Commodity Booms, Human Capital, and Economic Growth: An Application to Colombia

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Abstract
The idea that a trade-off exists between current levels of consumption and future levels of human capital is modeled. As shocks in international commodity prices affect income and modify the optimal consumption basket, household members adjust their time preferences between school and work. As a result, the dynamics of human-capital accumulation may be affected and, in cases in which commodity production and trade play a significant role in the economy, such dynamics may also have an impact on economic growth and the composition of economic sectors. Using a dynamic CGE model and Colombian macroeconomic data, we showed how shocks in commodity prices determined households’ educational demands and, at the same time, the composition of the labor market.

JEL: C68, I25; J24; O13
Keywords: Commodity Booms; Human Capital; CGE modeling, Colombia.

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Table of contents

I. Introduction p.1
II. Data p.5
III. Methodology p.7
IV. Application and Results p.10
   4.1. Main Macroeconomic Results
   4.2. Results for Education and Labor Composition
   4.3. Sensitivity Analysis
V. Conclusions and Policy Implications p.21
References p.24
Appendix p.26
List of tables

Table 1: Composition of the Colombian Economy, by Sector, 2015 (%) ........................................ 6
Table 2: Factor Intensity in the Colombian Economy, by Sector, 2015 (%) ........................................ 6
Table 3: Household Participation in Factor Remuneration, 2015 (% of total) .................................... 7
Table 4: Main Macroeconomic Results (% change) .............................................................................. 12
Table 5: Percent Change in Activity Output with Respect to the Baseline Scenario ....................... 13
Table 6: Percent change in Labor Demand by Type over Baseline ..................................................... 13
Table 7: Simulated Scenarios ............................................................................................................... 20

List of figures

Figure 1: Production Volume Index for the Colombian Economy, by Sector (2005=100) .......... 1
Figure 2: Share by Sectors in Total Colombian Real Exports ............................................................. 2
Figure 3: Percent Change in Labor Income over Baseline ................................................................. 15
Figure 4: Evolution of Relative Wages................................................................................................. 16
Figure 5: Behavior of the Incremental Supply of Unskilled Labor (%) ............................................. 17
Figure 6: Behavior of incremental supply of semi-skilled (left) and skilled labor (right), (%) ...... 17
Figure 7: Percent Change in Households Demand for Education (left) and in Skilled Labor Supply (right) over Baseline ........................................................................................................ 18
Figure 8: Evolution of Wages by Labor Type (%) ............................................................................. 19
Figure 9: Behavior of the Incremental Supply of Unskilled Labor ..................................................... 20
Figure 10: Behavior of Incremental Supply of Semi-Skilled (left) and Skilled Labor (right) ....... 21
I. Introduction

Motivated by the ongoing discussion regarding the role of natural resources in an economy, we studied the mechanisms through which a boom in commodity prices affects economic growth via human-capital accumulation. There are two different perspectives on this topic, one that considers positive effects on economic growth and another that contemplates negative effects, but neither is conclusive. We investigated the relationship among commodities booms, human-capital accumulation, and economic growth in the Colombian economy.

Since 2009, commodity production in Colombia has boomed. The high prices of mining and energy products have promoted expansion in that sector and, at the same time, have driven growth in complementary sectors. In particular, the services sector has been stimulated by this bonanza. Figure 1 shows the importance of the mining sector in the Colombian GDP after the international financial crisis. Figure 2 is more illustrative, however, and shows the commodity boom between 2009 and 2015 through the share by sector in total Colombian exports.

Figure 1: Production Volume Index for the Colombian Economy, by Sector (2005=100)

![Figure 1](image-url)

Source: Departamento Administrativo Nacional de Estadística (DANE).

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1 For more details, see Viner (1952), Rostow (1952), Sachs and Warner (1995), Gylfason (2001), and Badeeb, Lean, and Clark (2017), among others.

2 The Colombian National Department of Statistics.
The literature regarding the effects of natural resources on economic growth is vast. From the optimistic perspective, classical economists such as Viner (1952) and Rostow (1952) have suggested that an abundance of natural resources can support economic development. Conversely, authors such as Sachs and Warner (1995), Gylfason (2001), and Gylfason and Zoega (2006), among others, have proposed that natural-resource abundance could negatively affect economic growth through such channels as savings, investment, and human-capital accumulation (Badeeb, Lean & Clark, 2017).

In the literature, analyses of the mechanisms linking the boom in commodities and human-capital accumulation are approached from the demand side. Higher incomes could diminish agents’ incentives to accumulate human capital (Badeeb, Lean & Clark, 2017). Some empirical evidence in this context was presented by Gylfason, Herbertsson, and Zoega (1999) and Gylfason (2001, 2006) who found a reduction in school enrollment at every level when natural-resource dependence was greater. Other studies have also presented the inverse relation between commodities booms and human-capital accumulation, including Stijns (2005), Blanco and Grier (2012), and Shao and Yang (2014), all of whom showed that the income effect was greater than the substitution effect and that commodity booms increased human capital.³

The mechanism may be presented more specifically as follows: Households that are

³ For more details, see Badeeb, Lean, and Clark (2017).
trying to take advantage of expansive periods (with higher general income from non-wage incomes or commodities-based wages) reduce their demands for education at the expense of human-capital formation. In this direction, Santos (2014) showed the implications of a gold boom on child labor and school attendance in Colombia. Santos reported that the gold boom in Colombia decreased school attendance by 0.2 standard deviations during the recent bonanza. Other authors, including Krueger (2007), who studied coffee production in Brazil, have shown how the education of poor and middle-income children may be adversely affected in periods of economic growth.

There is a clear link between human capital and schooling because human capital is “the component of education that contributes to an individual’s labor productivity and earnings” (Son, 2010: 2). Numerous empirical studies have documented a positive relationship between human capital and economic growth. Azariadis and Drazen (1990), for example, showed that the literacy rate was significant in determining per capita GDP growth, while Mankiw, Romer, and Weil (1992) found relatively large elasticities in the response of per capita GDP to enrollment rates. Barro and Lee (2010) also found that an additional year of schooling of the labor force produced an elastic response in per capita GDP.

Nonetheless, a body of literature asserts that this causality runs in the opposite direction because economic growth increases returns to education which, in turn, increases people’s willingness to study and achieve a higher educational level. This is the point made in the works of Bils and Klenow (2000), who claimed that the effect noted above was erroneously enhanced by omitted-variable bias, and of Krueger and Lindahl (2001), who argued that cross-country studies did not control appropriately for policies that were not stationary and lacked valid instrumental variables.

