Labor Market Implications of Taiwan's Accession to the WTO: A Dynamic Quantitative Analysis*

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Abstract

This paper studies the effects of Taiwan's accession to the WTO in 2002 on the labor market dynamics in Taiwan during 1995–2020. Our dynamic quantitative framework builds on that of Caliendo, Dvorkin and Parro (2019) but allows for differently skilled labor inputs (low, middle, high) and sector-skill dynamic choice by workers. We map the model to the labor-market transition data in Taiwan, the country-sector-specific skill shares in production, and the bilateral trade flows and import tariffs, of 61 economies and 22 sectors for the period 1995–2007. We study the counterfactual dynamics if the bilateral tariffs related to Taiwan's imports and exports are rolled back to their 1995 levels, and calculate the cumulative effects on the employment shares and welfare of workers by sector and skill level. We find that the tariff reductions during this period help explain the phenomenal expansion of certain star sectors in Taiwan and the growing share of high-skilled workers in Taiwan's labor composition. Bilateral tariff concessions between China and Taiwan account for the bulk of the effects of Taiwan's WTO accession, illustrating the importance of China to Taiwan in the latter's trade structure. The skill-upgrade mechanism is critical in explaining the large employment effects of its WTO accession.

Key Words: WTO; Dynamic Quantitative Analysis; Labor Market Dynamics; Welfare Effects; Mobility Frictions; Skill Upgrade

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1 Introduction

The trade literature has extensively studied the labor-market and welfare effects of the "China shock" on large economies such as the US (e.g., Caliendo, Dvorkin and Parro, 2019; Adão, Arkolakis and Esposito, 2021; Autor, Dorn and Hanson, 2013, 2021) and their heterogeneous responses across regions and sectors. In this paper, we focus on Taiwan to highlight the importance of contexts for the study of labor market adjustments to a large-scale external shock. In particular, this paper aims to examine the effects of Taiwan's accession to the WTO in January 2002 on Taiwan's labor market outcomes. Because China also entered the WTO around the same time, the two economies became much more open to each other through the WTO platform, and thus the China shock also contributed to the overall effects of Taiwan's accession to the WTO.

Taiwan is an interesting case for several reasons. First, it is a small open economy that is geographically close to China. Therefore, it may have experienced much greater impacts of the China shock than distant/large economies. Second, during the period studied, Taiwan was more developed than China but less than the US. Along the lines of structural change and product cycles, China's rise may have posed greater and more immediate challenges to the manufacturing industries in Taiwan. How did the Taiwanese economy respond to it? Third, Taiwan saw swift changes in its skill compositions during the period of WTO accession, becoming a highly skill-abundant economy relative to China and much of the rest of the world. Related to the second point, how did these changes in skill composition play a part in Taiwan's response to the rise of China? At this writing, the tension between China and Taiwan and that between China and the US are both at historical high points. Understanding how the Taiwanese economy has become so intertwined with China's and how the China shock for Taiwan differs from that for the US may be not only an interesting study for economists, but also an informative background study for academics in the other disciplines and the general public.

The journey of Taiwan's accession to the GATT/WTO started when it formally applied for GATT membership in 1990. It became an observer in 1992 and finally entered the WTO in January 2002, shortly after China joined in December 2001. We first document a set of stylized facts on Taiwan's tariffs, trade patterns and labor markets. First, the tariff reductions associated with this event took place during a long period (from the mid-1990s to the late 2000s). During 1995–2007, Taiwanese import tariffs fell relatively more in the agricultural sector, while foreign tariffs against Taiwanese exports dropped relatively more in the manufacturing sectors. Second, two manufacturing sectors, "Machinery, Computer, Electronics & Electrical Machinery" (hereafter MCEE) and "Petroleum, Chemicals, Plastics, Metals" (hereafter PCPM), stood out as the engines of growth of Taiwanese exports during this period, especially for the exports in intermediate goods (and with respect to China). In contrast, the growth in trade volume in other manufacturing sectors was either modest or negative. Meanwhile, agricultural imports rose substantially after 2001. Third, we observe a salient trend of workers transitioning out of agriculture and labor-intensive manufacturing sectors and into the MCEE and service sectors. This trend is in line with the above-described changes in tariffs and the patterns of trade. Last but not least, the proportion of high-skilled workers in the economy increased substantially (from 17.4% in 1995 to 34.7% in 2007), and the increase was most significant in the Business Services and MCEE sectors.

The above stylized facts suggest that skill likely has played an important role in Taiwan's response to rising competition globally and with China. The rise of Taiwan's MCEE exports implies that Taiwan had comparative advantages in these sectors, in which production was relatively more skill-intensive as documented in the text. Moreover, the expansion of exports in these sectors was much larger in intermediates than in final goods, where the former also tended to be relatively more skill-intensive than the latter (e.g., computer chips and optical lenses versus computer and mobile-phone assemblies). This suggests a demand-side pull factor for skilled labor, as the economy repositioned itself across sectors and production stages in the process of its WTO accession. The substantial increase of the high-skilled labor share of the economy during the period as described above further underscores the importance of potential endogenous supply-side responses to the trade shock. Nonetheless, underlying the documented stylized facts, there could be other forces at work. Hence, a quantitative analysis is vital to understand the effects of trade, the role of China, and the relevance of compositional shifts in worker skills.

We extend the quantitative framework of Caliendo, Dvorkin and Parro (2019, henceforth CDP) to allow for skill-upgrade mechanisms. In particular, whereas CDP focused on the state-sector-specific labor market outcomes of the US due to the China shock, we focus on the sector-skill-specific labor market outcomes of Taiwan due to its own accession to the GATT/WTO. In our model, the production in each sector uses three types of skills (low, middle, and high), whose intensity is allowed to differ across economies and sectors. Individuals make dynamic sector-skill choices in each period in response to sector-skill-specific wages, goods prices, sector-skill switching costs and idiosyncratic preference shocks.

The model is calibrated to 60 economies and a residual Rest-of-World, 22 sectors (agriculture, 11 manufacturing sectors, and 10 service sectors) plus non-employment, and three skills. We compile data on Taiwanese labor market dynamics during 1995–2007, together with data on tariffs, trade flows, input-output linkages, and skill compositions for these economies and sectors. In particular, we obtain information on Taiwanese workers' transition across sectors and skills in each year during the period 1995–2007 based on *Manpower Utilization Quasi-longitudinal Data* of Taiwan. Following the approach of Artuç and McLaren (2015), we estimate the sector-skill transition elasticity that is required for the counterfactual analysis, along with the transition costs of skill-upgrading and sector-switching that characterize the Taiwanese labor markets.

