The Review of Regional Studies

The Official Journal of the Southern Regional Science Association

Estimating the Impacts of a Reduction in the Foreign-Born Labor Supply on a State Economy: A Nested CGE Analysis of the Idaho Economy*

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Abstract: This analysis examines the effects of reducing the supply of foreign-born labor on the Idaho economy. Estimates of labor usage by industry sector are obtained from governmental and non-governmental data sources and are incorporated into a 14-sector nested computable general equilibrium (CGE) model with five primary factors of production consisting of capital and four different labor groups (foreign-born less educated, native-born less educated, foreign-born more educated, and native-born more educated).

The results of the model indicate that at the expected elasticities of substitution between similarly educated native-born and foreign-born labor, the reduction of the foreign-born less educated labor supply modestly increases the demand for native-born less educated labor while causing reductions in state GDP, total economic output, and household utility. The importance of the elasticities of substitution between the various labor groups in influencing the impact results is discussed and a sensitivity analysis performed. The CGE results are then compared to those of an input-output model: the differences are discussed.

Keywords: foreign-born labor, elasticity of substitution, computable general equilibrium

JEL Codes: J15, R13, R11

1. INTRODUCTION

Immigration is the subject of considerable policy debate and action, especially at the state and local levels (Downes, 2012). For example, in 2010 Arizona passed the most stringent immigration legislation in the nation at the time, attracting national media attention (Archibold, 2010). Arizona's SB 1070 was not alone in recent legislation. In 2011, more than 30 states introduced bills similar to part or all of SB 1070 (Downes, 2012) and in 2009 48 states enacted 222 new laws dealing with immigration (Archibold, 2010). Not all new state immigration legislation restricts the rights of immigrants. In 2007, bills that expanded the rights of immigrants were passed at a higher rate than those that contracted their rights (Laglagaron et al., 2008).

Whether such legislation has positive or negative economic impacts is also a matter of debate in the literature (Hanson, 2009). Immigrants are claimed to both (1) adversely affect

*The authors thank Erin Cruz and Kaitlin Watson for their assistance and edits. We also thank three anonymous reviewers for their insights.

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native-born people by taking jobs from native-born workers while burdening social service resources (Mortenson, 2009), and conversely (2) accept jobs that native-born people are unwilling to take, contribute to local communities, and pay social security taxes which, depending on their legal status, they may never be able to collect upon (Hanson, 2009).

While this study does not attempt to analytically answer all the myriad of complicated combination of factors that could potentially influence how any component of the labor force might potentially interface with the regional economy, it does attempt to shed light on some important facets of how foreign-born labor functions in a state economy. This study contributes to the literature by using multiple data sources to estimate the size of the foreign-born labor force in Idaho and presenting a state level model for nested labor CGE model where labor is disaggregated by nativity and education. The model is intended to estimate the effects of a reduction in the supply of a segment of the foreign-born labor force on the other types of labor in the economy and on other broader economic measure such as state gross domestic product (SGDP). Like all economic models, the model of the Idaho economy presented here is a simplification of an actual economy and is based on a set of restrictive assumptions. The computable general equilibrium model presented here is an enhancement of the existing Washington-Idaho model which has been employed in previous studies (Holland, 2010; Devadoss et al., 2006; Cassey, Holland, and Razack, 2011). The model used here is enhanced in the inclusion of nested production functions which facilitate the inclusion of native born and immigrant labor classes further broken-down by educational attainment.

Immigrant labor has historically been concentrated in the agricultural, construction, and service sectors (Passel and Cohn, 2009). States such as Idaho that have strong agricultural sectors and have experienced rapid population growth during the last two decades are, therefore, likely to be experiencing a growing immigrant population. In fact, Capps et al. (2002) listed Idaho as one of the 16 “new growth states” that saw dramatic increases in the immigrant population throughout the 1990s and this trend continued through the late 2000s.

A 2010 summary report of state and local-level analyses indicates that immigrants, like other groups, have both positive and negative impacts on local economies (Immigration Policy Center, 2010). Because various studies have measured different impacts and used different methods, a straight forward comparison is difficult. However, the majority of studies summarized by the Immigration Policy Center (2010) found that immigrants have generally positive effects on state economies, suggesting that limiting the supply of immigrant labor would have negative impacts on state economies. Most of these studies estimate the economic activity attributable to immigrant labor using input-output models of their respective economies. Input-output models do not allow for substitution of factors of production (i.e., native-born labor for foreign-born labor) and have been shown to have the potential to overestimate economic impacts (Zhou et al., 1997; West, 1995; Matheson, 2002).

Formally understanding the effects of foreign-born labor (FBL) on a state economy creates a two-part problem. The first part is overcoming the clandestine nature of certain segments of the foreign-born labor force and the second is modeling the effects of changes in that labor force. This study focuses first on the problem of estimating the size of the foreign-born labor force in Idaho and then proceeds to describe the model used to estimate the effects of reductions in that labor force.

Because some segment of the foreign-born labor force may not be working in the state with the proper legal authority, unauthorized workers tend to avoid government officials and surveys that track their whereabouts and general information (Passel and Cohn, 2009). Fear of deportation essentially pushes a large part of the population underground where they are ‘invisible’ to surveys like the American Community Survey (ACS), and to a lesser extent, the Decennial Census. The Decennial Census and ACS are the most reliable and consistent ways to gather data on regional economies that include demographic information (i.e. nativity) within the United States. However, due to the known estimation errors in Decennial Census and ACS data when dealing with FBL (Passel and Cohn, 2009), additional data sources must be taken into consideration when estimating the size of the foreign-born population and looking at immigrant impacts on a regional economy.

A more accurate estimate of the size of a region’s FBL force is then incorporated as an input into a regional economic model that can estimate economic impacts and changes in household welfare resulting from changes in the supply of foreign-born labor. Because of the complex nature of the supply and demand of different type of labor, a similarly sophisticated economic model was necessary to capture these relationships.

This paper will first use modified methods based on two independent previous studies of the size of the Hispanic immigrant population (Passel, 2005; Kasarda and Johnson, 2006) to generate a point estimate of the size of Idaho’s foreign-born Hispanic labor pool. This point estimate is expected to be undercounted in standard secondary data sources such as the ACS. To this end, a series of secondary data sources are used to attempt to find a potentially latent population of foreign-born Hispanic workers which are then added back into the estimate of the size of the initial foreign-born labor supply. These data are then incorporated into a triple nested computable general equilibrium (CGE) model with four distinct labor groups: native-born more-educated, foreign-born more-educated, native-born less-educated, and foreign-born less-educated. This CGE model allows for, among other things, flexible wages and substitutability between foreign-born and native-born labor.

2. DATA

2.1 Estimating the Size of the Foreign-born Labor Supply

The first problem to overcome in estimating FBL’s impacts on a given state’s economy is determining an accurate estimate of the number of foreign-born workers in the labor force. Studies in states with increasing immigrant populations use a variety of methods to derive their data. The simplest method is to focus solely on industries that traditionally have a high demand for low-skilled immigrant labor and assume that the effects of changing labor situations will be indirectly reflected from a change in the industries’ output (Gans, 2008). A similar technique is to use known percentages of the immigrant workforce employed in various job classifications (Ryan 1997). However, relying on standard publicly available data sources such as the Decennial Census or the ACS can greatly underestimate the foreign-born population because many of these people, especially those of questionable legal immigration status, have a real or perceived incentive to avoid being detected (Passel and Cohn, 2009; Kasarda and Johnson, 2006). Because the documentation status of some immigrants is uncertain and some FBL may not want to be counted by government agencies, there is expected to be a degree of underestimation, or undercounting, in government data on FBL (Warren and Passel 1987, Passel and Cohn 2008).