On the CGE approach, a few papers have reported on the relationship between education and human-capital formation. Jung and Thorbecke (2003) found that educational expenditure raised economic growth in Tanzania and Zambia when levels of physical investment were high. Cloutier, Cockburn, and Decaluwé (2008) identified a relationship between education and poverty in Vietnam, showing that education-subsidy cuts reduced

4 Other important studies with the same perspective are Romer (1986), Barro and Sala-i-Martin (2004), Gyimah-Brempong and Wilson (2004), Hanushek and Woessmann (2008), Hartwig (2010), and Qadri and Waheed (2014), among others.
welfare and increased poverty. Dissou, Didic, and Yakautsava (2016) found that education returns were positive but that their magnitude depended upon the methods employed to finance public spending on education.

From the schooling-to-growth perspective, increases in child labor rates and, in general, increases in school dropout rates lower the dynamics of human-capital accumulation, which hinders economic growth. From the growth-to-schooling perspective, economic growth that does not increase the return to years of schooling would have a negative effect on human-capital accumulation. These relationships provide the foundation for an inquiry into the dynamics of human-capital accumulation in a context in which returns to schooling are determined by the general-equilibrium effects of growth in economic sectors and associated demands for various types of labor, whereas human-capital accumulation is affected by household decisions tied to income and schooling decisions that, in turn, affect economic growth.

We analyzed this issue through a recursive dynamic general equilibrium model that included a schooling module that allowed us to track human-capital formation and accumulation, as explained in the methodology section. In light of the above, our main research questions were these:

- What is the effect of commodity price shocks on human-capital accumulation on an economy-wide level?
- How does this effect feed into the composition of the labor force in terms of the distribution of years of schooling?
- How does the (changing) composition of the labor force interact with the demand for labor?
- What does this interaction imply for various economic sectors?
- What effect do the dynamics of human-capital accumulation have on GDP growth in the medium term?

---

5 This would happen under the assumption that the substitution effect was greater than the income effect.
II. Data

We built a Social Accounting Matrix (SAM) for Colombia using 2015 Colombian macroeconomic data to run the CGE model. The economy was classified into the following eleven activities: agriculture, mining, primary sector, other industries, industry, refinery and metals, services, financial services, other services, educational services, and public administration. These activities were further divided into three categories of labor according to level of skill (unskilled: workers with no formal education, semi-skilled: workers with a basic education, and skilled: workers who had completed post-primary levels of education). Households were classified according to whether they were located in rural, urban, or metropolitan areas based on the Colombian National Household Survey (Gran Encuesta Integrada de Hogares-GEIH) and the Colombian National Quality of Life Survey (Encuesta Nacional de Calidad de Vida-ENCV) for 2014.

Macrodata helped provide a summary of the Colombian economy, including its structure and other features relevant to our study. Table 1 provides a breakdown of the economy by sector, in terms of shares of value added, exports, imports, export/output, and imports/consumption. As the data in Table 1 show, services accounted for the bulk of the economy (61% of value added), while the mining sector and agriculture represented around 9% and 3.6% of value added, respectively. Mining was the most important exporting sector and was responsible for around 55% of exports for 2015, followed by refinery and metals with 19%. The mining-energy sector added around 75% of exports to the Colombian economy. On the import side, industry (49%) and refinery and metals (31.7%) were responsible for the majority of imports.

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6 We defined semi-skilled workers as those who had finished five years of schooling.
### Table 1: Composition of the Colombian Economy, by Sector, 2015 (%)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Value added share</th>
<th>Export share</th>
<th>Import share</th>
<th>Export – output share</th>
<th>Import – Cons. Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3.6</td>
<td>3.8</td>
<td>3.3</td>
<td>12.8</td>
<td>15.0</td>
</tr>
<tr>
<td>Mining</td>
<td>9.1</td>
<td>54.7</td>
<td>0.2</td>
<td>74.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Primary sector</td>
<td>4.1</td>
<td>2.1</td>
<td>3.3</td>
<td>3.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Other industries</td>
<td>1.5</td>
<td>6.8</td>
<td>3.3</td>
<td>19.5</td>
<td>14.1</td>
</tr>
<tr>
<td>Industry</td>
<td>3.2</td>
<td>8.5</td>
<td>49.0</td>
<td>13.3</td>
<td>55.1</td>
</tr>
<tr>
<td>Refinery and metals</td>
<td>5.9</td>
<td>18.8</td>
<td>31.7</td>
<td>22.1</td>
<td>39.5</td>
</tr>
<tr>
<td>Services</td>
<td>31.0</td>
<td>3.0</td>
<td>0.7</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Financial services</td>
<td>13.2</td>
<td>1.9</td>
<td>8.1</td>
<td>1.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Other services</td>
<td>16.8</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Education services</td>
<td>5.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Public administration</td>
<td>6.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>9.1</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Note: Authors’ calculations based on the Colombian Social Accounting Matrix.

As Table 1 also shows, three-fourths of mining production were exported vs. 22% of refinery and metals production. The industry sector was the most dependent on the external market and imported more than half of internal demand (55.1%), followed by refinery and metals with 39.5%

Table 2 shows factor-share intensities according to factors classification. Mining and refinery and metals were the most capital-intensive sectors while the agriculture and primary sectors intensively employed unskilled and semi-skilled laborers. The other sectors, mainly related to services, depended heavily on skilled labor.

### Table 2: Factor Intensity in the Colombian Economy, by Sector, 2015 (%)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Unskilled</th>
<th>Semi-skilled</th>
<th>Skilled</th>
<th>Capital</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>7.1</td>
<td>41.0</td>
<td>37.1</td>
<td>14.7</td>
<td>100</td>
</tr>
<tr>
<td>Mining</td>
<td>0.0</td>
<td>1.3</td>
<td>12.6</td>
<td>86.0</td>
<td>100</td>
</tr>
<tr>
<td>Primary sector</td>
<td>4.4</td>
<td>22.6</td>
<td>42.3</td>
<td>30.8</td>
<td>100</td>
</tr>
<tr>
<td>Other industries</td>
<td>0.4</td>
<td>6.4</td>
<td>51.1</td>
<td>42.2</td>
<td>100</td>
</tr>
<tr>
<td>Industry</td>
<td>0.2</td>
<td>6.0</td>
<td>66.5</td>
<td>27.3</td>
<td>100</td>
</tr>
<tr>
<td>Refinery and metals</td>
<td>0.1</td>
<td>1.6</td>
<td>21.5</td>
<td>76.7</td>
<td>100</td>
</tr>
<tr>
<td>Services</td>
<td>0.7</td>
<td>9.2</td>
<td>50.4</td>
<td>39.8</td>
<td>100</td>
</tr>
<tr>
<td>Financial services</td>
<td>0.1</td>
<td>1.3</td>
<td>57.9</td>
<td>40.6</td>
<td>100</td>
</tr>
<tr>
<td>Other services</td>
<td>0.4</td>
<td>5.1</td>
<td>40.1</td>
<td>54.4</td>
<td>100</td>
</tr>
<tr>
<td>Education services</td>
<td>0.0</td>
<td>1.1</td>
<td>89.9</td>
<td>9.0</td>
<td>100</td>
</tr>
<tr>
<td>Public administration</td>
<td>0.0</td>
<td>1.2</td>
<td>86.7</td>
<td>12.1</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Authors’ calculations based on the Colombian Social Accounting Matrix.
In addition, we specified income distribution among household types, depending upon whether respondents lived in rural, urban, or metropolitan areas, and then calculated remuneration for unskilled, semi-skilled, and skilled work (see Table 3). Table 3 shows that the main source of income for urban and metropolitan households was skilled labor while earnings in rural households came from capital. In addition, the earlier, direct transfers from other institutional sectors were distributed to households according to their share of the total transfers; those transfers were calculated based on the Colombian National Household Survey. According to the latest survey, metropolitan households received a greater proportion of direct transfers from government while rural households received more from firms.