Using the calibrated model, we first simulate a baseline economy (in terms of changes over time) that reflects factual unobserved time-varying fundamentals for the data period 1995–2007, and with constant fundamentals afterwards (up to a specified simulation terminal period). To study the effect of Taiwan's WTO accession, we then simulate a counterfactual economy in which all the Taiwan-related tariffs (Taiwanese tariffs on imports and foreign tariffs on Taiwanese exports) are rolled back to their levels in 1995. The comparison of such a counterfactual economy with the baseline economy (which incorporates factual changes in fundamentals, including tariffs) reveals the effect of Taiwan's WTO accession on the Taiwanese economy and labor markets, as well as on the other economies. We simulate the transition dynamics for a sufficiently long time period (for the effects of the trade shocks to reach steady states) and report the effects on labor markets and welfare for the period 1995–2020.

The counterfactual analysis delivers a rich set of results. We find that Taiwan's accession to the WTO induced a decline in the agricultural sector's employment, accounting for 4.0% of the agricultural labor force in 1995. Meanwhile, the manufacturing and service sectors combined saw an increase in their employment shares (by 5.7% of the total population), whereas the share of non-employment declined (by 5.3% of the population). These changes are one order of magnitude larger than those reported in CDP (around $\pm 0.3\%$), which can be attributed to the export-oriented, small-and-open nature of the Taiwanese economy. Among manufacturing sectors, the growth of the employment shares is particularly pronounced in the MCEE sector. These are consistent with the stylized facts. Note that the stylized facts can be explained by multiple forces, but here we find that Taiwan's accession to the WTO indeed contributed to the observed patterns.

When the above changes at the sectoral level are further broken down into skill groups, we find that most of the labor outflow from the agricultural sector was by low-skilled workers. The manufacturing sectors saw increases of employment of all skill types, and there was a skill-upgrade trend in manufacturing overall. The skill upgrade was most pronounced in the MCEE sector, as it absorbed disproportionately more high-skilled workers. There was also a skill-upgrade trend in the service sectors. Overall, the sectors with larger employment gains also underwent larger degrees of skill upgrading. These model-simulated effects of Taiwan's WTO accession are in line with the stylized facts on the changes in skill compositions.

In the aggregate, Taiwanese workers experienced a 2.4% welfare gain during 1995–2020 from the WTO entry. This welfare effect is large in comparison with the recent findings based on similar analytical frameworks for different economies (Caliendo, Dvorkin and Parro, 2019; Caliendo, Parro, Opromolla and Sforza, 2021). This might again be due to the small and open export-oriented nature of the Taiwanese economy. Most importantly, the welfare effects are heterogeneous across sectors and skills. The welfare gains for low-, middle-, and high-skilled workers are 2.14%, 2.59%, and 2.69%, respectively. This reiterates that Taiwan was relatively skill-abundant with respect to the majority of the other economies, and the high-skilled Taiwanese workers benefitted the most from trade liberalization via the Stolper-Samuelson mechanism. In terms of sectors, Taiwan's WTO entry led to the largest welfare gains for workers in manufacturing sectors (3.07%), followed by service sectors (2.22%) and agriculture (1.76%).

As suggested by the opening remarks, the China shock could be important in explaining the observed trade patterns and labor market outcomes in Taiwan during the period studied. To investigate this, we conduct three additional counterfactuals to examine: (i) the effects of China's accession to the WTO; (ii) the effects of both Taiwan's and China's accession to the WTO; and (iii) the effects of bilateral tariff concessions between Taiwan and China only. For example, to evaluate the effects of China's WTO accession, the import tariffs of China and the foreign tariffs on China's exports are rolled back to their levels in 1995 in the counterfactual economy. In contrast, for the effects of bilateral tariff concessions between the two economies, only their tariffs imposed against each other's exports are returned to their 1995 levels in the counterfactual. Thus, bilateral tariff concessions are part of the tariff changes in all of the other three scenarios (which include, in addition, each economy's trade liberalization with respect to the rest of the world).

We find that most of the labor-market impacts observed in the benchmark case (the effects of Taiwan's WTO accession) were driven by the bilateral tariff concessions between Taiwan and China. Compared with bilateral tariff concessions, Taiwan's WTO accession strengthened the quantitative impacts, while China's WTO accession created an additional "competition effect" for Taiwanese exports in third countries and in China's local market. This dampened the positive effects for manufacturing/service sectors and higher-skilled workers in Taiwan. While the literature typically finds that the China shock hurt manufacturing jobs in the other economies, our work suggests that context is important for such discussions. In the case of Taiwan, the China trade shock created both a positive employment effect for Taiwanese workers—through deeper international specialization in key sectors (such as the surge in MCEE and PCPM) and reorganization of value chains (e.g., the surge in MCEE intermediate exports to China)—and a negative employment effect via direct competition with Taiwan on the world stage. We find that quantitatively the first channel dominated the latter.

To investigate the role of the skill-upgrade mechanism in explaining the effect of Taiwan's WTO accession, we conduct counterfactual analyses by constructing a new baseline economy in which skill upgrading costs are set at prohibitive levels and then examine the effect of Taiwan's WTO accession in the same way as before. We find that the employment effects of Taiwan's WTO accession in the absence of the skill-upgrade mechanism are much smaller than those with the skill-upgrade mechanism. This suggests the existence of strong complementarity between skill upgrade and tariff concessions during the period studied. The important role played by the skill-upgrade mechanism is strongly linked to the finding above that bilateral tariff concessions with China accounted for the bulk of the effects of Taiwan's WTO accession, whereby Taiwan re-oriented its sectoral specializations and repositioned itself in the global value chain. These changes demanded higher skills relative to China (and much of the rest of the world). If the labor supply of each skill type were fixed, a standard Stolper-Samuelson argument would imply that wages for higher skills in Taiwan would increase. The large size of China implies that such increase in skill premiums in Taiwan could be sharp. However, the skill-upgrade mechanism allowed the supply side to respond to the increased demand for higher skills and helped mitigate the upward pressure on skill premiums. The increased supply of skilled labor also spilled over into the service industries and other manufacturing industries. As a result, we observe significantly larger responses in employment across sectors, and less income redistribution effects across skills, following Taiwan's WTO accession.