Passel and Cohn 2008 estimate the national and individual state inflow of unauthorized immigrants. These estimates of unauthorized immigrants have been used in previous studies to determine FBL's contributions to tax revenue and economic output, as well as this population's use of public services (Pearson and Sheehan, 2007; Decker et al., 2008; Gans, 2008).

To facilitate estimating the total amount of FBL in Idaho, the following three assumptions were imposed. First, it is assumed that the ACS systematically underestimates the size of at least one segment of the foreign-born labor force. Second, drawing from Passel and Cohn (2009) and Kasarda and Johnson (2006), it is assumed that the foreign-born Hispanic population accounts for a disproportionate and large share of the undercount. Last, it is assumed that through the use of other secondary data sources it is possible to estimate these latent workers and determine the amount of undercounting of FBL that exists in the ACS data. This updated total of FBL is then added back and proportionally distributed to the ACS estimates of FBL by sector to obtain the total employment of foreign-born and native-born employment by sector.

The estimates of the undercounted FBL in Idaho used in this study are derived from the findings by Passel (2005) and Kasarda and Johnson (2006). Using methods detailed in Warren and Passel (1987), Passel (2005) developed estimates of the size of the undocumented (and likely undercounted) Hispanic labor force in each state, including Idaho. Passel's estimate of the undocumented Hispanic labor force in Idaho in 2004 was between 20,000 and 35,000 people. After adjusting those numbers to account for population growth in Idaho, the adjusted 2006 estimate is between 23,500 and 41,000 undocumented and undercounted Hispanic workers.

To generate a point estimate and to corroborate the range estimated by Passel (2005), the method developed by Kasarda and Johnson (2006) was modified to estimate the size of the undercounted Hispanic labor force in Idaho. Kasarda and Johnson (2006) used a novel methodology to estimate the total number of Hispanic residents to determine their effects on North Carolina's economy. Taking an actual count of Hispanic school-age children from public school data and coupling it with 2000 decennial census data, Kasarda and Johnson (2006) estimated the number of Hispanics residing in North Carolina. They found that publicly available secondary data sources such as the American Community Survey underestimate the foreign-born Hispanic population. A detailed description of the calculations used to modify and apply the Kasarda and Johnson (2006) method to estimate Idaho's undercounted Hispanic labor force is presented in Appendix 1. The Kasarda and Johnson (2006) method applied to Idaho yielded an estimate of 37,770 undercounted Hispanics. This number is well within the range of the 2006 adjusted estimate (23,500 to 41,000) of the undocumented and undercounted Hispanic laborers reported by Passel (2005). These undercounted Hispanic laborers are then added back into the total of foreign-born labor and distributed proportionally across the of the Idaho economy based on ACS derived percentages of foreign-born labor by industry in Idaho.

2.2 Social Accounts Data

The SAM data were taken from a 2008 IMPLAN SAM and the default employment and labor payment accounts were disaggregated using the method described above. The IMPLAN SAM houses the data detailing all of the transactions that take place within a regional economy. The SAM in this study consists of 14 industries, 4 labor groups, 9 household income groups, 3 federal government accounts, 3 state and local government accounts, and 2 trade categories (rest of U.S. and rest of world).

Table 1. Distribution of Idaho's Labor Groups by Industry

Sector	FBME ^a	FBLE ^b	NBME ^c	NBLE ^d	Total	%FB ^e	%FB ^f
Crop Production	10	7,817	2,334	10,671	20,832	0.38	0.18
Livestock Production	187	8,145	2,414	6,578	17,324	0.48	0.23
Construction	1,850	9,249	10,859	58,729	80,687	0.14	0.07
Forestry	5	83	781	3,158	4,027	0.02	0.01
Technology Manufacturing	1,925	1,532	6,288	5,772	15,517	0.22	0.11
Other Manufacturing	471	11,629	7,860	33,259	53,219	0.23	0.11
Mining	5	159	443	2,727	3,334	0.05	0.02
Professional Services	10,526	11,278	87,795	96,034	205,633	0.11	0.05
Hospitality Services	439	8,349	4,408	44,754	57,950	0.15	0.07
Other Services	4,258	12,774	35,070	97,326	149,428	0.11	0.05
Maintenance Services	363	1,632	1,478	7,858	11,331	0.18	0.08
Retail Trade	3,333	10,952	26,578	98,702	139,565	0.10	0.05
Utilities	5	5	623	1,582	2,215	<.01	<.01
Government	40	10	155,617	50	155,717	<.01	<.01
Total	23,417	83,614	342,548	467,200	916,779	0.12	0.06

Notes: ^a FBME denotes foreign-born & more-educated. ^b FBLE denotes foreign-born & less-educated. ^c NBME denotes nonforeign-born & more-educated. ^d NBLE denotes nonforeign-born & less-educated. ^e Estimate of foreign-born share of labor that was applied. ^f Foreign-born share calculated from the American Community Survey.

IMPLAN develops their SAM based on the structure of the National Income and Product Accounts (MIG 1998). The default IMPLAN SAM contains 440 industry sectors, 4 value added accounts (employee compensation, proprietor's income, other property income, and indirect business taxes), 9 household types based on income class, 6 government accounts (state and local education, state and local non-education, state and local investment, federal defense, federal nondefense, and federal investment), enterprises (corporate profits), capital (savings and investment), domestic trade, and foreign trade. In this model the 440 industries from the original IMPLAN SAM were aggregated to 14 sectors to accommodate sectoral data from the ACS on employment by nativity and education level (Table 1). There was not enough detail within the ACS to break out employment by nativity and education at a more disaggregated level.

Because the social accounts data are from IMPLAN, the employment totals were also adjusted to match total employment estimates from IMPLAN. Therefore the ACS estimates of employment by industry, nativity, and educational attainment were converted to percentages and applied to IMPLAN estimates of total employment by sector. The total FBL is then proportionally distributed across the industries based on the percentage distribution reported in ACS data. Therefore, the undercounted FBL will be proportionally allocated to industries based on the concentration of FBL in the baseline ACS data. For example, if the crop agriculture sector used 50 percent of the FBL, then they would also receive 50 percent of the undercounted estimate. The estimated employment levels in each industry from IMPLAN are multiplied by the percent of the labor group as estimated in the ACS. This yields base levels of labor group distribution.

Next, the FBL population is distributed into two educational attainment groups, proportionate to their share in ACS. Foreign-born workers with at least a two-year, post-

Figure 1. The Size and Distribution of Idaho's Labor Force by Nativity and Education level

secondary degree were classified as “foreign-born more educated” (FBME). Foreign-born workers with less than a two year post-secondary degree were classified as foreign-born less educated. A similar calculation was employed to separate the native-born labor force into “native-born more educated” (NBME) and “native-born less educated” (NBLE) labor groups. The breakdown of the labor groups is presented in Figure 1 and Table 1.

