.13	-0.13
Metals	2.25	4.25	2.99	2.52	2.41
Manufacturing	0.30	0.20	0.25	0.27	0.28
Trade & transport	-0.02	-0.13	-0.07	-0.05	-0.04
Services	-0.04	-0.16	-0.09	-0.07	-0.06
CGDS	0.07	-0.03	0.03	0.04	0.05
Change in output qo					
Land	0	0	0	0	0
Unskilled labor	0	-0.11	-0.09	-0.08	-0.08
Skilled labor	0	-0.12	-0.10	-0.09	-0.08
Capital	0	0	0	0	0
Natural resources	0	0	0	0	0
Food & agriculture	0.04	0.07	0.05	0.03	0.03
Extraction	-0.09	-0.001	-0.04	-0.06	-0.06
Metals	11.83	7.83	10.29	11.27	11.50
Manufacturing	-0.65	-0.46	-0.58	-0.63	-0.64
Trade & transport	0.04	-0.05	-0.03	-0.02	-0.02
Services	-0.01	-0.10	-0.09	-0.08	-0.08
CGDS	-0.54	-0.82	-0.74	-0.70	-0.70

Source: Author calculation`s.

the standard GTAP model. Table 14 presents a comparison of the model results for the U.S. between the standard GTAP model and the GTAP-LAB model with four different elasticities of substitution between matched and unmatched labor: 2.5, 10.0, 30.0, and 50.0. In general, the results of the GTAP-LAB model are converging to the results from the standard GTAP model as the elasticity of substitution is increased.

7.3 Sluggish capital scenario

With mobile capital and perfectly immobile existing labor between sectors, the increase in the U.S. tariff on metals increases wage rates in the U.S metals sector and decreases the capital rental rate in the United States. However, one might expect that at least in the short-run, the tariff increase would also increase the capital rental rate in the U.S. metals sector as well. To explore the short-run impacts of an increase in the U.S. metals tariffs, capital is assumed to be imperfectly mobile between sectors, with an elasticity of transformation of -0.1. A small, but non-zero elasticity of transformation is chosen based on the assumption that over a shorter period, it may be easier for some capital to move between sectors than for people to move, given the transactions costs associated with moving.

Table 15 presents a comparison of select results for the GTAP-LAB model for the increase in the U.S. tariff on metals between mobile and sluggish capital scenarios. In the scenario with sluggish capital, the increase in U.S. metals production draws in a much smaller increase in capital: 1.2 percent versus 15.7 percent with mobile capital. The increase in the demand for capital with limited mobility leads to a 12.2 percent increase in the capital rental rate in the U.S. metals sector. Because the capital rental rate increases relative to wage rates for unskilled labor, the use of unskilled labor is 0.6 percentage points larger in the sluggish capital scenario compared with the mobile capital scenario. The impacts on the use of skilled labor by the U.S. metals sector are similar. With higher factor prices, the market price of U.S. metals is 1.2 percentage points higher. With less available capital and a higher output price, U.S. production of metals is 2.8 percentage points lower in the sluggish capital scenario.

In the U.S manufacturing sector, the limited capital mobility reduces the outflow of capital, but the reduction in the demand for capital, due to a reduction in output, leads to a 1.0 percent reduction in the capital rental rate. As opposed to the U.S. metals sector, the drop in the capital rental rate in U.S. manufacturing is larger than the decrease in wage rates. The resulting substitution effect leads to a larger decrease in the use of unskilled and skilled labor compared with the mobile capital scenario. A similar effect occurs in the U.S. services and trade and transport sectors.

While the use of labor increases in the U.S. metals sectors, the decrease in labor use in U.S. manufacturing, trade and transport, and services, compared with the mobile capital scenario, causes unemployment to increase. For skilled and unskilled labor, unemployment is about 0.2 and 0.1 percentage points higher with sluggish capital compared to with mobile capital. Thus, the short-run impacts on employment of the increase in the U.S. tariff on metals are higher.