Related Literature

This paper is related to several strands in the literature. First, it is closely related to studies on dynamic labor-market adjustments across different "categories" in open-economy environments. Such categories can be occupations, sectors, regions, etc. For some prominent examples, see Caliendo, Dvorkin and Parro (2019), Artuç, Chaudhuri and McLaren (2010), Artuç and McLaren (2015), and Caliendo, Parro, Opromolla and Sforza (2021). This paper is also closely related to the set of studies on labor-market adjustments in static environments, including Lee and Yi (2018), He (2019), Tombe and Zhu (2019), Burstein, Hanson, Tian and Vogel (2020), Kim and Vogel (2020), Lee (2020), Adão, Arkolakis and Esposito (2021), and Kim and Vogel (2021). Our work differs from these studies in that we provide a quantitative analysis of the effects of trade on workers' dynamic adjustments across both sectors and skills.[1]

Second, our paper is related to the literature on how trade liberalization influences skill acquisition and skill premiums; see, e.g., Greenland and Lopresti (2016), Atkin (2016), Blanchard and Olney (2017), and Li (2018). These papers provide empirical evidence that trade-driven demand shocks can alter the incentives of human capital investment choice and the skill supply of a country, across countries, or regions within a country. Our work complements these studies by revisiting the issue with the toolkits of the dynamic quantitative trade model of labor markets (Artuç, Chaudhuri and McLaren, 2010) and dynamic hat algebra (Caliendo, Dvorkin and Parro, 2019; Caliendo and Parro, 2020). The skill upgrade decision is modeled as a discrete choice problem, with a fully tractable analytical solution.

Third, our study is related to the empirical literature on the impacts of the China shock. This includes the seminal studies of Autor, Dorn and Hanson (2013), Acemoglu, Autor, Dorn, Hanson and Price (2016), Bloom, Handley, Kurman and Luck (2019), Feenstra, Ma and Xu (2019), and Autor, Dorn and Hanson (2021). While these works focused mainly on China and the US, our study focuses on the case of Taiwan and shows how Taiwan, given its unique position in the global value chain and skill structure, may respond to the China shock differently from the US. Yet another line of literature focuses on quantifying the welfare impacts of the China shock on the world economy across countries. See, for example, Hsieh and Ossa (2016). Our quantitative work rooted in CDP allows us to study the dynamic labor market adjustment for the local economy, in addition to providing welfare impact evaluation for the economies around the world.

Last but not least, our work is related to an old but constantly evolving literature on dynamic Heckscher-Ohlin models, which includes Oniki and Uzawa (1965), Stiglitz (1970), Findlay (1970), Mussa (1978), Findlay and Kierzkowski (1983), Borsook (1987), Chen (1992), Bond, Trask and Wang (2003), Falvey, Greenaway and Silva (2010), Harris and Robertson (2013), and Auer (2015). While the earlier studies are typically limited in terms of the set of countries, sectors, factors, or periods of study, our work can be seen as a modern recast of the old question by using state-of-the-art techniques (with multiple periods, countries, sectors and factors in a dynamic general equilibrium setting) to study the dynamic Heckscher-Ohlin effects with much more empirical content.

The rest of the paper is organized as follows. Section 2 presents a set of key stylized facts on Taiwan's trade patterns and labor market dynamics to motivate our study. We set up the model with skill attainment choice and characterize the dynamic equilibrium conditions in

[1] In another strand of the literature, Dix-Carneiro (2014) and Traiberman (2019) incorporated structural estimation of dynamic labor models in general equilibrium to study the effect of international price changes on workers' occupational and sectoral choice. Our work complements their approach and exploits analytical solutions to study how tariff liberalization influences trade, sectoral allocation, and skill acquisition.

Section 3. In Section 4, we calibrate/estimate the key labor-market parameters for Taiwan, and document the mapping between the model and the data. Section 5 presents the quantitative simulation results of the impact of Taiwan's WTO accession on the Taiwanese labor market and on other economies. Section 6 provides an anatomy of the results obtained in Section 5, by investigating the roles of China and of the skill-upgrade mechanism. Section 7 concludes. Additional theoretical derivations, documentations, and analyses are provided in the appendices following the text, and in the Online Appendix.[2]

2 Stylized Facts

In this section, we characterize Taiwan's structures of tariffs, trade, and labor markets. Taiwan applied for GATT membership in 1990, and became an observer in 1992. Its average tariff was already modest in 1990, at 9.7%. This was due to a long history of bilateral trade talks with the US since 1959. Nevertheless, to become a member of GATT/WTO, Taiwan negotiated with the other member countries, and this induced further reductions of its tariffs, many of which took effect after Taiwan became a formal WTO member. Taiwan joined the WTO in January 2002, right after China joined (in December 2001). For this study, we choose the period 1995–2007, which spans seven years before and six years after its accession to the WTO. This period is also the time when China undertook substantial trade liberalization (unilaterally before its WTO entry and multilaterally afterward). Taiwan's close proximity to China in geography and historical ties, its complementarity with China in the production network, and its relatively small size mean that the effects on trade and labor markets that Taiwan sustained would be heavily influenced by the Chinese economy. We study how Taiwan's WTO entry and trade liberalization during this period reshaped its labor markets, against the backdrop of China's integration into the world economy.

The data that we use in this section came mainly from three sources. First, the tariff data were downloaded at the HS 6-digit level from the World Integrated Trade Solution (WITS) database for the years 1995–2007 and aggregated to the sectoral definition we use using the WITS trade value as weights. Second, we extracted the Taiwanese international trade data from the OECD TiVA ICIO Tables (2016 edition), which report trade data for both intermediate use and final demand. In particular, we deflate Taiwanese exports and imports by the corresponding "export price index" and "import price index" in each year, so that all trade flows are converted to 1995 price level in USD. The export and import price indices are obtained from the Taiwanese Directorate General of Budget, Accounting and Statis-

[2]Available at Pao-Li's website: http://www.mysmu.edu/faculty/plchang/, or Wen-Tai's: http://wthsu.com.

tics (DGBAS). Third, for the Taiwanese labor statistics, we used the *Manpower Utilization Quasi-longitudinal Data* from the Survey Research Data Archive (SRDA) of Academia Sinica, Taiwan.