### Table 3: Household Participation in Factor Remuneration, 2015(% of total)

<table>
<thead>
<tr>
<th>Households</th>
<th>Unskilled</th>
<th>Semi-Skilled</th>
<th>Skilled</th>
<th>Capital</th>
<th>Firm</th>
<th>GVT</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>2.5</td>
<td>12.9</td>
<td>11.6</td>
<td>36.47</td>
<td>36</td>
<td>0.7</td>
<td>100</td>
</tr>
<tr>
<td>Urban</td>
<td>0.9</td>
<td>7.7</td>
<td>68.8</td>
<td>9.4</td>
<td>9.3</td>
<td>3.9</td>
<td>100</td>
</tr>
<tr>
<td>Metropolitan</td>
<td>0.6</td>
<td>8.6</td>
<td>71</td>
<td>7.7</td>
<td>7.7</td>
<td>4.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Authors’ calculations based on the Colombian Social Accounting Matrix.

III. Methodology

To achieve the objectives listed above, we used a recursive dynamic computable general equilibrium model. We started with the single-country, static version of the Partnership for Economic Policy (PEP) model, fully documented in Decaluwé et al. (2013). We extended the single-period PEP-1-1 model to multiple periods by linking successive periods through a set of variables inherited from the previous period and transmitted to the following period by a set of “dynamic equations.” The model belongs to the neoclassical tradition in a perfect-competition setting, and (intra-period) agents’ behavior was drawn from optimization problems.

Because this model is thoroughly documented, we have not described it here. We
did, however, introduce changes into the model in order to achieve our objectives,\(^8\) the main example of which concerned household behavior. In the standard setting, a household’s endowment of production factors is exogenous to the household, and (aside from transfers) household income is determined once salaries and capital rents are established in equilibrium. Conversely, we followed Jung and Thorbecke (2003) in making human-capital accumulation endogenous to the household decision-making process. In this context, households decided, in every period, their level of demand for education services and, as a result, how much they would increase future levels of human capital in the form of skilled workers.

We hypothesized, therefore, that a trade-off existed between decisions regarding schooling and current household income. In the face of potentially higher relative wages for unskilled workers, households may have chosen to stop the school cycle of some of their members in return for higher current income to the detriment of future human capital (skilled labor).

We assumed that production depended upon how the labor force was divided among skilled, semi-skilled, and unskilled workers. The level and extent of human-capital formation was computed as the product of the interaction among household schooling decisions (given the income-maximization problem), initial endowments of human capital, and government and household spending on education.

In this framework, because households could endogenously modify the composition of the labor force (among skilled, semi-skilled, and unskilled components), they simultaneously determined their current income level: the consequence of wages for each category of labor and the cost of education. Assuming, therefore, as Jung and Thorbecke (2003) did, that transversality conditions held, households maximized utility each period given the maximization of their lifetime incomes. Shocks in international commodity prices affected current income by changing relative wages, and households adjusted whether and how much their younger (school-aged) household members would participate in education services. Consequently, household-level decision-making could affect human-capital accumulation for the economy at large and, potentially, the prospects for economic growth (especially in cases

\(^8\) See Appendix 1 for the details about the modification of PEP-1-1 v2.1 model.
in which commodity production and trade played a significant role in the economy).

The household-optimization problem can be described as follows: In the first stage, agents maximized their lifetime income, choosing between increasing their level of education or keeping the same levels of education and skill. Higher educational levels promised higher future wages while an unchanged educational level meant the same expected wage. In this sense, household members who worked provided a new short-run income source for the household. The second stage was the standard household utility maximization problem subject to the intertemporal budget restriction.

At the aggregate level, the total labor force of household \( h \) in period \( t \) \( (L_{h,t}) \) was the sum of each category of labor, which was the consequence of households’ income-maximization problem

\[
L_{h,t} = L_{u,h,t} + L_{bs,h,t} + L_{s,h,t}
\]

where \( L_{u,h,t} \) was the unskilled labor, \( L_{bs,h,t} \) was the semi-skilled labor, and \( L_{s,h,t} \) was the skilled labor of household \( h \).

Following Jung and Thorbecke (2003), we established the expected wage for an increased education level—relative to the current wage for the educational level that had been achieved to that point—as the decision variable in the household’s income-maximization problem. Under these assumptions, households had two possible income paths depending upon their work/study choices. If the members of the household decided to increase their education level, their expected income would be:

\[
Y_{t}^{edu} = f_t^h \sum_{t=1}^{T} W_{t-1}^{edu} (1 + g)(1 - T) \left( \frac{1 + g}{1 + r} \right)^s
\]

Alternatively, if they did not decide to study:

\[
Y_{t}^w = W_{t-1}^w (1 + g)(1 - T) + \sum_{t=1}^{T} W_{t-1}^w (1 + g)(1 - T) \left( \frac{1 + g}{1 + r} \right)^s
\]

where \( Y \) was the expected income path, \( f_t^h \) was a variable that summarized the availability of education in terms of government expenditures, \( W_{t-1}^{edu} \) was the expected salary for the next
level of education, $W^w_{t-1}$ was the salary for the current level of education, and $g$ and $r$ were economic growth and interest rates, respectively.

The agent’s decision depended upon the relative income of each of the two income paths. In this way, an agent chose study if the expected income after schooling was greater than the income that could be expected if no change was made in her or his work, $Y^\text{edu}_t > Y^w_t$. This meant that educational choice depended upon relative wages and the availability of access to educational services:

$$f^h_t \geq \left( \frac{W^w_{t-1}}{W^\text{edu}_{t-1}} \right) \left( \frac{(r - g) + \left[ 1 - \left( (1 + g) / (1 + r) \right)^T \right]}{(1 + g) \left[ 1 - \left( (1 + g) / (1 + r) \right)^T \right]} \right)$$

Income maximization determined the household’s budget constraint and, once that was determined, the household chose its consumption levels of goods through the utility-maximization problem.