The baseline IMPLAN SAM used in this study included only one labor payment account. This single employee compensation account had to be disaggregated into the four labor groups used in this study. This was accomplished by obtaining wage differentials from ACS data and compared to previous literature (Pastor et al. 2010). Pastor et al. (2010) found that, within similar occupations, the average native-born wage is almost 10 percent higher than the foreign-born wage. This finding corroborated by ACS data for Idaho found an average wage differential of 10 percent. However, specific sectors for individual labor groups often had insufficient observation to develop sector specific wage differentials based solely on ACS data. Therefore the average 10 percent differential between native-born and foreign-born labor was applied uniformly across all sectors. The sum of wages paid across the four new labor accounts for each respective sector were forced to equal the original employee compensation payment from the baseline IMPLAN SAM.

Thus, our estimates of Idaho's labor force now include the undercounted individuals as defined by Kasarda and Johnson (2006). Passel and Cohn refer to this group as the adjusted residual population, or the unauthorized population. Assuming all of the ‘missing’ workers are unauthorized, the adjustments to industries now include unauthorized workers in Idaho's economy. This makes it possible to estimate the state-level economic effects of unauthorized workers, rather than simply foreign-born labor as a whole. This method more accurately reflects what is likely to happen if Idaho passed legislation restricting the supply of foreign-born workers. However, this analysis is not primarily concerned with the role of unauthorized labor per se, but rather a broader analysis of how foreign-born labor interfaces with a state's economy.

3. MODEL

To conduct this part of the analysis, a nested CGE model is constructed as to capture the complex nature of supply and demand for more and less educated foreign- and native-born workers. CGE models are widely considered to yield the most accurate estimates of how a reduction in labor supply would affect wages, household income, and government revenues (Johnson, Otto, and Deller, 2006). Many previous studies of the impacts of immigrant or foreign-born labor were estimated using input-output models such as IMPLAN or ITEP (Gans, 2008, Kasarda et al., 2007, Eisenhauer et al., 2007). Although input-output models are ubiquitous and are a type of general equilibrium model that is able to estimate economy wide impacts, some of the assumptions associated with input-output models can make them less than ideal for this application (Poot and Cochrane, 2005). Some of the key assumptions of input-output models that are assumed to be violated in this study include zero substitutability of factors of production (i.e., elasticity of substitution equal to zero between foreign-born and native-born labor), perfectly elastic supply of factors (i.e., no limit to the supply of any type of labor), fixed prices and wages, and all shocks must be translated outside the model into shocks to final demands. Violations to each of these assumptions are believed to be foundational to this analysis. Since this assumption is unrealistic in a model that incorporates foreign-born and native-born workers (which are assumed to substitute for each other to some degree), it is necessary to use a CGE approach rather than an input-output model.

The CGE model developed here is a Neoclassical Walrasian general equilibrium model and the model shares a pedigree with the standard IFPRI CGE model (Lofgren, Harris, and Robinson, 2001) and the Washington-Idaho CGE model (Holland, Stodick and Devadoss, 2005). The standard Washington-Idaho model is altered to introduce nested production function with four labor groups and one capital account. The model is structured such that foreign-born and native-born labor within the two education groups are a nested factor of production in a constant elasticity of substitution (CES) production function for each sector of the Idaho economy. Equations 1 through 4 present the nested production functions used in this study. Appendix 2 presents code for key components of the nested model. A full description of the CGE model with all 885 equations is available from the authors.

$$\begin{aligned}
 (1) \quad & U_i = \phi 1_i \left[\alpha 1_i F 1_i^{\frac{\epsilon 1 - 1}{\epsilon 1}} + (1 - \alpha 1_i) N 1_i^{\frac{\epsilon 1 - 1}{\epsilon 1}} \right]^{\frac{\epsilon 1}{\epsilon 1 - 1}} \\
 (2) \quad & M_i = \phi 2_i \left[\alpha 2_i F 2_i^{\frac{\epsilon 1 - 1}{\epsilon 1}} + (1 - \alpha 2_i) N 2_i^{\frac{\epsilon 1 - 1}{\epsilon 1}} \right]^{\frac{\epsilon 1}{\epsilon 1 - 1}} \\
 (3) \quad & L_i = \phi 3_i \left[\alpha 3_i U_i^{\frac{\epsilon 2 - 1}{\epsilon 2}} + (1 - \alpha 3_i) M_i^{\frac{\epsilon 2 - 1}{\epsilon 2}} \right]^{\frac{\epsilon 2}{\epsilon 2 - 1}} \\
 (4) \quad & Q_i = \frac{\phi 4_i}{(1 - \tau) - \rho_i} \left[\alpha 4_i L_i^{\frac{\epsilon 3 - 1}{\epsilon 3}} + (1 - \alpha 4_i) K_i^{\frac{\epsilon 3 - 1}{\epsilon 3}} \right]^{\frac{\epsilon 3}{\epsilon 3 - 1}}
 \end{aligned}$$

where i is a subscript denoting industry

$F1$: foreign-born, less-educated labor

$F2$: foreign-born, more-educated labor

$N1$: native-born less-educated labor

$N2$: native-born more-educated labor

U : composite less-educated labor

M : composite more-educated labor

L : composite total labor

K : capital inputs

Q : industry output

ϕ : technology coefficient

α : share parameter

ε : substitution elasticity

τ : indirect business tax rate

ρ : total quantity of intermediate inputs used as a fix share of output (Leontief intermediate inputs)

Underlying the CGE model used in our analysis is an important assumption about how foreign-born and native-born workers substitute for each other within given skill categories. This assumption has implications for the wage rate required to attract foreign-born and native-born workers for any given job. Borjas (2003) found that while foreign-born and native-born workers with similar education levels are not perfect substitutes for each other, they do substitute for each other more easily than workers with different education levels. Therefore, in building this model it is assumed that, given similar education levels, foreign-born and native-born workers are imperfect substitutes with an elastic substitutability (Berck et al., 1996). It is also assumed that more-educated and less-educated workers are relatively inelastic in their ability to substitute for one another (Card and Lemieux, 2001). The nesting structure and elasticities used in the CGE model are presented in Figure 2.

That native-born workers would be willing to take some share of the newly vacated jobs does not imply that they would be willing to work at the same wage rate as foreign-born workers (Pastor et al. 2010). The substitutability assumption plays an important role in the results of this study. Therefore, the sensitivity of our results to changes in the degree of substitutability between NBLE and FBLE labor are also explored. The findings of the CGE model are compared to the results of an identical reduction in labor in an input-output model of Idaho and the findings of our sensitivity analysis and comparison of the models are discussed.

Another key assumption of this model is that foreign-born labor and their corresponding households do not have any additional demands on social services or make additional contributions to public resources relative to native-born labor and households of the same income group. This is not to say that foreign-born labor and households do not receive public resources, rather that they receive them proportionately to native-born labor and households in the same income group. While there is evidence in the literature that foreign-born labor and foreign-born households do use social services, there is little research that indicates this strain is any greater than native-born labor and households within the same income group (Camarata, 2004; Capps et al., 2005; Kasarda and Johnson, 2006). The exact nature of foreign-born households' demand for social services relative to native-born households in the same income group may be an area for future research. Additionally, this model does not attempt to model the migration decision of foreign-born households and assumes only that returns to households and household expenditures are a function of returns to factors. Household migration is admittedly more complicated than simple labor demand dynamics, but that issue remains outside the scope of this study.