2.1 Patterns of Tariff Changes

We first document how the Taiwanese tariffs on imports and foreign tariffs on Taiwanese exports changed in the agriculture and manufacturing sectors during this period.

Fact 1(a): Taiwanese import tariffs fell relatively more in the agriculture sector, while foreign tariffs against Taiwanese exports fell relatively more in the manufacturing sectors.

In Table 1, we report the changes (in percentage points) of average tariffs (across products and trading partners of Taiwan) in agriculture and in manufacturing, before and after its accession to the WTO. During 1995–2001, foreign economies reduced tariffs on Taiwanese manufactures (−2.54%) while increasing tariffs on Taiwanese agricultural exports (0.07%). Meanwhile, Taiwanese import tariffs decreased, and relatively more in manufacturing than in agriculture. After its accession to the WTO, Taiwan further decreased its import tariffs during 2002–2007, much more so in agriculture (−4.42%) than in manufacturing (−1.31%). Foreign economies reciprocated and further reduced their tariffs on Taiwanese exports, similarly more so in agriculture (−3.10%) than in manufacturing (−1.75%). Combining the changes across the two periods, Taiwan reduced tariffs on agriculture (−4.84%) by more than its trading partners reduced tariffs on Taiwanese agricultural exports (−3.03%). The reverse is true for manufacturing: the foreign economies reduced tariffs on Taiwan's exports of manufactures (−4.29%) by more than Taiwan's tariff reduction on manufactures (−2.56%). Thus, overall, Taiwan liberalized its agricultural sector in exchange for access to foreign markets in the manufacturing sectors.

Fact 1(b): Tariff changes were heterogeneous across disaggregated product lines, with many products that saw tariff reductions of more than 20%.

Although the mean tariff changes reported in Table 1 are small, there is a large degree of heterogeneity at the tariff line level. We plot the tariff changes at the HS 6-digit level from 1995 to 2007 in Figure 1. While the previous stylized fact states that average tariff changes are in the range of −4% to 0.07%, this figure shows that changes at the disaggregated product level are very dispersed. On the import side, most of the product lines saw a reduction in tariffs, and the tariff changes could be as large as −20%. Meanwhile, tariffs on Taiwanese exports did not uniformly decrease. A non-negligible share of Taiwanese products faced an increase (instead of a decrease) in foreign tariffs, although in contrast certain products that Taiwan exported saw significant tariff reductions of more than 20%.

2.2 Trade Patterns

During this period, Taiwanese trade with the world increased drastically by 128.3%, while its domestic trade share dropped from 76.5% to 67.4%. We investigate the changes in the patterns of trade associated with such phenomenal growth in overall trade volume.

Fact 2(a): China overtook the US and became the leading trading partner of Taiwan.

In Figure 2, we plot the trade share of Taiwan with its major trading partners, including itself, during 1995–2007. Taiwan's import share rose from 23.5% to 32.6% during 1995–2007, whereas its export share rose from 22.0% to 33.7%. In 1995, the US was the largest trading partner of Taiwan when combining exports and imports. By the end of 2007, China had risen to become Taiwan's largest export destination and its second largest import origin (behind Japan).[3] The overall trade volume (exports plus imports) with China exceeded that of all the other trading partners of Taiwan since 2002.

Figures 3–4 document the changes in trade values at the sector level. Two sectors, "Machinery, Computer, Electronics & Electrical Machinery" (hereafter MCEE) and "Petroleum, Chemicals, Plastics, Metals" (hereafter PCPM), emerged to be particularly important in accounting for the changes in the patterns of trade.

Fact 2(b): The MCEE and PCPM sectors were the engines of growth of Taiwanese exports, especially for exports of intermediates.

For MCEE, export growth in both final goods and intermediates were substantial, but the export growth in intermediates was much faster than in final goods. During this period, the export volume in intermediates nearly quadrupled (286% growth) whereas that in final goods more than doubled (133% growth). MCEE imports in both final goods and intermediates also grew, but to a much lesser degree. For PCPM, exports in intermediates and final goods grew at similar rates (282% and 257% increase). The imports in intermediates also grew substantially (109% increase). Since the PCPM sector produces mostly intermediates, its smaller presence in final goods trade than the MCEE sector is expected.

Fact 2(c): MCEE export growth was mainly driven by exports to China. PCPM export growth in intermediates was driven by that to China, whereas its export

[3] The import share from Japan decreased slightly during the period while that of China rose substantially. In recent years, China has become the largest import origin of Taiwan.

growth in final goods could be attributed to a number of destination markets.

In light of Fact 2(b), we further break down trade in major sectors by country of origin and destination in Figures 5–7. For MCEE, both exports to and imports from China in final goods and intermediates grew drastically during this period. The volume of exports outweighed that of imports, and the growth of exports also outpaced that of imports. The intermediates exports of this sector to China grew by 2634.8%, whereas the final-goods exports to China grew by 782.3%. Thus, the phenomenal export growth of this sector was mainly driven by the growth of exports to China, and in particular that of intermediates.

For PCPM, the volume of final goods trade with China was small and insignificant. In contrast, the growth in exports to ASEAN countries and the US accounted for most of this sector's export growth in final goods. On the other hand, exports to China accounted for the bulk of the growth in intermediates exports, while several economies were important in accounting for the growth in intermediates imports (Japan, ASEAN countries, and China).

The three facts shown so far for the trade patterns suggest the importance of the MCEE and PCPM sectors, as well as the trade with China. These patterns suggest there was likely repositioning (moving upstream) of Taiwan's MCEE sector in the global value chain. Some anecdotal evidence supports this view; e.g., Taiwan is known to have gained mastery in semiconductors, optical lenses, and precision instruments, while relocating electronic assemblies to China. Consistently, Taiwan moved toward capital- and skill-intensive products/sectors, given that it has no comparative advantage in labor-intensive activities (compared with China). This is reflected by minor or even negative export growth in its other manufacturing sectors (cf. Figures 3–4). The supply-chain view can also be understood through this lens, since the upstream products in both MCEE and PCPM sectors are likely more capital- and skill-intensive than the downstream activities in these sectors.

Fact 2(d): Agricultural imports rose substantially after 2001.

The agricultural sector warrants special attention in the case of Taiwan. Even though its value added is dwarfed by the other sectors, it accommodated a relatively large number of low-skilled workers in Taiwan (cf. Table A.3). Entering the WTO was a political goal of the then Taiwanese government for various reasons, but it faced major objections from farmers. How to compensate the agricultural sector was a contentious political issue for the government at the time.