The dynamics of labor endowment in the model were governed by the population growth rate. The population grew at rate $n$, which we assumed to be constant, so $L_{t+1} = L_t(1 + n)$. The population from the previous period became either skilled, semi-skilled, or unskilled laborers and added to households’ labor stocks, depending upon the household’s response to the income-maximization problem. Therefore, the dynamics of population growth were interlinked among labor categories and were determined as follows: The new population was allocated between people with a basic education and those who were uneducated. Some of those with a basic education proceeded to the labor market, and the rest went on to enter the higher-education group. Finally, people from a higher-education level entered the labor market as skilled workers.\footnote{For more details, see Appendix 1 and Jung and Thorbecke (2003)}

**IV. Application and Results**

Based on the model presented above, we simulated the impact on both labor composition and demand for education of an increase in the international export price in the mining
sector. We simulated a shock of 25% in exports of mining commodities. The shock went in the same direction as the real shock that affected the Colombian economy between 2009 and 2014. In that case, export prices in mining products increased extraordinarily and later returned to historical levels. This exceptional shock in commodity prices transformed both labor composition and levels of human-capital accumulation in different regions of the country. We wanted to identify some of these effects in our simulation.

The simulated scenario was compared to the base scenario. The base scenario was established by initial conditions in the Colombian economy in 2015. We additionally assumed that the economy was on a stable growth path, defined as the potential economic growth rate calculated by finance authorities in Colombia (average 4.9%). We also assumed that capital was sector-specific and that government savings were fixed; the numeraire was the exchange rate.

The 25% shock in the export prices of mining products was simulated to begin in 2019 and to persist for the successive six years. The shock would affect relative wages in various categories of labor and, consequently, household decisions regarding education, determining in this way levels of human capital and of economic growth. The final effect would depend upon demands for labor of various kinds in distinct economic sectors and upon government decisions regarding transfers to households for education.

4.1. Main Macroeconomic Results

Table 4 shows the percent change over baseline in the main macroeconomic indicators. Note that real GDP at market prices was higher in all years affected by the shock and increased slightly during the simulation period: from 2.59% in 2019 to 2.86% in 2025. The higher GDP reflected higher consumption, which increased consistently from 2.9% in 2019 to 3.17% in 2025.

Investment, too, increased over baseline but to a lesser degree than did consumption because we use a closure in which investment was driven by savings, and the savings rate was kept constant. Although there were small increases in investment, on average it grew 0.63% above baseline. Government consumption was kept constant in the model.
As expected, exports increased appreciably. They were situated 11.8% above baseline in 2019 (the first year of the shock) and gradually increased value until they reached a level 14% above baseline in 2025. Because the current account was kept fixed in the model (i.e., at baseline values), imports had to increase to compensate in part for the increase in exports. As a result, dynamic changes took place in that parameter as well, leading from a level 7.6% above the baseline in 2019 to one that was 9.1% above in 2025. The main equilibrating variable that determined this behavior was the real exchange rate, which appreciated during the simulated period from a level 7.5% points below the 2019 baseline to 8.7% below in 2025.

### Table 4: Main Macroeconomic Results (% change)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil prices</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
<td>25.00</td>
</tr>
<tr>
<td>GDP at market prices</td>
<td>2.59</td>
<td>2.65</td>
<td>2.67</td>
<td>2.68</td>
<td>2.74</td>
<td>2.82</td>
<td>2.86</td>
</tr>
<tr>
<td>Consumption</td>
<td>2.90</td>
<td>2.95</td>
<td>3.01</td>
<td>3.06</td>
<td>3.11</td>
<td>3.14</td>
<td>3.17</td>
</tr>
<tr>
<td>Investment</td>
<td>0.64</td>
<td>0.64</td>
<td>0.63</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>Government expenses</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Exports</td>
<td>11.78</td>
<td>12.19</td>
<td>12.57</td>
<td>12.95</td>
<td>13.33</td>
<td>13.70</td>
<td>14.05</td>
</tr>
<tr>
<td>Imports</td>
<td>7.63</td>
<td>7.90</td>
<td>8.16</td>
<td>8.41</td>
<td>8.66</td>
<td>8.91</td>
<td>9.14</td>
</tr>
<tr>
<td>Real exchange rate</td>
<td>-7.50</td>
<td>-7.71</td>
<td>-7.91</td>
<td>-8.10</td>
<td>-8.31</td>
<td>-8.53</td>
<td>-8.73</td>
</tr>
</tbody>
</table>

Note: CGE model simulation.

The trade balance was negative for the economy in the baseline and amounted to 5.2% of GDP. Given the behavior observed above, it closed moderately, reaching levels that went from 4.5% in 2020 to 4.4% in 2025, keeping its negative character. In a manner somewhat reminiscent of Dutch Disease, exports from any other sector in the economy, excluding the booming sector, decreased. As a simple average across sectors, the drop in exports amounted to 14.7% as compared to baseline 2019 values and continue decreasing until 2025 when they were 17.6% below the baseline. On the other hand, given the evolution of the real exchange rate, imports increased across the whole economy. The largest increases took place in the mining sector (35% above the baseline on average across years), followed by other services (21% on average), services (19% on average), and primary industries (15% on average), while, for the remaining sectors, the increase ranged from 6.3% (refinery products) to 14.2% (other industry).

Decreases in exports and increases in imports tended to dampen output for most
sectors of the economy. As the mining sector increased in response to the shock (output was 4.1% above baseline in 2019 and increased continuously until 2025 when it was 8.7% above baseline), input-output effects arising from this growth led to mixed results in terms of output by sector (shown in Table 5).

### Table 5: Percent Change in Activity Output with Respect to the Baseline Scenario

<table>
<thead>
<tr>
<th>Activity</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>-4.48</td>
<td>-4.65</td>
<td>-5.17</td>
<td>-5.69</td>
<td>-5.66</td>
<td>-5.18</td>
<td>-5.22</td>
</tr>
<tr>
<td>Mining</td>
<td>4.21</td>
<td>5.01</td>
<td>5.82</td>
<td>6.61</td>
<td>7.33</td>
<td>7.99</td>
<td>8.67</td>
</tr>
<tr>
<td>Primaries</td>
<td>0.26</td>
<td>0.25</td>
<td>0.10</td>
<td>-0.05</td>
<td>0.02</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td>Other industry</td>
<td>-5.04</td>
<td>-5.24</td>
<td>-5.55</td>
<td>-5.87</td>
<td>-6.00</td>
<td>-6.01</td>
<td>-6.16</td>
</tr>
<tr>
<td>Industry</td>
<td>-4.90</td>
<td>-5.10</td>
<td>-5.23</td>
<td>-5.35</td>
<td>-5.58</td>
<td>-5.92</td>
<td>-6.13</td>
</tr>
<tr>
<td>Refinery</td>
<td>-4.02</td>
<td>-4.45</td>
<td>-4.83</td>
<td>-5.21</td>
<td>-5.62</td>
<td>-6.07</td>
<td>-6.46</td>
</tr>
<tr>
<td>Services</td>
<td>0.67</td>
<td>0.69</td>
<td>0.69</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Finance</td>
<td>-1.61</td>
<td>-1.69</td>
<td>-1.71</td>
<td>-1.73</td>
<td>-1.83</td>
<td>-2.02</td>
<td>-2.12</td>
</tr>
<tr>
<td>Other services</td>
<td>0.77</td>
<td>0.78</td>
<td>0.80</td>
<td>0.82</td>
<td>0.82</td>
<td>0.78</td>
<td>0.76</td>
</tr>
<tr>
<td>Education</td>
<td>1.00</td>
<td>1.01</td>
<td>1.09</td>
<td>1.15</td>
<td>1.15</td>
<td>1.09</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Note: CGE model simulation.