4. LABOR SUPPLY AND DEMAND AND OTHER MODEL CLOSURES

While modeling factor demand is fairly straight-forward in general equilibrium models, factor supply specifications are much more open to assumptions. Factor demand in this model is simply derived from the first order profit maximization conditions (Hotelling's Lemma). Factor supply, on the other hand, requires some assumptions as to the nature of factor mobility and, wage responsiveness. It is common for CGE models to choose either a perfectly inelastic labor supply where supply is fixed and wages are allowed to clear the market, or a perfectly elastic labor supply where wages are fixed and supply varies to clear the market (Shoven and Whalley, 1992). Alternatively, an upward-sloping labor supply curve can be employed in which case both the wages and the supply are allowed to vary.

Figure 2. Nesting Structure of the CES Production Functions Used in the CGE Model.

Elasticity node	CGE model 1	CGE model 2
ε1	3.5	1.3
ε2	1.3	1.3
ε3	0.9	0.9
ε4	0.0	0.0

The closure used in this study allows for changes in the supply of all types of labor except for FBLE. The supply of FBLE labor is necessarily modeled as exogenous thus facilitating its use as a choice variable in the model (i.e. exogenously shocked). Therefore, the labor supply closure for FBLE labor allows the average FBLE wage to vary but keeps the total supply of FBLE labor exogenous. The labor supply for NBLE, NBME, and FBME labor is modeled as being upward sloping and responsive to wages. For these labor groups, both the total supply and the respective average wages are allowed to vary. The labor-supply equation is presented as follows:

$$(5) \quad QLS_l = \beta_l W_l^{\eta_l}$$

Where QLS is the labor supply for labor type l , which represents the three labor types (NBLE, NBME, and FBME) that are not exogenously determined, W is the wage rate for the respective labor class, β is the slope shift variable that is initialized using base employment and wage data, and η is the labor elasticity of supply for the respective labor classes. The labor elasticity of supply has generally been shown to be slightly inelastic ($\eta=0.8$) with respect to wages (Berck et al., 1996; Hausman, 1985). Allowing for upward sloping is an improvement on previous CGE closures where either perfectly elastic or perfectly inelastic factor market closures are common (Shoven and Whalley, 1992). Necessarily the supply of FBLE labor was made exogenous so allow this variable to be shocked. For all labor groups the wage distortion factor was fixed to its initial condition meaning that, while the average wage for each labor group is variable, the relative difference between wages paid for each type of labor across all sectors is fixed. This is a proxy for human capital differences between different sectors.

This model is set up as an open-economy, single-region model with an upward-sloping labor-supply function for native-born labor and FBME labor. This means that the supply of native-born and FBME labor can increase or decrease in response to changes in wages and industry output. The increase in supply of this labor can come from either in-migration of labor from other states or from unemployed labor from within the state. Because there are no constraints on labor migration within the United States, there is no distinction made between labor coming from within Idaho or from a neighboring state. The supply function for FBLE labor, however, is modeled to be fixed or exogenously determined. This was done so that exogenous shocks to the FBLE labor supply could be examined, and because the study is designed to investigate the economic impacts and welfare implications of changes in the FBLE labor supply. The reduction in the supply is assumed to come from potential changes in state policies that discourage at least a segment of the FBLE labor supply. A more sophisticated foreign-born labor supply function could be adopted where the foreign-born labor supply is upward sloping and responds to wages and potential policies designed to enact penalties on illegal in-migration. In this case the exogenous choice variable that would be shocked in the model would be the state's immigration policy variable which enacts a cost on a segment of the FBLE labor supply. However, the goal of this paper is to investigate the effects of losing varying amounts of the FBLE labor supply, and as such the shock to the state's immigration policy variable would be the necessary magnitude to reduce the supply of the FBLE labor supply by a fixed amount. Therefore, the model results are equivalent to simply reducing the FBLE labor supply directly. Because this model is of a medium-run (one to two years) regional economy, capital is assumed to be fixed and industry specific. If this were conceived to be a longer-run model, the supply of capital would need to be variable and mobile across sectors.

Domestic and international with the region is handled through Armington functions (Armington 1969). Armington functions are incorporated into the model to allocate demand for inputs by the respective sectors between imports and domestic production. The relationship is generally modeled as a constant elasticity of substitution (CES) function. This means that demand preferences over imports and domestic output are expressed as a CES function. These equations arise due to the possibility of imperfect substitutability between imported and domestic output by domestic demand agents. Additionally, Armington functions allow for different goods to be modeled as either highly localized or highly tradable commodities. This function also serves the same function as a regional absorption coefficient, allocating regional demand between imports and local production and allowing for cross hauling of goods.

The numeraire price in this model is set to the consumer price index (CPI), which is the weighted sum of the consumer prices (Lofgren, Harris, and Robinson, 2002; Holland, Bhattacharjee, and Stodick, 2006). All price changes must therefore be interpreted as relative price changes and relative to the CPI. Prices are initialized to a value of one and the quantities come from the baseline social accounting matrix.

5. RESULTS

Results of the CGE model are presented in Table 2. They were run under the assumption that foreign-born and native-born workers within the same education class have an elasticity of substitution of 3.5 (Borjas, 2003). The supply of FBLE labor in the model was reduced by 10 percent, 25 percent, and 50 percent, respectively. Table 4 shows results from all four simulation runs, but for simplicity's sake the discussion here pertains only to the 50 percent scenario as a means of illustrating the results.

Among less-educated workers, a 50 percent reduction in foreign-born labor would result in a 26 percent increase in the wages of the remaining foreign-born labor. It would have a smaller but still positive effect on the wages of native-born workers, increasing their average wage by 2 percent.

Table 2. CGE Model Results from Shocks of Reductions in the Supply of Foreign-born, Less-educated Labor on the Idaho Economy

Elasticity of substitution of 3.5 between native- and foreign-born labor by class

Change in:	10%	25%	50%
Wages – NBME (% Change)	-0.11	-0.27	-0.58
Wages – FBME (% Change)	-0.11	-0.27	-0.57
Wages – NBLE (% Change)	0.38	1.00	2.00
Wages – FBLE (% Change)	3.70	10.40	26.30
Employment – NBME (Change in # of jobs)	-329	-843	-1,777
Employment – FBME (Change in # of jobs)	-22	-57	-120
Employment – NBLE (Change in # of jobs)	1,583	4,100	8,799
Employment – FBLE (Change in # of jobs)	-8,213	-20,533	-41,067
State Gross Domestic Product (\$ millions)	-168	-430	-905
State and Local Tax Revenue (\$ millions)	-17	-43	-90
Total Economic Output (\$ millions)	-497	-1,275	-2,685
Household Welfare-Equivalent Variation (\$ millions)	-108	-278	-586

The effect of the reduction of FBLE labor on the NBLE labor force is made up of two effects, the “output effect” and the “substitution effect.” Since reducing the availability of inputs cannot increase the output of a production function, then it stands to reason that reducing the availability of a factor of production can either have no effect or a negative effect on output. If an unlimited supply of perfectly substitutable labor existed, then the reduction in FBLE labor would have no effect on output. However, if substitutability is not perfect and the supply is constrained, then the effect of a reduction in output is unambiguously negative. Thus, *ceteris paribus*, the economic output of the state’s industries would expect to decrease with the reduction in the availability of a primary factor of production. As the industrial output decreases, this puts downward pressure on the demand for other factors of production (the output effect). However, factors of production which are close substitutes to the FBLE labor could stand to benefit from the reduction in their supply. The reduction in the supply of FBLE puts upward pressure on the demand for NBLE labor (the closest technical substitute for FBLE labor). The greater the elasticity of substitution between FBLE and NBLE labor, the greater this “substitution effect” and the greater the upward pressure on demand for NBLE labor. In response to the exogenous reduction in the supply of FBLE labor, the output effect puts downward pressure on demand for NBLE while the substitution effect elicits upward pressure.