In terms of exports, the agricultural sector has little importance in the whole picture of the economy's exports. However, agricultural imports (in both intermediates and final goods) were an order of magnitude larger than exports (albeit still quite small compared with manufacturing). Agricultural imports grew by 90.2% during 2002–2007. Indeed, as shown in

Table 1, most of the import tariff reductions in agriculture occurred after Taiwan joined the WTO. Farmers' worry about import competition was vindicated. For this sector, China was not the main issue; rather, imports from the US and ASEAN countries were behind these import increases.

The changes in trade patterns documented above could have had profound implications for factor demand, in particular for the labor transition across sectors and the skill distribution in Taiwan. We now provide some more stylized facts related to the Taiwanese labor market during this period.

2.3 Patterns of Labor Transition

Table 2 summarizes the pattern of labor transition across sectors in Taiwan during the period 1995–2007. We calculate the proportion of workers from an origin sector in a year that chose to switch to a destination sector in the following year. The number in each cell in the table measures the average transition rate across years from an origin sector (along a row) to a destination sector (along a column). The top five destination sectors for each origin sector are highlighted. In particular, the cells that are highlighted in blue denote the proportions of worker that chose to stay in the same sector, while those highlighted in yellow denote the top four destinations other than the origin sector. The last two columns of the table show the average years of schooling of workers in each sector and the percentage change in the employment share of each sector (measured in terms of shares of total employment plus non-employment) across the period.

Fact 3(a): Labor transitioned out of agriculture and labor-intensive manufacturing sectors and into MCEE and service sectors.

Several patterns in the table are noteworthy. First, the agricultural sector suffered a large drop in its employment share (by 5.3 percentage points across the period). In addition, on average and in each year, 5.2% of its labor were displaced from the sector and did not find an alternative job. This could be attributed to the increased import competition in the sector during this period, as documented in the previous subsections. This labor displacement effect could be further exacerbated by the fact that the transition cost for peasants to switch to alternative sectors of employment is likely higher than the other sectors, because the agricultural sector's general skill level (i.e., years of schooling) is the lowest among all sectors, and the sector-specific human capital in this sector likely does not transfer to jobs in the other sectors.

Second, in addition to the agricultural sector, workers also tended to move out of the manufacturing sectors except the MCEE. Comparison of the diagonal cells in blue from the top left quadrant (i.e., the agriculture and manufacturing sectors) with the diagonal cells in blue from the bottom right quadrant (i.e., the service sectors) reveals that the numbers reported for the manufacturing sectors are in general lower than for the service sectors. Thus, smaller fractions of workers in the manufacturing sectors stayed in the same sectors than workers in the service sectors. In particular, workers in Taiwan tended to move out of sectors in which Taiwan was losing comparative advantage, e.g., textiles, wood, and paper. These sectors either faced rising foreign competition or became less attractive in comparison with the sectors that were expanding, which we now detail.

Third, workers were observed to move into the MCEE, PCPM, and service sectors. This is evident from the yellow cells, which represent the top destination sectors for each origin sector (other than the origin itself). All but three such cells are to these sectors. The fact that the MCEE and PCPM sectors received labor inflow from other sectors is consistent with the trade patterns documented above. However, overall PCPM also experienced a large labor outflow (close to 20% of its workers on average) and hence only a small increase in its employment share (+0.2%) during the period 1995–2007. This likely reflected the sector's technological change over the years, when its production became more capital-intensive (which displaced workers) and skill-intensive (which attracted new workers with higher skill levels).

To understand the general movement from manufacturing to service sectors, note that this structural transformation often accompanies the process of economic development, and this might explain part of the observed movement from manufacturing to service sectors in the case of Taiwan. But what might be more important is the fact that manufacturing sectors in general faced fierce competition from China during this period, especially in labor-intensive sectors. Anecdotal evidence suggests that the manufacturing sectors in Taiwan saw many firms relocating to China during this period. Some of the displaced workers went to the MCEE and PCPM sectors, but many of them went to the service sectors. In particular, the service sectors that witnessed the highest labor inflows were "Wholesale, Retail, Hotels, Restaurants" and "Business Services".

Fact 3(b): The proportion of high-skilled workers increased overall, and most significantly in the Business Services and MCEE sectors.

We now examine how the sectoral patterns in both trade and labor markets mattered for skill acquisitions of workers. As indicated in Table 2, the average years of schooling of workers were the highest in the MCEE, Electricity, Gas & Water (EGW), and Business Services sectors, while they were the lowest in agriculture.[4] Except for the EGW sector, these sectors were also those with the largest labor inflow. This suggests that the expanding

[4]The EGW sector in Taiwan is mainly state-owned, and one needs to pass certain entrance exams in order to enter this sector. This may help explain the high average years of schooling of workers in this sector.

sectors were also the most skill intensive.

Figure 8 shows the evolution of the annual share of low-skilled (with $\leqslant$ junior-high school education), middle-skilled (with senior-high or vocational school education), and high-skilled workers (with college education) in each sector. Overall, the shares of high-, middle-, and low-skilled workers in the population changed from 17.4%, 30.3%, and 52.3% in 1995 to 34.7%, 34.5%, and 30.8% in 2007, respectively.[5] It is evident that the proportion of high-skilled workers increased the most in the MCEE, EGW, and Business Services sectors, which suggests increasing demand for high-skilled workers in these expanding sectors.

In sum, we have documented key stylized facts on tariffs, trade patterns, and labor markets in Taiwan during the period 1995–2007. Taken together, these stylized facts reflect a complex picture, where Taiwan's accession to the WTO as well as the China shocks (in both senses of China's increased openness and productivity growth) were prominent. Because labor market transitions are dynamic and general-equilibrium objects by nature, this motivates our use of the CDP's dynamic general equilibrium framework. Moreover, the role of skill upgrading mattered significantly in the transformation of Taiwan's trade structure — the shrinking/expanding sectors that were less/more skill-intensive in nature exerted push/pull force that motivated skill acquisition on the supply side. Hence, we now generalize the CDP framework to allow for skill transitions (in addition to sector transitions) in workers' choices, in order to examine the quantitative importance of this mechanism.