As the table shows, the Primaries, Services, and Other Services sectors showed positive output changes over baseline. In the base year, these activities accounted for 60% of the demand for unskilled labor, 66% of the demand for semi-skilled labor, and 50% of the demand for skilled labor year. Meanwhile, the largest labor demand within these sectors was for skilled labor (61% for primaries, 84% for services, and 88% for other services), followed by the demand for semi-skilled labor (33%, 15%, and 11%, respectively) and for unskilled labor (6.3%, 1.1%, and 0.9%, respectively). The above changes in output are reflected in adjustments in the composition of the labor-force. Table 6 shows percent changes in total labor demand by labor type, illustrating that the demand for unskilled labor decreased over baseline from 2021 through 2023, then increased in 2024 and 2025. Meanwhile, the demand for semi-skilled and skilled labor grew over the whole period.

### Table 6: Percent change in Labor Demand by Type over Baseline

<table>
<thead>
<tr>
<th>Labor type</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unskilled</td>
<td>-4.56</td>
<td>-9.01</td>
<td>-4.67</td>
<td>8.08</td>
<td>10.55</td>
</tr>
<tr>
<td>Semi-skilled</td>
<td>-0.29</td>
<td>-0.58</td>
<td>-0.85</td>
<td>-1.12</td>
<td>-1.19</td>
</tr>
<tr>
<td>Skilled</td>
<td>0.11</td>
<td>0.22</td>
<td>0.20</td>
<td>0.03</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note: CGE model simulation.

The labor-demand figures depend heavily upon two factors: first, as discussed above, the dynamics of output by sector (and corresponding demand for factors), and, second,
households’ response in the form of their supply of labor by type (within the framework of optimizing behavior discussed in Section 3 and in the subsection below). Even though the shock began in 2019, there were no changes over baseline in total labor demand by type in that year because households’ endogenous labor-supply decisions were backward-looking. In other words, households adjusted their demand for education and labor supply according to the wage dynamics of the previous period, and there were no changes in relative wages during 2018. Therefore, a shuffling in labor demand by type among sectors took place during 2019 even as total labor supply by type remained constant.

There were also no changes in total labor demand by type in 2020 because there were no changes in labor supply by type in 2019. The reason for this is that education decisions by households in a period (in this case 2020, as households reacted to changes in relative wages in 2019) only affected labor supply in the period that followed (2021 in this case). There was, as a result, a two-period delay from the point at which relative wages changed to the point at which changes occurred in the labor supply. Specifically, the effect of the price shock that began in 2019 only translated into changes in labor supply (and demand, as firms reacted to relative labor supply) in 2021 (the first year included in Table 6).

Lastly, although consumption increased along the period, the behavior of household types was not homogeneous. Rural households increased their consumption the most: from 4.1% over baseline in 2019 to 4.5% in 2025. Households in metropolitan areas showed the second largest increases, beginning at 2.5% in 2019 and ending at 2.7%, while households in intermediate-size cities showed the smallest increases (2.4% to 2.6%). Household consumption increased in tandem with changes in income, which rose slightly in all households during the simulated period. Between 2019-2025, on average, the total real income of rural households grew 3.7% over baseline, metropolitan household income increased 2.2%, and household income in intermediate-sized cities increased 2.1%.

Household labor income increased over baseline in all cases, but these increases were lowest for rural households and higher for households in metropolitan areas and intermediate-sized cities. Figure 3 shows changes in household real labor income. While total income increased regularly for all households, the fluctuations in labor income shown in

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10 We assumed the economy was growing in a steady-state fashion.
Figure 3 arose as a consequence of changes in the composition of labor supply (and in relative wages that predated those changes).

![Figure 3: Percent Change in Labor Income over Baseline](image)

Note: CGE model simulation. HHDR: Rural Households; HHDM: Metropolitan Households; HHDC: Households in Intermediate-Sized Cities.

4.2. Results for Education and Labor Composition

As mentioned above, the price shock generated a shuffling in labor demand for all labor types following the adjustment in activity levels as the economy reacted to the shock. During 2019 and 2020, these changes only affected the allocation of labor types across sectors with no effect on total demand for them because labor supply by type was, to this point, unchanged. Starting in 2021, changes in activity levels not only affected labor allocation across sectors but also total labor demand for each labor type, given that the labor supply adjusted as households decided how much of each labor type they could supply.

Labor supply is determined by relative wages in a “sequential” manner. If households perceive that relative wages favor semi-skilled over unskilled labor, they will educate new household members (the population increase from the previous period) to be semi-skilled workers. Alternately, if they perceive that relative wages favor skilled over semi-skilled labor, they will decide to further the education of new household members beyond the educational level required to be semi-skilled (making them skilled workers). It is, therefore, the behavior of relative wages that drives education/labor supply decisions.
Figure 4 shows the dynamics of relative wages.\footnote{A “pipeline” effect may also exist. Absent an increase in the wage premium between skilled and semi-skilled workers, an increase in the supply of semi-skilled workers will also increase the supply of skilled workers.}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Evolution of Relative Wages}
\end{figure}

Note: CGE model simulation. WUNS: unskilled wages; WSSK: semi-skilled wages; WSKI: skilled wages.

From the data presented in Table 4, it can be seen that the price shock induced a deterioration of unskilled wages as compared to semi-skilled wages (blue line in the graph, read on the left-hand axis) and a similar situation for semi-skilled wages vs. skilled wages (dashed orange line, read on the right-hand axis). Households reacted before these changes by demanding more education to increase their supply of semi-skilled and skilled workers in the following period. As relative wages changed for the first time in 2019, households adjusted their education/labor supply decisions in 2020 and the effect on the labor market was felt in the following year. The relative contraction in labor supply of unskilled workers (relative to semi-skilled ones) and of semi-skilled workers (relative to skilled ones) led to new changes in relative wages in response to relative labor abundance (wages were endogenous in the model). This changed the behavior of relative wages in favor of scarcer labor types (unskilled and semi-skilled workers) in 2021, with the particularity that, while unskilled wages become more attractive than semi-skilled wages, semi-skilled wages improved but did not become more attractive than skilled wages (something that did happen in the subsequent period).
Therefore, the incremental supply of labor by households—that is, the way households, through their education decisions, allocated new members to labor types and, in turn, supplied that labor to the market—was the result of the processes described above. The resulting cyclical dynamic led to decreases and increases in the incremental supply of unskilled labor (as compared to baseline), largely decreased the incremental supply of semi-skilled labor, and was responsible for a nuanced oscillation (due to its relative size) of the incremental supply of skilled labor as shown in Figures 5 and 6.