8. Summary

This paper documents the development of a labor module for the standard GTAP model. Dubbed GTAP-LAB, this model incorporates job-search frictions, following the work of Hafstead and Williams (2018), thereby introducing frictional unemployment into the standard GTAP model. In this approach, unemployed individuals must search for a job opening and firms that want to hire must search

Table 15. Comparison of impacts of 25% increase in U.S. metals tariffs between mobile and sluggish capital on U.S. factor markets and output

Sector	Mobile capital	Sluggish capital[a]
Output	percent change	
Metals	7.83	5.02
Manufacturing	-0.46	-0.33
Trade & transport	-0.05	-0.07
Services	-0.10	-0.10
qfe – unskilled labor[b]		
Metals	5.54	6.19
Manufacturing	-0.37	-0.43
Trade & transport	-0.09	-0.10
Services	-0.14	-0.16
qfe - capital		
Metals	15.65	1.19
Manufacturing	-0.74	-0.06
Trade & transport	0.07	0.01
Services	-0.03	0
pfe – unskilled labor		
Metals	7.21	7.99
Manufacturing	-0.59	-0.69
Trade & transport	-0.20	-0.23
Services	-0.21	-0.25
pfe - capital		
Metals	-0.30	12.20
Manufacturing	-0.30	-0.98
Trade & transport	-0.30	-0.29
Services	-0.30	-0.37
Unemployment		
Unskilled labor	0.83	0.96
Skilled labor	1.53	1.75

Notes: [a] The elasticity of transformation equals -0.1.
[b] Similar results for skilled labor.

Source: Author calculation`s.

for worker to fill the job. The number of "matches" or new hires in an industry is determined by a matching function that depends on the recruiting effort in each industry and the level of unemployment. The number of matches required in a given sector depends on the turnover rate of workers in that sector, which is defined as the total number of job separations divided by total employment in the base year of the GTAP database. Data on U.S. job separations are available from the Job Openings and Labor Turnover Survey (JOLTS) from the U.S. Bureau of Labor Statistics (BLS).

To illustrate the potential of a GTAP model with frictional unemployment, the impacts of a 25 percent increase in U.S. tariffs on metal products (e.g., ferrous and non-ferrous metals) are simulated. While employment of skilled and unskilled labor increases in the U.S. metals sector, employment of both types of labor declines in U.S. manufacturing and services sectors. These decreases in employment offset the increase in the metals sector, leading to a 0.8 percent increase in the unemployment of unskilled labor and a 1.5 percent in the unemployment of skilled labor. These increases would translate to a 0.1 percent point increase in the unemployment rate in the U.S. labor market.

There are several potential barriers to wider use of GTAP-LAB. First is the availability of job separation or turnover rate data in regions other than the United States. In the example simulation, job turnover rates, and thus the initial levels of matched labor in the non-U.S. regions are assumed to be the same as for United States. Region-specific data are required for serious policy extensions to other regions. Data on job tenure intervals available from the Organisation for Economic Co-operation and Development (OECD) do show significant differences job turnover rates across OECD member countries, but these statistics do not include turnover rates by industry. However, this data source could provide a basis for differences in the total levels of matched labor across OECD member countries. Second, the small initial level of recruiters is based on a calibrated value from Hafstead and Williams (2018). Further work should focus on exploring available data on recruitment costs by sector and countries to determine if the small level of recruiters assumed in this manuscript is an accurate depiction or not. Third, the values of supply elasticities for skilled and unskilled labor by region, the elasticities of substitution between existing and matched labor across sectors, and the matching efficiency parameter across sectors and regions are uncertain, and, in some cases unknown. Fortunately, a sensitivity analysis for these parameters indicated that the results in U.S. metal tariff simulations were not overly sensitive to the values of these labor parameters. Most of the standard deviations were one-third to one-tenth the size of the mean value of the endogenous variable.

In summary, with the introduction of GTAP-LAB for use by the global AGE modeling community, it is hoped that others will now be motivated to contribute to the improved specification and parameterization of labor supply and demand in their own countries. This is an aspect of global trade policy analysis that has long been neglected. Beginning to seriously address the underlying mechanisms behind frictional unemployment represents an important step forward.

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References

Angel, A., B. Narayanan, and R. McDougall (2016). "An Overview of the GTAP 9 Data Base." *Journal of Global Economic Analysis* 1(1): 181-208.

Angel, A., M. Chepeliev, E.L. Corong, R. McDougall, and D. van der Mensbrugghe (2019). "The GTAP Data Base: Version 10." *Journal of Global Economic Analysis* 4(1): 1-27.