3 Model

We extend the dynamic hat algebra framework of Caliendo, Dvorkin and Parro (2019) to allow for sector-skill transition. In each period, workers choose endogenously the sector of employment and whether or not to upgrade their skills. Given that skill transition is unidirectional, we introduce mortality and new birth to replenish the pool of low-skilled workers.

The world consists of N economies, and $J + 1$ sectors, with workers of S different skill levels. We denote the economies by $n, o \in \{1, 2, \ldots, N\}$ and sectors by $j, k \in \{0, 1, 2, \ldots, J\}$, where $j = 0$ corresponds to non-employment (jobless). The worker skill level is indexed by $s, i \in \{1, 2, 3\}$, with 1/2/3 representing low-/middle-/high-skill level, respectively.

[5] The total population is measured as the sum of employed, unemployed, and not-in-labor-force, as elaborated in Appendix B.1.

3.1 Workers: Consumption

Each employed worker inelastically supplies one unit of labor, and earns a competitive market wage w_t^{njs} in period t. An njs worker consumes local final goods from all sectors with a Cobb-Douglas aggregator:

$$C_t^{njs} = \prod_{k=1}^{J} \left(c_t^{njs,k} \right)^{\alpha^k},$$

where $\sum_{k=1}^{J} \alpha^k = 1$, with a corresponding price index denoted by $P_t^n = \prod_{k=1}^{J} \left(\frac{P_t^{nk}}{\alpha^k} \right)^{\alpha^k}$, where P_t^{nk} is the price index of goods of sector k in economy n to be derived below. Jobless workers (of any skill) perform home production, and consume

$$C_t^{n0s} = b^n > 0, \quad \forall s.$$

Utility per period is defined by the final goods consumed, as: $U\left(C_t^{njs}\right) \equiv \ln C_t^{njs}$.

3.2 Workers: Sector-Skill Choice

Let L_0^{njs} denote the initial mass of labor with sector-skill combination js in economy n, which adds up to the total population $L^n = \sum_{j=0}^{J} \sum_{s=1}^{3} L_0^{njs}$. In each period, a fraction of workers die, with a survival rate given by δ, while new agents are born into the home production sector ($j = 0$) with low-skill level ($s = 0$). We assume that the death rate equals the birth rate so that the total population size is constant over time.

In each period t, an agent of sector-skill combination js in economy n chooses a sector-skill combination for the coming period (ki) in a forward-looking manner. Agents observe all economic conditions and the realizations of their own idiosyncratic preference shocks ϵ_t^{ki} (with respect to each ki combination) before making decisions. We denote the cost of transition from sector-skill combination js to ki by $\rho^{njs,nki} \geq 0$. A choice of $i > s$ indicates skill-upgrading by the agent. To capture the *irreversibility* of education, we assume that $\rho = \infty$ for $i < s$, so in practice skill downgrading is not observed. The above setup implies that the lifetime utility v_t^{njs} of an agent is given by the following Bellman equation:

$$v_t^{njs} = \ln C_t^{njs} + \max_{\{k,i\}_{k=0,i=1}^{J,3}} \left\{ \beta\delta V_{t+1}^{nki} - \rho^{njs,nki} + \nu\epsilon_t^{ki} \right\}, \tag{1}$$

where β is the discount rate; V_{t+1}^{nki} denotes the expected lifetime utility of an agent with sector-skill combination ki at period $t+1$, with the expectation taken over future realizations of the idiosyncratic shocks; and the parameter ν scales the variance of the idiosyncratic shocks. The idiosyncratic shocks ϵ_t^{ki} are assumed to be *i.i.d.* over time, and drawn from a Type-I extreme value distribution: $F(\epsilon) = e^{-e^{(-\epsilon-\gamma)}}$, with γ representing the Euler constant. Note that the extra discount factor δ on future utilities is introduced by the possibility of death, in addition to the time discount factor β. We assume that wages are the only source of income for workers; it follows that consumption is given by: $C_t^{njs} = \frac{w_t^{njs}}{P_t^n} \equiv \omega_t^{njs}$ for $j \neq 0$, and $C_t^{n0s} = b^n$.

3.3 Workers: Labor Market Transition Probabilities

Given the distribution of ϵ_t^{ki}, it follows that the lifetime expected utility V_t^{njs} is:

$$V_t^{njs} = \ln C_t^{njs} + \nu \ln \sum_{\text{K}=0}^{J} \sum_{\text{I} \geq s}^{3} e^{\frac{\beta\delta V_{t+1}^{n\text{KI}} - \rho^{njs,n\text{KI}}}{\nu}}, \tag{2}$$

and the probability $\mu_t^{njs,nki}$ of transition from sector-skill js to cell ki is:

$$\mu_t^{njs,nki} = \frac{e^{\frac{\beta\delta V_{t+1}^{nki} - \rho^{njs,nki}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I} \geq s}^{3} e^{\frac{\beta\delta V_{t+1}^{n\text{KI}} - \rho^{njs,n\text{KI}}}{\nu}}}. \tag{3}$$

The laws of motion for the labor pool in each sector-skill combination are thus:

$$L_{t+1}^{njs} = \delta \sum_{k=0}^{J} \sum_{i \leq s}^{3} \mu_t^{nki,njs} L_t^{nki}, \ js \neq 01, \tag{4}$$

$$L_{t+1}^{n01} = \delta \sum_{k=0}^{J} \mu_t^{nk1,n01} L_t^{nk1} + (1-\delta) L^n, \tag{5}$$

where the population size L^n remains constant by assumption (that the death rate equals the birth rate); and $(1-\delta) L^n$ represents the new additions to the population that start with non-employment and home production.