**Figure 5: Behavior of the Incremental Supply of Unskilled Labor (%)**

Note: CGE model simulation.

**Figure 6: Behavior of incremental supply of semi-skilled (left) and skilled labor (right), (%)**

Note: CGE model simulation.

Overall, the behavior depicted above led to an oscillating supply of unskilled labor over baseline, to an increasingly lower supply of semi-skilled labor, and to a slightly higher but decreasing supply of skilled labor. The corresponding percent changes over baseline are presented in Table 6. Market clearing implies equality between labor demand and
supply for each labor type. Demand for education increased over baseline as a result of this process. It did so because income and consumption increased and because of the dynamics of labor supply (following relative wages). Because the supply of skilled workers increased during the period and was the largest labor category (86.2% of total labor in the base year), the demand for education roughly followed. Figure 7 shows the percent changes in households’ demand for education in the left-hand panel and percent changes in skilled labor supply on the right hand (both over baseline).

**Figure 7: Percent Change in Households Demand for Education (left) and in Skilled Labor Supply (right) over Baseline**

![Graph showing percent change in households demand for education and skilled labor supply over baseline.]

Note: CGE model simulation

Household demand for education increased in 2019 as a result of the increase in income alone. From 2020 on, the demand grows in response to additional income increases and to greater adjustments in labor supply by type. On the other hand, the supply of skilled labor increased from 2021 on, as mentioned, loosely mirroring the behavior of demand for education (with a delay of a year). Differences between the two patterns arose, on the one hand, from the behavior of the other labor types and, on the other, from demand for education by agents other than households (mainly intermediate consumption). In all, total demand for education increased over baseline, following a pattern similar to that of demand by households as shown in the graph.

From a distributional standpoint, household shares of each labor type and the evolution of wages determined the way labor income behaved. As shown in Figure 3, rural households registered the lowest percentage increase in labor income and, as Figure 8 makes clear, this behavior followed that of unskilled wages. Furthermore, the evolution of semi-skilled and skilled wages was quite similar, which in turn made the evolution of
household labor income in metropolitan areas and intermediate-sized cities also similar. In fact, rural households were the most dependent on unskilled wages (9.2% of their total labor income), while the figures for households in metropolitan areas and intermediate-sized cities were 1.1% and 0.8%, respectively. On the other hand, the labor income of households in metropolitan areas and intermediate-sized cities depended heavily upon skilled wages: 88.9% for the former and 88.5% for the latter. For rural households, conversely, the figure was 42.9%. Lastly, rural households depended the most on semi-skilled wages, which represented 47.9% of their labor income. In contrast, wages from semi-skilled labor only represented 9.9% and 10.8% for households in metropolitan areas and intermediate-sized cities, respectively.

**Figure 8: Evolution of Wages by Labor Type (%)**

Note: CGE model simulation. WUNS: unskilled wages; WSSK: semi-skilled wages; WSKI: skilled wages

### 4.3. Sensitivity Analysis

We tested the robustness of the model under conditions in which the main parameter values changed, and we discuss those results here. We introduced changes into the more sensitive parameters in relation to the problem addressed in the model: income elasticity for education in the households ($\sigma_B$) and labor-substitution elasticity ($\sigma_{LD}$). Table 7 presents the values assigned to the elasticities under different simulations.
The initial simulation (sim0) is the main simulation discussed above. Simulation 1 (sim1) included an extreme value in the substitution elasticity among different kinds of labor. Finally, Simulation 2 (sim2) modeled an extreme value in the income elasticity for education.

The results are presented through households’ supply of each type of labor. The variation in labor supply of each category of labor was the consequence of households’ decisions regarding education. The variation in the parameters values thus affects households’ education choices as well as the mode in which they allocated the new population to each labor type.

Figures 9 and 10 present the results regarding labor supply in each category under the four different scenarios simulated. What is clear is that the cyclical dynamic in unskilled-labor supply decreased the supply of semi-skilled labor, and the small oscillation in the skilled-labor supply persisted under the different scenarios.

![Figure 9: Behavior of the Incremental Supply of Unskilled Labor](image)

Note: CGE simulations (change in thousands)

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12 Acevedo, Zuluaga, and Jaramillo (2008) found an income elasticity for education in Colombia of between 0.41 and 1.1, which provided empirical support for the values selected in our model simulations.
Figure 10: Behavior of Incremental Supply of Semi-Skilled (left) and Skilled Labor (right)

Note: CGE simulations (change in thousands)

The results from the variations in elasticity values under the different scenarios indicate that the effects moved in the same direction under all three simulations. Income elasticity for education was the main determinant in fluctuations of the labor supply. Additionally, the greater the substitution among different labor categories, the smoother was the variation in labor supply.

In terms of economic growth, the shock increased growth rates in all scenarios. The lower average in the economic growth rate is presented under the lower values for substitution elasticity among types of labor. Despite this, the difference among the average economic growth rates was not ample. In terms of simulations, the lower average in the economic growth rate is presented under Simulation 1; the average economic growth rate was 0.2% lower than in the initial simulation.

As a result, for the sensitivity analysis, we can conclude that, even under extreme values of elasticities, the effects moved in the same direction and with a similar magnitude. The earlier result reflects the robustness of the model to variations in the parameter values and the validity of the analysis.

V. Conclusions and Policy Implications

The Colombian economy has been characterized by the continued importance of commodities production. Some decades ago, coffee production was the main economic activity and, more recently, oil and mining have become the country’s main production
sector. The boom in these markets came after international price shocks directly affected Colombian production. In particular, booms in these sectors modified the demand for labor and, at the same time, affected labor demand in other, related sectors, especially the services sector, in different areas of the country. This phenomenon had immediate implications for labor qualification, for human-capital accumulation, and for economic growth.

Our results show a direct relationship between the boom in the commodities sector and educational demand. The shock in international commodity prices increased the relative wage between unskilled and skilled labor for some periods, and that became an incentive for some agents to leave school and enter the labor force as unskilled workers or as workers with basic skills. Concurrently, the shock increased both direct and opportunity costs for households contemplating educating their members, presuming the government did not adjust transfers to households for education.

As a result of the shock, the demand for education from households was lower after some periods, and unskilled labor increased its share of the total labor force (ceteris paribus). This had direct repercussions for long-term human-capital formation and for the growth of the economy. Agents who left their studies to work did not return to school, which was detrimental to skilled-labor formation in Colombia. A greater number of dropouts from schooling meant lower human-capital formation and lower long-term economic growth.