The net effect of a reduction in FBLE on the other labor groups is largely a function of the elasticity of substitution between FBLE labor and the other respective labor groups. Under the elasticities obtained from Borjas (2003), where native-born and foreign-born labor within the same education class are fairly good substitutes, the net result is a small increase in wages paid to native-born less educated labor, but an overall reduction in the output of the entire Idaho economy. Among workers with more education, the effects on wages of native-born and foreign-born workers are slightly negative, although both effects are smaller than the two less educated labor groups.

The effects of the 50 percent reduction in the supply of FBLE labor (50 percent reduction in a population of approximately 84,000, or a direct loss of 42,000 FBLE workers) on the other labor groups would translate into a loss of 1,777 NBME jobs, a further loss of 120 FBME jobs, and an increase in NBLE jobs of 8,799. The net change in total jobs in the Idaho economy from a 50% reduction in the supply of FBLE labor is a loss of 34,165 jobs, or almost 4% of the total workforce.

Due to the loss of a considerable quantity of foreign-born, less educated labor, Idaho’s SGDP is estimated to fall by \$905 million, or 1.7 percent. This reduction in SGDP would in turn result in a \$90 million reduction in state and local government tax revenues, or 0.7 percent.

Total aggregate household welfare, as measured by changes in equivalent variation in the economy, also went down as a result of the loss of 50 percent of the FBLE labor. Household welfare was reduced by \$586 million, which is a reduction of 3 percent of the original net household income. Based on this calculation, households across Idaho would be made worse off as a whole from the reduction in the supply of FBLE labor.

Another policy related finding from the analysis is that, depending on assumptions about how much different groups of workers substitute for each other, a 50 percent reduction in foreign-born less educated workers would result in \$90 million less in state and local tax revenues. These lower tax revenues are the result of lower overall economic activity in the state. It is possible that a decline in the number of FBLE workers would be matched by a proportionate

decline in the demand for public services, although research from south central Idaho suggests that native born and foreign-born households within the same income classification use public services similarly, therefore it is likely the demand for public services would not change significantly (Salant et al. 2009).

In the absence of an unlimited supply of perfect substitute labor willing to work at the same wage, then losing a factor of production used to varying degrees by most industries in the economy would increase the cost of production for many firms. And since industrial output is heavily influenced by the cost of production in a regional economy, it would stand to reason that increased cost of production would yield a reduction in output. In fact, the model estimates that the total economic output (total sales) of Idaho business would be reduced by \$2.685 billion, a reduction of 2.5 percent of the total economic output in the state. Reducing the supply of foreign-born labor by 50 percent would have a ripple effect throughout the Idaho economy, starting with the industries that use foreign-born labor and eventually impacting other industries. This is because even widely disparate industries are linked through the purchase of a diverse set of inputs and the selling of a diverse set of outputs.

As noted above, the model was first run under the assumption that foreign- and native-born workers are highly substitutable, in other words, that in most cases native-born workers would take jobs newly vacated by foreign-born workers. Because an assumption of an elasticity of substitution of 3.5 is in keeping with the literature, the results in Table 2 are assumed to be the best estimate of the degree to which reducing labor supply would impact Idaho's economy.

However, there are reasons why the assumption that FBLE labor and NBLE labor are highly substitutable may be unrealistic, especially in some specific sectors of the economy. Personal communications with Idaho agricultural and construction industry stakeholders presented with the assumptions of this model indicated that their perception is that the two groups may be less substitutable than previous literature indicates, at least in the short run. For example, differences in language, culture, and cultural stigmas may make it less likely that native-born workers would take jobs vacated by foreign-born workers, especially in jobs that require less education.

6. SENSITIVITY TO LABOR SUBSTITUTABILITY AND I-O COMPARISON

Therefore, to investigate the sensitivity of the model to lower elasticities of substitution between foreign-born and native-born labor within the same education class, the model was again run, this time under the new assumption that foreign- and native-born workers are less substitutable for each other. The elasticity of substitution between native-born and foreign-born labor within the same education class was set to 1.3, the same degree of substitutability estimated for more educated and less educated labor. Results are presented in Table 3. Because this is a more restrictive assumption, the results in Table 3 can be considered the "upper bound" of the degree to which reducing labor supply would impact Idaho's economy.

Under the new assumption, the effects of losing FBLE workers are greater as it is now more difficult for industries that hire significant numbers of FBLE workers to mitigate the impacts of their reduced labor supply. They can't find as many NBLE workers to take jobs vacated by FBLE, which in turn puts upward pressure on wages. Thus, the loss of a primary input (FBLE) that has no close substitute increases the production costs for firms. The net result

Table 3. CGE Model Results from Shocks of Reductions in the Supply of Foreign-born, Less-educated Labor on the Idaho Economy

Elasticity of substitution of 1.3 between native- and foreign-born labor by class

Change in:	10%	25%	50%
Wages – NBME (% Change)	-13.00	-0.34	-0.79
Wages – FBME (% Change)	-0.11	-0.30	-0.69
Wages – NBLE (% Change)	-0.10	-0.20	-0.44
Wages – FBLE (% Change)	8.40	24.50	70
Employment – NBME (Change in # of jobs)	-398	-1,065	-2,441
Employment – FBME (Change in # of jobs)	-24	-63	-145
Employment – NBLE (Change in # of jobs)	-308	-817	-1,850
Employment – FBLE (Change in # of jobs)	-8,213	-20,533	-41,067
State Gross Domestic Product (\$ millions)	-211	-563	-1,286
State and Local Tax Revenue (\$ millions)	-21	-56	-128
Total Economic Output (\$ millions)	-660	-1,757	-4,005
Household Welfare-Equivalent Variation (\$ millions)	-136	-364	-833

is that higher wages for NBLE workers are more than offset by reduced demand for this group of workers.

To investigate the point to which the substitution effect and the output effect on NBLE labor was perfectly offset to make the impact on labor demand for NBLE labor unchanged by the loss of FBLE labor, a sensitivity analysis was performed. It was found that at an elasticity of substitution of 1.465, the two effects perfectly offset one another. At elasticities lower than 1.465, the output effect trumped the substitution effect and the effects of a loss in FBLE labor had a negative effect on the demand for NBLE labor. Conversely, at elasticities higher than 1.46, the substitution effect outweighed the output effect and the loss of FBLE labor had a positive effect on the demand for NBLE labor. Because it is believed that the elasticity of substitution between native-born and foreign-born labor within the same education class is 3.5, then it would be expected that a loss in FBLE labor would put upward pressure on the demand for NBLE labor in Idaho. However, without an unlimited supply of perfect substitute labor, this model would indicate that a reduction in the supply of FBLE labor would have a net negative effect on state GDP, total economic output of the state, state tax revenue, and household welfare.