3.4 Production

The production structure largely follows that of Eaton and Kortum (2002) and Caliendo and Parro (2015), with modifications for labor inputs that are differentiated by skill types. In each economy-sector nj, a continuum of intermediate goods varieties is produced by perfectly competitive firms with heterogeneous productivity levels z^{nj}. Firms in sector j of economy n combine structure h^{nj}, labor of all three skill types l_t^{njs}, and materials $M_t^{nj,nk}$ in a Cobb-Douglas manner to produce an output quantity of:

$$q_t^{nj} = z^{nj} \left(A_t^{nj} \left(h^{nj} \right)^{\xi^n} \left(\left(l_t^{nj1} \right)^{\zeta^{nj1}} \left(l_t^{nj2} \right)^{\zeta^{nj2}} \left(l_t^{nj3} \right)^{\zeta^{nj3}} \right)^{1-\xi^n} \right)^{\gamma^{nj}} \prod_{k=1}^{J} \left(M_t^{nj,nk} \right)^{\gamma^{nj,nk}},$$

where $M_t^{nj,nk}$ is the material input demanded by a firm in sector j from sector k within economy n; A_t^{nj} is the time-varying economy-sector specific productivity level; γ^{nj} is the share of value-added, such that $\gamma^{nj} = 1 - \sum_k \gamma^{nj,nk}$; ξ^n is the share of structures in value-added; and ζ^{njs} is the share of skill-type s in value-added of *labor*. It follows that the unit price of an input bundle is given by:

$$x_t^{nj} = B^{nj} \left(r_t^{nj} \right)^{\xi^n \gamma^{nj}} \prod_{s=1}^{3} \left(w_t^{njs} \right)^{\zeta^{njs}(1-\xi^n)\gamma^{nj}} \prod_{k=1}^{J} \left(P_t^{nk} \right)^{\gamma^{nj,nk}}, \tag{6}$$

where B^{nj} is a constant; r_t^{nj} is the rental price of structures; w_t^{njs} is the wage rate of skill-type s in economy-sector nj; and P_t^{nk} is the same price index for sector k in economy n as used for consumption, to be explained below.

Exporting intermediate goods of sector j from economy o to n incurs iceberg trade cost ($d_t^{nj,oj}$) as well as ad valorem tariffs ($\tau_t^{nj,oj}$) imposed by economy n, such that: $\kappa_t^{nj,oj} \equiv d_t^{nj,oj} \left(1 + \tau_t^{nj,oj} \right) \geq 1$. Competitive markets imply that the price of a variety of goods in economy-sector nj is given by:

$$p_t^{nj} \left(z^j \right) = \min_o \left\{ \frac{\kappa_t^{nj,oj} x_t^{oj}}{z^{oj} \left(A_t^{oj} \right)^{\gamma^{oj}}} \right\},$$

where the vector $z^j = \left(z^{1j}, ..., z^{Nj} \right)$ represents the productivity draws of the N economies in sector j for a variety.

Intermediate goods demanded by economy n in sector j from all sources, $\widetilde{q}_t^{nj}$, are aggregated into a local sectoral good in a CES manner, denoted by:

$$Q_t^{nj} = \left[\int \left(\widetilde{q}_t^{nj} \left(z^j \right) \right)^{1-\frac{1}{\eta^{nj}}} d\phi^j \left(z^j \right) \right]^{\frac{\eta^{nj}}{\eta^{nj}-1}},$$

where η^{nj} denotes economy n's elasticity of substitution across varieties of sector j. The local final goods of sector j are then used either for consumption by local workers ($c_t^{nks,j}$), or used as material inputs by domestic firms from all sectors ($M_t^{nk,nj}$).

Assume that the productivity vector z^j follows a joint Fréchet distribution, with:

$$\phi^j\left(z^j\right) = e^{-\sum_{o=1}^{N}\left(z^{oj}\right)^{-\theta^j}},$$

which implies that $\phi^{nj}\left(z^{nj}\right) = e^{-\left(z^{nj}\right)^{-\theta^j}}$. It follows that the sectoral price index is equal to:

$$P_t^{nj} = \left[\sum_o \left(\kappa_t^{nj,oj} x_t^{oj}\right)^{-\theta^j} \left(A_t^{oj}\right)^{\gamma^{oj}\theta^j}\right]^{-\frac{1}{\theta^j}} \left(\Gamma^{nj}\left(\frac{1-\eta^{nj}+\theta^j}{\theta^j}\right)\right)^{\frac{1}{1-\eta^j}}, \tag{7}$$

and the share of intermediate varieties in sector j that economy n imports from economy o is:

$$\pi_t^{nj,oj} = \frac{\left(\kappa_t^{nj,oj} x_t^{oj}\right)^{-\theta^j} \left(A_t^{oj}\right)^{\gamma^{oj}\theta^j}}{\sum_{\mathrm{o}} \left(\kappa_t^{nj,\mathrm{o}j} x_t^{\mathrm{o}j}\right)^{-\theta^j} \left(A_t^{\mathrm{o}j}\right)^{\gamma^{oj}\theta^j}}. \tag{8}$$

3.5 Market Clearing

Local structures are used locally and owned by a mass of local rentiers. Let H^{nj} denote the fixed supply of structures used in sector j of economy n. Rentiers send their rental income to a global portfolio of total size χ_t, and receive a share ι^n of the portfolio in return:

$$\iota^n \chi_t = \iota^n \sum_{\mathrm{o}=1}^{N}\sum_{j=1}^{J} r_t^{\mathrm{o}j} H^{\mathrm{o}j}.$$

The difference between what the rentiers send $r_t^{\mathrm{o}j} H^{\mathrm{o}j}$ and what they receive in return $\iota^n \chi_t$ generates imbalance between income and expenditure, and reflects the economy's trade surplus. The parameter $\{\iota^n\}$ is thus used to accommodate the observed trade imbalance in a mechanical way.

Let X_t^{nj} denote economy n's total expenditure on sector-j goods. The goods market-clearing condition requires that:

$$\begin{aligned} X_t^{nj} = & \sum_{k=1}^{J} \gamma^{nk,nj} \sum_{\mathrm{o}=1}^{N} \frac{\pi_t^{\mathrm{o}k,nk} X_t^{\mathrm{o}k}}{1+\tau_t^{\mathrm{o}k,nk}} \\ & + \alpha^j \left(\sum_{k=1}^{J}\sum_{s=1}^{3} w_t^{nks} L_t^{nks} + \iota^n \chi_t + \sum_{k=1}^{J}\sum_{\mathrm{o}=1}^{N} \tau_t^{nk,\mathrm{o}k} \frac{\pi_t^{nk,\mathrm{o}k} X_t^{nk}}{1+\tau_t^{nk,\mathrm{o}k}} \right), \end{aligned} \tag{9}$$

where the first term on the right-hand side corresponds to local firms' expenditures on sector-j goods as material inputs; and the second big term reflects the final demand for sector-j goods by workers (given their wage income), rentiers (given their share of global portfolio income), and the government (with the tariff revenues).