On the other hand, the results from the model could be interpreted with reference to government policy. Larger transfers from government to households for education would mean that households would face lower costs, decreasing the number of school dropouts (ceteris paribus). This scenario implies that the government has the instruments to promote education and qualification in such a way as to ensure greater levels of skilled labor that contribute in the long term to economic growth.

Though results from our model consider the whole economy, the policy recommendations can nonetheless focus governmental interventions in particular regions and sectors. The shock on international commodity prices has significant implications for the economy, but its effects are greater in production regions whose economy is more dependent on mining and oil commodities. In this light, the government might concentrate its actions on those areas in which the shock effects are greater. Instruments such as
conditional transfers for education can counteract the effect of the shock on dropouts from schooling and, simultaneously, on human-capital formation.
References


Appendix 1A

Extensions to PEP-1-1 v2.1

In this Appendix we present the modifications introduced to the single-country static PEP model PEP-1-1 v2.1. We assume familiarity with the original documentation for the PEP-1-1 v2.1 model and use the same abbreviation and variables.

Dynamics: Investment and Capital Accumulation

As its name indicates, PEP-1-1 is a static model. In this paper, we made PEP-1-1 dynamic by following the approach first proposed by Dervis, De Melo, and Robinson (1982) for allocating new capital among sectors. (We could certainly have used PEP-1-t as our starting point, but all the other improvements we introduced to the PEP-1-1 GAMS code made such an alternative less cost-effective.)

In this set of equations, we present the model dynamics and, specifically, the mechanisms used to assign each period investment among sectors. We distinguished between private and public capital stocks, which is particularly relevant when simulating increases in government investment in public infrastructure.

For domestic non-government institutions, investment in each period increased the capital stock available in the next period. We then needed to determine how the new capital was distributed among industries. In our model for private investment (i.e., households and/or enterprises), we assumed that the new capital was distributed among activities based on differences in capital rates of return. Sectors with a relatively higher (lower) capital rate of return thus received a relatively larger (smaller) share of new capital. For the government, investment was determined (1) as a policy variable (i.e., exogenously) or (2) as a residual to balance the budget.

Equation INV1 computes the average capital rate of return as the ratio between total capital income and total capital stock. Equation INV2 computes the share of each activity in the new capital stock, following the explanation given above. The \( \kappa \) parameter, which varied between zero and one, measured the degree of capital mobility among productive sectors. When \( \kappa \) was zero, investment was distributed among sectors only based on the initial share
of each sector in total capital stock. When \( \kappa \) was positive, investment was distributed among sectors based also on relative capital returns. Finally, Equations INV3 and INV4 show how private and public capital stocks are updated, respectively, by sector.

\[
\text{INV1} \quad RAVG_{k,t} = \frac{\sum_{j \in J} R_{k,j,t} \cdot KD_{k,j,t}}{\sum_{j \in K} KD_{k,j,t}} \quad k \in K \quad t \in T
\]

\[
\text{INV2} \quad QINVDEST_{A,k,j,t} = GFCF^{REAL}_t \cdot \frac{KD_{k,j,t}}{\sum_{j \in J} KD_{k,j,t}} \left[ 1 + \kappa \left( \frac{R_{k,j,t}}{RAVG_{k,t}} - 1 \right) \right] \quad k \in KCAP \quad j \in J \quad t \in T
\]

\[
\text{INV3} \quad KD_{k,j,t} = KD_{k,j,t-1} (1 - \text{deprat}_k) + QINVDEST_{A,k,j,t-1} \quad k \in KCAP \quad j \in J \quad t \in T
\]

where

- \( RAVG_{k,t} \): average capital rent
- \( R_{k,j,t} \): Capital rent by sector
- \( KD_{k,j,t} \): Capital demand by sector
- \( QINVDEST_{A,k,j,t} \): investment by destination
- \( \kappa \): capital mobility parameter
- \( \text{deprat}_k \): capital depreciation rate

**Dynamics: Labor Growth Skill Composition of Labor Force**

Equation L1 defines the share of labor type \( l \) in a given pair of labor categories. In turn, given that labor shares must add up to one, Equation L2 defines the residual labor share in each pair of labor categories. Equation L3 defines the total supply of education level first labor category. Equation L4 defines the total supply of education level non-first labor category. Equation L5 defines new entrants to the labor market. Equation L6 defines the wage ratio (or skill premium). Equation L7 defines real spending in education. Finally, Equation L8 in this bloc defines the labor supply by labor category.

\[
\text{L1} \quad SHRSK_{l,t} = SHRSK_{l}^{DO} \cdot \left( \frac{WRAT_{l,t-1}}{WRAT_{l}^{DO}_{t-1}} \right)^{edu_{l,wrat}} \cdot \left( \frac{QEDU_{l,t-1}}{QEDU_{l}^{DO}_{t-1}} \right)^{edu_{l,edu}} \quad l \in LMIN \quad t \in T
\]

\[
\text{L2} \quad SHRSKRES_{l,t} = 1 - \sum_{l' \in \text{map}(l,l')} SHRSK_{l',t} \quad l \in L \quad t \in T
\]

\[
\text{L3} \quad MS_{l,t} = (\text{aqacgrw}_{l,t} + \text{deprat}_t) \cdot \text{lstot}_t \quad l \in L \quad t \in T
\]
where

\(SHRSK_{l,t}\): share of labor type \(l\) in pair

\(SHRSKRES_{l,t}\): share of labor type \(l\) in pair (residual)

\(MS_{l,t}\): total supply of labor with education level \(l\)

\(ML_{l,t}\): new incomers of level \(l\) to labor market

\(WRAT_{l,t}\): relative wage bt \(l\) and \(lp\) (lower)

\(QEDU_{t}\): real spending in education

\(eduelas_{t,ac}\): education-related elasticities.

\(qfacgrw_{labtot,t}\): growth rate factor stocks (total labor and natural resources)

\(deprat_{t}\): factor depreciation rates

\(lstot_{t}\): total labor supply (economically active population)

\(mapllp(l', l)\) is mapping between labor categories based on their skill level.