The results of a 50 percent reduction in the supply of FBLE labor in the alternative CGE models are then compared to the results of two alternative scenarios in an input-output analysis (scenarios A, B, C, and D respectively in Table 4). Because an input-output model explicitly and invariably assumes an elasticity of zero between all input (including factors), it would be assumed that the results of similar scenario shocks in an input-output model would be greater than in a CGE model where the elasticity of substitution between at least some inputs is greater than zero. It is found that the highest regional economic impacts on total output and SGDP are garnered from an input-output model where changes in employment are translated into output changes using an employment to output ratio (scenario C in Table 4). This was performed by shocking the employment by sector vector in the respective sectors that correspond to 50 percent reduction in their FBLE labor usage in IMPLAN. This removes the total output of that labor and

Table 4. Results of a CGE Contrasted against Those for an Equivalent Input-Output Model for a 50 Percent Reduction in Foreign-born, Less-educated Labor in Idaho

Scenario	Type of analysis and assumptions	Change in Employment	Change in State GDP	Change in Total Output	Change in Welfare (Equivalent Variation)
A	Results of computable general equilibrium model that directly reduces the supply of foreign-born less educated labor by 50% assuming foreign born and native born labor within an education class are highly substitutable. This corresponds to table 3.	-34,000	-\$904M	-\$2.7B	-\$586M
	Results of computable general equilibrium model that directly reduces the supply of foreign-born less educated labor by 50% assuming foreign born and native born labor within an education class are less substitutable. This corresponds to table 4.	-45,500	-\$1.3B	-\$4.0B	-\$883M
C	Results of input-output model that translates 50% reduction in foreign-born less educated labor into a change in industry output using total output per worker.	-72,575	-\$4.1B	-\$10.3B	N/A
D	Results of input-output model that translates 50% reduction in foreign-born less educated labor into a change in exogenous demand using exogenous demand per worker.	-19,510	-\$1.2B	-\$3.2B	N/A

assumes that no other labor can take its place, and functionally equates all output with exogenous demand. This is the most common way that immigrant labor impacts have been performed in the literature

However, if only the truly exogenous demand is shocked (scenario D in table 4), then the impact on total output and SGDP of the state's economy is strikingly close to the results from the CGE model with highly substitutable labor within the same education groups (scenario A in Table 4). Scenario D in Table 4 is accomplished by converting direct changes in employment to changes in output using the respective industry's output to employment ratio, then converting the output to exogenous demand using the respective industry's output to exogenous demand ratio. This converts the employment shock to an exogenous demand shock and is the theoretically correct way to conduct an input-output impact analysis. It is hypothesized that the reason that the results of this method are similar to the results of scenario A is due to offsetting assumptions about fixed prices and wages, and a lack of substitutability between factors. The fixed price assumption of input-output models results in wages not increasing in response to a reduction in the labor supply as neoclassical theory would suggest they would. The assumption of fixed

prices and wages would serve to lessen the impacts of the reduction in FBLE labor, while the assumption of a lack of substitutability between factors would serve to increase the impacts. Together these seemingly unrealistic assumptions served to offset and yield the results of the input-output model described in scenario D of Table 4 that approach our best available science estimates presented in scenario A of Table 4.

Additionally, Table 4 presents household welfare results only for the CGE models as, contrary to a CGE analysis, welfare impacts are not able to be directly measured in an input-output model. Input-output models assume perfectly elastic supply functions and perfectly inelastic demand; therefore there is no way to directly measure equivalent variation, consumer surplus or producer surplus changes due to shocks to the model. The implications of the ability to measure only impacts and not changes in welfare in input-output models and CGE's ability to measure both is a topic that deserves greater attention in the literature.

7. SUMMARY AND CONCLUSION

The finding that ACS data understate the number of foreign-born workers in Idaho is not surprising. As noted above, some foreign-born residents have a real or perceived incentive to avoid being counted. It is hypothesized that the difference between ACS estimates and our estimates may be representing the unauthorized immigrant population. Following Passel and Cohn (2009), the roughly 56,000 Idaho residents who are undercounted by the ACS are hypothesized to fall into two groups: those who are uncounted unauthorized immigrants and those legal immigrants who are undercounted for other reasons (e.g., immigrants who have gained citizenship, asylum seekers, and special legal status immigrants). If Passel and Cohn's (2009) method is used for assigning our undercounted population to these two categories, then the estimated number of people in Idaho working without proper documentation roughly corresponds to 50 percent of the supply of FBLE labor.

Therefore, based on the findings of Passel and Cohn (2009), the analysis of a 50 percent reduction of the supply of FBLE labor presented in the last column of Tables 1 and 2 is roughly equivalent to an estimate of the effects of losing 100 percent of the unauthorized FBLE labor. It can be said, then, that unauthorized FBLE labor contributes \$2.7 billion in total economic output and \$90 million in state and local tax revenue to the state of Idaho. This number represents 2.5 percent of the total economic output of the state's economy, which is somewhat less than the 4.5 percent reduction in total employment that the loss of the 41,067 FBLE workers represents.

The results of the CGE model serve to inform policy related discussions on how immigrant labor affects a state's economy and particular segments of the regional labor market. It was found that reducing the supply of FBLE labor would create increased demand for NBLE labor if and only if the elasticity of substitution between NBLE and FBLE labor was sufficiently high, that is, above 1.46. Below this level, a reduction in the supply of FBLE labor would create less demand for NBLE labor and job losses in the NBLE labor group. Therefore, any argument as to how immigrant labor affects native-born labor must come with either implicit or explicit assumptions about the degree to which these two labor groups substitute for one another. The limited literature that exists as to the substitutability between immigrant and native-born labor within a similar education or experience level suggests that the two are good, but not perfect, substitutes for one another and have an elasticity of substitution of 3.5 (Borjas, 2003). However, certain industries are likely to have significantly lower substitutability between labor types due to cultural and linguistic constraints. Personal communication with industry leaders in agriculture

and construction suggest that these industries may be examples where the substitutability between different labor groups is perceived to be lower than average. This issue of substitutability between immigrant labor and native-born labor is an important area for further research.

The annual average unemployment rate in Idaho for 2008 was 4.75 percent, a rate that approaches full employment and well below the national unemployment rate in 2008 of 5.8 percent. This model is mute on the actual effect of the reduction in FBL on the subsequent unemployment rate in Idaho. This is because there is no distinction made between jobs coming from unemployed workers already within the state, or labor moving into the state to take jobs. The number of jobs created or lost in the region is calculated within the model but not subsequent effect on the state unemployment rate. To estimate the effect of a reduction of FBLE labor on the state's unemployment rate, assumptions would need to be made regarding domestic labor migration. This analysis shows that at low levels of labor substitutability, that a reduction in FBLE labor has an unambiguously negative effect on the economic output of the state and on the demand for native born labor. At higher levels of substitutability, then the reduction of FBLE labor still has a negative effect on the economic output of the state, but has a positive effect on the demand and wages of native born labor. Therefore, under an assumption of high substitutability of foreign-born and native-born labor, it must be stated that a reduction in the supply of FBLE labor could very well also reduce the demand for public services in Idaho; even if foreign-born and native-born households use government services at the same rate (Bartik, 1991).