Bargain, O. K. Orsini, and A. Peichl (2014). "Comparing Labor Supply Elasticities in Europe and the United States: New Results." *Journal of Human Resources* 49(3): 723-838.

Blundell, R. and T. MaCurdy (1999). "Labor Supply: A Review of Alternative Approaches." In *Handbook of Labor Economics*, Vol. 3A, ed. O. Ashenfelter and D. Card, 1559–695. Elsevier: Amsterdam.

Boeters, S. and L. Savard (2013). "The Labor Market in Computable General Equilibrium Models," in *Handbook of CGE Modeling*, Vol. 1, ed. P.B. Dixon and D.W. Jorgenson 1645-1718. Elsevier North-Holland: Oxford.

Corong, E.L, T.W. Hertel, R. McDougall, M.E. Tsigas, and D. van der Mensbrugghe (2017). "The Stanard GTAP Model, Version 7." *Journal of Global Economic Analysis* 2(1): 1-119.

Dixon, P.B. and M.T. Rimmer. (2002) "*Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH*." North-Holland: Amsterdam.

Evers, M., R. de Mooij, and D. van Vuuren (2008). "The Wage Elasticity of Labour Supply: A Synthesis of Empirical Estimates." *De Economist* 156(1):25–43.

Hafstead, M.A.C. and R.C. Williams III (2016). "Unemployment and Environmental Regulation in General Equilibrium." NBER Working Paper No. 22269, May 2016, 36 pp.

Hafstead, M.A.C. and R.C. Williams III (2018). "Unemployment and environmental regulation in general equilibrium." *Journal of Public Economics* 160(2018): 50-65.

Hall, R.E. (2005). "Employment fluctuations with equilibrium wage stickiness." *American Economic Review* 95(1): 50–65.

Hall, R.E., and P.R. Milgrom. (2008). "The Limited Influence of Unemployment on the Wage Bargain." *American Economic Review* 98 (4): 1653–74.

Harrison, W.J., K.R. Pearson, A.A. Powell, and E.J. Small (1994). "Solving Applied General Equilibrium Models Represented as a Mixture of Linear and Levels Equations." *Computational Economics* 7: 203-223.

Hertel, T.W., J.M. Horridge, and K.R. Pearson (1992). "Mending the Family Tree: A Reconciliation of the Linearization and Levels School of AGE Modeling." *Economic Modelling* 9(4): 385-407.

Kehoe, T.J. and J. Serra-Puche (1983). "A Computational General Equilibrium Model with Endogenous Unemployment." *Journal of Public Economics* 22: 1-26.

Mortensen, D.T., and C.A. Pissarides. (1994) "Job Creation and Job Destruction in the Theory of Unemployment." *Review of Economic Studies* 61 (3): 397–415.

Organisation for Economic Co-operation and Development (OECD). Employment by Job Tenure Intervals. Available at https://stats.oecd.org/Index.aspx?DatasetCode=STLABOUR.

Petrongolo, B. and C.A. Pissarides. (2001). "Looking into the black box: a survey of the matching function." *Journal of Economic Literature* 39(2): 390–431.

Pissarides, C.A. (1985) "Short-Run Equilibrium Dynamics of Unemployment, Vacancies, and Real Wages." *American Economic Review* 101 (6): 2823–43.

Shimer, R. (2005). "The cyclical behavior of equilibrium unemployment and vacancies." *American Economic Review* 95(1): 25–49.

Shimer, R. (2009). "Convergence in macroeconomics: the labor wedge." *American Economic Journal: Macroeconomics* 1(1): 280–297.

Shimer, R. (2010). *Labor Markets and Business Cycles*. Princeton University Press: Princeton, NJ.

U.S. Census Bureau. Current Population Survey. Available at: https://www.census.gov/programs-surveys/cps.html.

U.S. Department of Labor, Bureau of Labor Statistics. Job Openings and Labor Turnover Survey. Available at: https://www.bls.gov/jlt/.

Yedid-Levi, Y. (2016). "Why Does Employment in All Major Sectors Move Together over the Business Cycle?" *Review of Economic Dynamics* 22: 131-156.