Exports

In the PEP 1-1 Standard Model, the world demand for exports of product \(i\) is (see Equation 62 in Decaluwé et al., 2013):

\[
EXD_i = EXD^O_i \left( \frac{e \cdot PWX_i}{PE_{i}^{FOB}} \right)^{\sigma_i^{XD}}
\]

In case \(\sigma_i^{XD} = \infty\), this equation simplifies to

\[PE_{i}^{FOB} = e \cdot PWX_i\]

which represents the “pure” form of the small-country hypothesis; producers can always sell as much as they want on the world market at the (exogenous) current price, \(PWX_i\). In our simulations, we assumed that \(\sigma_i^{XD} = \infty\). Hence, the domestic (FOB) price of exports was defined as
\[ PE_{l,t}^{FOB} = e_t \cdot PWX_{l,t} \]

**Current Account BoP**

Equation RW1 defines the current account balance in foreign currency. Equations RW2 and RW3 define the index for domestic producer prices and the real exchange rate, respectively. As we show, variables CAB\_FCU and REXR were used to select the macroeconomic closure rule for the model.

\[ \text{RW1} \quad CAB_{t}^{FCU} = \frac{CAB_t}{e_t} \quad t \in T \]
\[ \text{RW2} \quad DPI_t = \sum_{i \in I} dwts_i \cdot P_{Li,t} \quad t \in T \]
\[ \text{RW3} \quad REXR_t = \frac{e}{DPI_t} \quad t \in T \]

where

- \( CAB_t^{FCU} \): current account balance in foreign currency units
- \( DPI_t \): index for domestic producer prices (PL-based)
- \( REXR_t \): real exchange rate
- \( dwts_i \): domestic sales price weights

**Government**

In the PEP Standard Model, government consumption of commodity \( i \) is determined by the equation (see Equation 55 in Decaluwé et al., 2013):

\[ PC_i \cdot CG_i = \gamma_i^{GVT} \cdot G \]

with \( G \) (i.e., current government expenditures on goods and services) fixed and equal to its initial value (i.e., \( G_t = G^0 \)). As an alternative, we modified government behavior, assuming that real government spending could be exogenous (i.e., all the \( CG_i \) variables) while \( G \) was endogenous. Specifically, we dropped the previous equation from the model and added Equations G1 and G2. In addition, we added Equation G3 to define real government savings as the ratio between nominal government savings and the GDP deflator.

\[ \text{G1} \quad CG_{i,t} = cgbar_{i,t} \cdot CGADJ_t \quad i \in I \]
\[ G_t = \sum_{i \in I} P_{C_{i,t}} \cdot C_{G_{i,t}} \quad t \in T \]

\[ SG_t^{\text{REAL}} = \frac{SG_t}{P_{IXGDP_t}} \quad t \in T \]

where

\[ CGADJ_t : \text{adjustment factor for } CG \]

\[ cgbar_{i,t} : \text{base-year } CG(i) \]

\[ SG_t^{\text{REAL}} : \text{real government savings} \]

**Tax Rates**

By default, in PEP-1-1 the government can clear its government budget by adjusting savings (variable SG) or current government expenditures on goods and services (variable G). Thus, to allow for changes in household income or commodity tax rates to clear the government budget, we added Equations T1 and T2.

\[
T1 \quad TTDH1_{h,t} = ttdh1bar_{h,t} \cdot TTDHADJ_t \quad h \in H \quad t \in T
\]

\[
T2 \quad TTIC_{i,t} = tticbar_{i,t} \cdot TTICADJ_t \quad i \in I \quad t \in T
\]

where

\[ TTDHADJ_t : \text{adjustment factor for } TTDH1_{h,t} \]

\[ TTICADJ_t : \text{adjustment factor for } TTIC_{i,t} \]

\[ ttdh1bar_{h,t} : \text{exogenous (base-year) } TTDH1_{h,t} \]

\[ tticbar_{i,t} : \text{exogenous (base-year) } TTIC_{i,t} \]

**Household Savings**

By default, PEP-1-1 assumes that investment is savings-driven. In other words, the marginal propensities to save for non-government institutions are fixed while investment clears the savings-investment balance. In contrast, our model allows the opposite assumption. To that end, Equation SH defines households’ marginal propensity to save. Its structure is the same as that of Equations T1 and T2 for tax rates and Equation G1 for government consumption. In fact, whether MPSADJ is flexible depends upon the closure rule
for the savings-investment balance.

\[ SH_{sh1h,t} = sh1bar_{h,t} \cdot MPSADJ_t \quad h \in H \quad t \in T \]

where

\[ MPSADJ_t: \text{savings rate scaling factor} \]
\[ sh1bar_{h,t}: \text{exogenous (base-year) } sh1_{h,t} \]

**Calibration using Employment by Sector**

In PEP-1-1 it is assumed that all sectors pay the same wage. In the extended PEP-1-1, the analyst can complement the SAM with data on number of workers by sectors. To do so, the remuneration to labor type \( l \) paid by the activity \( j \) is computed as

\[ W_{t,wdist_{t,j}}(1 + ttiw_{i,j}) \]

where \( wdist_{t,j} \) is a “distortion” factor applied to \( W_{t,j} \) for labor type \( l \) in industry \( j \) that allows modeling cases in which the factor remuneration differs across activities. In other words, each activity pays an activity-specific wage that is the product of the economy-wide wage and an activity-specific wage (distortion) term. To calibrate \( wdist_{t,j} \), the model dataset must provide physical labor quantities. In implementing this extension, the following equations of the original model were modified.

\[ YHL_h = \sum_{l}^{WL} W_{i,wdist_{t,j}}LD_{i,j} \quad h \in H \quad t \in T \]

\[ TIW_{t,i} = ttiw_{i,j}W_{i,wdist_{t,j}}LD_{i,j} \quad l \in L; j \in J \quad t \in T \]

\[ YROW = e \quad PWM_i \quad IM_i \]
\[ + \sum_{k}^{RK} R_{k,j}KD_{k,j} \]
\[ + \sum_{k}^{TR} TR_{row,agd} \]

\[ WTI_{t,j} = W_{i,wdist_{t,j}}(1 + ttiw_{i,j}) \quad l \in L; j \in J \quad t \in T \]
\[ (92) \quad GDP_{IB} = \sum_{i,j} W_i \text{wdist}_{i,j} LD_{i,j} + \sum_{k,j} RK_{k,j} KD_{i,j} + TPRODN + TPRCTS \quad t \in T \]

**Wage Curve**

The PEP Standard Model assumes full employment of the labor force. As explained above, we introduced endogenous unemployment by means of a wage curve. Specifically, we added to the model Equation WC and the endogenous variable UERAT (unemployment rate). The value of the Phillips parameter (i.e., the wage curve elasticity) was set at 0.1 based on international evidence documented in Blanchflower and Oswald (2005). Of course, the equilibrium condition for labor market was adjusted accordingly (see Equation 85 in PEP 1-1).

\[ \text{(WC)} \quad \frac{W_{it}}{PIXCON_t} = \frac{WOO_t}{PIXCONOO} \left( \frac{UERAT_{it}}{UERATO_O} \right)^{\eta_{it}^{WF}} \]

\[ (85) \quad LS_i(1 \ UERAT_i) = LDD_{i,j} \]

where

- \( UERAT_{it} \): unemployment rate for type i labor
- \( \eta_{it}^{WF} \): elasticity of real wage with respect to unemployment rate
- \( WOO_t \): base-year (average) wage for type i labor
- \( PIXCONOO \): base-year consumer price index
- \( UERATO_O \): base-year unemployment rate for type i labor