States across the country are either considering, or have enacted, legislation intended to restrict the supply of foreign-born workers. If such legislation were passed in Idaho, our analysis shows it would have a substantively negative impact on the state's economy. Employment for one group of workers, those who are native-born and have less education, would increase by about 4,100 jobs. However, there would be a net loss in jobs in the state as a whole, and total economic output and tax revenue would decline. Under assumptions in line with the literature, the analysis indicates that foreign-born labor has a net positive effect on the Idaho economy as a whole, and reducing the supply of FBLE labor would have a net negative effect on SGDP, output, and tax revenue. However, the analysis also indicates that the presence of a FBLE workforce can hold down wages of NBLE workers by a small but noticeable amount.

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APPENDIX 1: METHODS EMPLOYED TO ESTIMATE IDAHO'S FOREIGN-BORN LABOR FORCE

Drawing from and modifying Kasarda and Johnson's (2006) method, estimates of FBL by industry sector from the American Community Survey (ACS) are adjusted using other data sources employing the steps detailed below.

Public school enrollment numbers give a count of the number of Hispanic children enrolled in Idaho public schools (PbHpse). For purposes of estimation 'school aged children' are defined to be between the ages of 5 and 19 which are the ages for which children would most typically be enrolled in k-12 education. Based on Idaho public school records, in 2006 there were 33,599 k-12 public school students of Hispanic descent. Next, the number of private school attendees is calculated by using ratios derived from the American Community Survey for Idaho. Hispanic private school attendees (PvHacs) were found to make up 0.073% of the entire population and Hispanic school aged children not enrolled in school (USHacs) comprise 0.254% of the population. Multiplying the Census Bureau estimate for July 2006 of Idaho's population yields estimates for each of these school aged groups: 1,079 and 3,727 respectively. Adding these to the data on children enrolled in public school yield the final estimate of 38,405 school-aged Hispanic children (SAHest). This calculation is presented in Equation A.1.

$$(A.1) \quad SAH_{est} = PbH_{pse} + PvH_{acs} + USH_{acs} = 38,405$$

Using our estimate of school aged Hispanic children (SAHest) coupled with ACS data on school-aged Hispanic children (SAHacs) and total non-school-aged Hispanics (NSAHacs), the total Hispanic population in Idaho (HPest) is estimated in Equation A.2.

$$(A.2) \quad HP_{est} = \left(\frac{NSAH_{acs}}{SAH_{acs}} * SAH_{est} \right) + SAH_{est} = 181,655$$

Our estimate of Idaho's Hispanic population (HPest) is 31 percent higher than the census estimate of the Hispanic population (HPacs) in Idaho of 138,871. A comparison of our estimate of the Hispanic population in Idaho to the ACS estimate of the Hispanic population in Idaho is presented in Table A1.

Kasarda and Johnson (2006) break down North Carolina's Hispanic population into born in state, born in another U.S. jurisdiction, and foreign-born. This study follows their method for doing this by using birth data for Idaho from the National Vital Statistics (NVS) System to get a count of Hispanic births in the state of Idaho until 2006 (SBHPnvs). The total number of Hispanics living in Idaho that were born in other states (OBHPacs) is calculated from subtracting SBHPnvs from the ACS data on the number of foreign-born people living in Idaho. Subtracting the number of Idaho born Hispanics and Hispanics born in other states from our estimate of total

**Table A1. Comparison of the Idaho's Hispanic Population Estimates
(Census Data versus that Used)**

	American Community Survey (ACS)	Estimate Used in this Study
Total Hispanic Population	138,871	181,655
Total Idaho Population	1,464,413	1,527,393
Percent Hispanic	9.4	11.89

number of Hispanics living in Idaho gives the total number of Hispanics born abroad (FBHP_{est}) in Equation A.3.

$$(A.3) \quad FBHP_{est} = HP_{est} - SBHP_{nvs} - OBHP_{acs} = 85,034$$

Using this method, it is determined there are 37,770 more foreign born people living in Idaho than estimated by ACS data alone, giving us a total of 85,034 foreign-born Hispanics.

The foreign-born Hispanic undercount ratio (HUR) is then calculated by dividing FBHP_{est} by the ACS estimate of the foreign-born Hispanic population in Equation A.4.

$$(A.4) \quad HUR = \frac{FBHP_{est}}{FBHP_{acs}} = 1.48 = \frac{HP_{est}}{HP_{acs}}$$

The entire foreign born Hispanic population, however, is not included in the FBL as some of the population is under working age or does not work outside of the home. To find the total estimate of the foreign-born Hispanic labor force, it is assumed that the foreign-born Hispanic labor population is underestimated at the same rate as the foreign-born Hispanic population as a whole. Therefore, the ACS estimate of the total foreign-born Hispanic labor force (FBHL_{acs}) is multiplied by HUR to obtain the total foreign-born Hispanic labor force (FBHL_{est}) and is presented in Equation A.5.

$$(A.5) \quad FBHL_{est} = HUR * FBHL_{acs} = 86,924$$

To obtain the entire FBL force in the state's economy, the foreign-born non-Hispanic labor force (FBOL_{acs}) is obtained from ACS data and is added to FBHL_{est} as represented in Equation A.6.

$$(A.6) \quad FBL = FBHL_{est} + FBOL_{acs} = 107,000$$

There are an estimated 107,000 foreign-born workers in Idaho including the 37,700 workers that were estimated to be undercounted in the ACS estimates. The foreign-born laborers are distributed proportionally based on ACS estimates of foreign-born labor by sector and these numbers are then split into foreign-born more educated (with a two year post-secondary degree) and foreign-born less educated (without a two year post-secondary degree) again using ACS derived percentages of educational attainment by nativity and sector.

APPENDIX 2: SELECTED MODIFIED EQUATION SPECIFICATION

This appendix describes a three-level nested production function with five factors of production. The factors of production are:

CAP: Capital
NATMEDU: Native-born more-educated labor
FORMEDU: Foreign-born more-educated labor
NATLEDU: Native-born less-educated labor
FORLEDU: Foreign-born less-educated labor

In addition to the labor sectors listed above, the following sectors must be added to set K (the set of all sectors) and set F(K) (the set of all factors of production):

LAB: The total labor sector

MEDU: The combined more-educated labor sector
LEDU: The combined less-educated labor sector

Sets are:

$A = \{\text{activities}\}$
 $F(K) = \{CAP, NATMEDU, FORMEDU, NATLEDU, FORLEDU, LAB, MEDU, LEDU, INDU\}$
 $FF(F) = \{CAP, NATMEDU, FORMEDU, NATLEDU, FORLEDU, LAB, MEDU, LEDU\}$
 $FF5(FF) = \{NATMEDU, FORMEDU, NATLEDU, FORLEDU, LAB, MEDU, LEDU\}$
 $FF4(FF) = \{CAP, NATMEDU, FORMEDU, NATLEDU, FORLEDU\}$
 $FF1(FF) = \{CAP, LAB\}$
 $FF2(FF) = \{MEDU, LEDU\}$
 $FF3(FF) = \{NATMEDU, FORMEDU, NATLEDU, FORLEDU\}$
 $FF31(FF) = \{NATMEDU, FORMEDU\}$
 $FF32(FF) = \{NATLEDU, FORLEDU\}$

Each nest in the production function has a name L1 through L4:

L1 : $QA = f(CAP, LAB)$
 L2 : $QF(LAB) = f(MEDU, LEDU)$
 L3 : $QF("MEDU") = f(NATMEDU, FORMEDU)$
 L4 : $QF("LEDU ") = f(NATLEDU, FORLEDU)$

The set for the production function names:

LEVEL = (L1, L2, L3, L4)

Parameters are:

$esubp(A, LEVEL)$: Elasticity of substitution at each level, (exogenous)
 $\rho(LEVEL, A)$: CES production function exponent
 $\Delta(FF, A)$: Share parameters
 $ad(LEVEL, A)$: Technical coefficients for CES

Original levels:

$QAO(A)$: Output of activity A
 $QFO(FF, A)$: Quantities of factors
 $WFDISTO(FF, A)$: Wage or rent distortion factors
 $WFO(FF)$: Average wage or rent

Variables are:

$QFL1(LAB, A)$: Quantity of composite labor
 $QFL2(FF2; A)$: Quantity of composite more educated labor and less educated labor
 $QF(FF; A)$: Quantities of factors
 $QA(A)$: Quantity of output of activity A
 $PVA(A)$: Price of value added
 $WFDIST(FF; A)$: Wage or rent distortion factors
 $WF(FF)$: Average wage or rent

The production functions are:

$$\begin{aligned}
 QF("MEDU",A) &= ad("L3",A) \left[\sum_{FF31} (FF31,"L3",A) * QF(FF31,A)^{-\rho("L3",A)} \right]^{\frac{-1}{-\rho("L3",A)}} \\
 QF("LEDU",A) &= ad("L4",A) * \left[\sum_{FF32} \Delta(FF32,"L4",A) * QF(FF32,A)^{-\rho("L4",A)} \right]^{\frac{-1}{\rho("L4",A)}} \\
 QF("LAB",A) &= ad("L2",A) * \left[\sum_{FF2} (FF2,"L2",A) * QF(FF2,A)^{-\rho("L2",A)} \right]^{\frac{-1}{\rho("L2",A)}} \\
 QA(A) &= \frac{ad("L1",A)}{1-tb(A) - \sum_C ica(C,A)} * \left[\sum_{FF1} \Delta(FF1,"L1",A) * QF(FF1,A)^{-\rho("L1",A)} \right]^{\frac{-1}{\rho("L1",A)}}
 \end{aligned}$$

The factor demand functions are:

$$\begin{aligned}
 WFDIST("CAP",A) * WF("CAP") &= \\
 \frac{PVA(A) * ad("L1",A)}{1-tb(A) - \sum_C ica(C,A)} * \left[\sum_{FF1} \Delta(FF1,"L1",A) * QF(FF1,A)^{-\rho("L1",A)} \right]^{\frac{-1}{\rho("L1",A)}-1} \\
 * \Delta("CAP","L1",A) * QF("CAP",A)^{-\rho("L1",A)-1} \\
 WFDIST("NATMEDU",A) * WF("NATMEDU") &= \\
 \frac{PVA(A) * QA(A) * \Delta("NATMEDU",A) * QF("NATMEDU",A)^{-\rho("L3",A)-1}}{\sum_{FF4} \Delta(FF4,A) * QF(FF4,A)^{-\rho("L3",A)}} \\
 WFDIST("FORMEDU",A) * WF("FORMEDU") &= \\
 \frac{PVA(A) * QA(A) * \Delta("FORMEDU",A) * QF("FORMEDU",A)^{-\rho("L3",A)-1}}{\sum_{FF4} \Delta(FF4,A) * QF(FF4,A)^{-\rho("L3",A)}} \\
 WFDIST("NATLEDU",A) * WF("NATLEDU") &= \\
 \frac{PVA(A) * QA(A) * \Delta("NATLEDU",A) * QF("NATLEDU",A)^{-\rho("L4",A)-1}}{\sum_{FF4} \Delta(FF4,A) * QF(FF4,A)^{-\rho("L4",A)}} \\
 WFDIST("FORLEDU",A) * WF("FORLEDU") &= \\
 \frac{PVA(A) * QA(A) * \Delta("FORLEDU",A) * QF("FORLEDU",A)^{-\rho("L4",A)-1}}{\sum_{FF4} \Delta(FF4,A) * QF(FF4,A)^{-\rho("L4",A)}}
 \end{aligned}$$

Parameter calculations:

$$\rho(\text{LEVEL}, A) = \frac{1}{\text{esubp2}(A, \text{LEVEL})} - 1$$

$$\Delta(\text{FF1}, A) = \frac{WFDISTO(\text{FF1}, A) * WFO(\text{FF1}) * QFO(\text{FF1})^{\rho(\text{"L1"}, A)+1}}{\sum_{\text{FF4}} [WFDISTO(\text{FF4}, A) * WFO(\text{FF4}) * QFO(\text{FF4})^{\rho(\text{"L1"}, A)+1}]}$$

$$\Delta(\text{FF2}, A) = \frac{WFDISTO(\text{FF2}, A) * WFO(\text{FF2}) * QFO(\text{FF2})^{\rho(\text{"L2"}, A)+1}}{\sum_{\text{FF4}} [WFDISTO(\text{FF4}, A) * WFO(\text{FF4}) * QFO(\text{FF4})^{\rho(\text{"L2"}, A)+1}]}$$

$$\Delta(\text{FF31}, A) = \frac{WFDISTO(\text{FF31}, A) * WFO(\text{FF31}) * QFO(\text{FF31})^{\rho(\text{"L3"}, A)+1}}{\sum_{\text{FF4}} [WFDISTO(\text{FF4}, A) * WFO(\text{FF4}) * QFO(\text{FF4})^{\rho(\text{"L3"}, A)+1}]}$$

$$\Delta(\text{FF32}, A) = \frac{WFDISTO(\text{FF32}, A) * WFO(\text{FF32}) * QFO(\text{FF32})^{\rho(\text{"L4"}, A)+1}}{\sum_{\text{FF4}} [WFDISTO(\text{FF4}, A) * WFO(\text{FF4}) * QFO(\text{FF4})^{\rho(\text{"L4"}, A)+1}]}$$

$$ad(\text{"L1"}, A) = \frac{[1 - tb(A) - \sum_C ica(C, A)] * QAO(\text{FF1}, A)}{\left[\sum_{\text{FF1}} \Delta(\text{FF1}, A) * QFO(\text{FF1}, A)^{-\rho(\text{"L1"}, A)} \right]^{\frac{-1}{\rho(\text{"L1"}, A)}}}$$

$$ad(\text{"L2"}, A) = \frac{QFO(\text{"LAB"}, A)}{\left[\sum_{\text{FF2}} \Delta(\text{FF2}, A) * QFO(\text{FF2}, A)^{-\rho(\text{"L2"}, A)} \right]^{\frac{-1}{\rho(\text{"L2"}, A)}}}$$

$$ad(\text{"L3"}, A) = \frac{QFO(\text{"MEDU"}, A)}{\left[\sum_{\text{FF3}} \Delta(\text{FF3}, A) * QFO(\text{FF3}, A)^{-\rho(\text{"L3"}, A)} \right]^{\frac{-1}{\rho(\text{"L3"}, A)}}}$$

$$ad(\text{"L4"}, A) = \frac{QFO(\text{"LEDU"}, A)}{\left[\sum_{\text{FF3}} \Delta(\text{FF3}, A) * QFO(\text{FF3}, A)^{-\rho(\text{"L4"}, A)} \right]^{\frac{-1}{\rho(\text{"L4"}, A)}}}$$