Perfect competition and Cobb-Douglas production function together imply that the market-clearing conditions for labor and structure markets are respectively:

$$L_t^{njs} = \frac{\zeta^{njs}(1-\xi^n)\gamma^{nj}}{w_t^{njs}} \sum_{o=1}^{N} \frac{\pi_t^{oj,nj} X_t^{oj}}{1+\tau_t^{oj,nj}}, \tag{10}$$

$$H^{nj} = \frac{\xi^n \gamma^{nj}}{r_t^{nj}} \sum_{o=1}^{N} \frac{\pi_t^{oj,nj} X_t^{oj}}{1+\tau_t^{oj,nj}}. \tag{11}$$

3.6 Equilibrium

We now characterize the dynamic equilibrium of the economy following Caliendo, Dvorkin and Parro (2019). Let $\Theta_t \equiv (A_t, d_t, \tau_t)$ denote the set of time-varying fundamentals. This includes the economy-sector productivities $A_t = \{A_t^{nj}\}$, the iceberg trade costs $d_t = \{d_t^{nj,oj}\}$, and the tariff wedges $\tau_t = \{\tau_t^{nj,oj}\}$. Let $\overline{\Theta} \equiv (\rho, H, b)$ collect the set of constant fundamentals, which include the labor transition costs $\rho = \{\rho^{njs,nki}\}$, the stock of structures $H = \{H^{nj}\}$, and home production $b = \{b^n\}$. The other parameters of the model include the value-added shares (γ^{nj}), the labor shares in value added $(1-\xi^n)$, the skill shares in the value-added of labor (ζ^{njs}); the input-output coefficients ($\gamma^{nj,nk}$); the portfolio shares (ι^n); the final consumption expenditure shares (α^j); the discount factor β; the survival rate δ; the trade elasticity (θ^j); and the scaling factor of the variance of the idiosyncratic shocks (ν).

As in CDP, we can solve the dynamic equilibrium in two loops: first in terms of temporary equilibrium (for each period) and then in terms of sequential equilibrium (across periods). In each period, given $(L_t, \Theta_t, \overline{\Theta})$, a temporary equilibrium is a vector of wages $w(L_t, \Theta_t, \overline{\Theta})$ that satisfies the equilibrium conditions (6)–(11). Given $\left(L_0, \{\Theta_t\}_{t=0}^{\infty}, \overline{\Theta}\right)$, a sequential equilibrium is a sequence of $\left\{L_t, \mu_t, V_t, w(L_t, \Theta_t, \overline{\Theta})\right\}_{t=0}^{\infty}$ that solves equilibrium conditions (2)–(5) and the temporary equilibrium at each t, where $\mu_t = \left\{\mu_t^{njs,nki}\right\}$ and $V_t = \{V_t^{njs}\}$.

3.7 Dynamic Hat Algebra

We now characterize the equilibrium in terms of *time differences*. This greatly reduces the set of parameters required to implement the analysis. In fact, the equilibrium in time differences can be solved without information on the level of the fundamentals $\{\Theta_t\}_{t=1}^{\infty}$ or $\overline{\Theta}$, as elaborated in CDP. Given the baseline economy's equilibrium path over time, we can then conduct counterfactual analysis and study how allocations change across space, sector, skill and time, relative to the baseline economy, given a new sequence of fundamentals $\{\Theta_t'\}_{t=1}^{\infty}$.

Let $\dot{y}_{t+1} \equiv y_{t+1}/y_t$ represent the change of y over time and $\widehat{y}_{t+1} \equiv \dot{y}_{t+1}'/\dot{y}_{t+1}$ the relative change between the counterfactual equilibrium path $\dot{y}'_{t+1} \equiv y'_{t+1}/y'_t$ and the baseline equilibrium path $\dot{y}_{t+1} \equiv y_{t+1}/y_t$. The following propositions summarize the equilibrium characterization, in a manner similar to CDP.

Proposition 1. *Given the allocation of the temporary equilibrium at* t, $\{L_t, \pi_t, X_t\}$, *consider a given change in* $\dot{L}_{t+1}$ *and* $\dot{\Theta}_{t+1}$. *The temporary equilibrium at time* $t+1$ *solves the following equations, and requires no information on the level of fundamentals at* t*:*

$$
\begin{aligned}
\dot{x}^{nj}_{t+1} &= \left(\dot{r}^{nj}_{t+1}\right)^{\xi^n \gamma^{nj}} \prod_{s=1}^{3} \left(\dot{w}^{njs}_{t+1}\right)^{\zeta^{njs}(1-\xi^n)\gamma^{nj}} \prod_{k=1}^{J} \left(\dot{P}^{nk}_{t+1}\right)^{\gamma^{nj,nk}} & (12)\\
\dot{P}^{nj}_{t+1} &= \left[\sum_{o} \pi^{nj,oj}_t \left(\dot{\kappa}^{nj,oj}_{t+1} \dot{x}^{oj}_{t+1}\right)^{-\theta^j} \left(\dot{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\right]^{-\frac{1}{\theta^j}} & (13)\\
\pi^{nj,oj}_{t+1} &= \pi^{nj,oj}_t \left(\frac{\dot{\kappa}^{nj,oj}_{t+1} \dot{x}^{oj}_{t+1}}{\dot{P}^{nj}_{t+1}}\right)^{-\theta^j} \left(\dot{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j} & (14)\\
X^{nj}_{t+1} &= \sum_{k=1}^{J} \gamma^{nk,nj} \sum_{\mathrm{o}=1}^{N} \frac{\pi^{\mathrm{o}k,nk}_{t+1} X^{\mathrm{o}k}_{t+1}}{1+\tau^{\mathrm{o}k,nk}_{t+1}} & (15)\\
&\quad + \alpha^j \left(\sum_{k=1}^{J}\sum_{s=1}^{3} \dot{w}^{nks}_{t+1} \dot{L}^{nks}_{t+1} w^{nks}_t L^{nks}_t + \iota^n \chi_{t+1} + \sum_{k=1}^{J}\sum_{\mathrm{o}=1}^{N} \tau^{nk,\mathrm{o}k}_{t+1} \frac{\pi^{nk,\mathrm{o}k}_{t+1} X^{nk}_{t+1}}{1+\tau^{nk,\mathrm{o}k}_{t+1}}\right) &\\
\dot{w}^{njs}_{t+1} \dot{L}^{njs}_{t+1} w^{njs}_t L^{njs}_t &= \zeta^{njs} \left(1-\xi^n\right) \gamma^{nj} \sum_{\mathrm{o}=1}^{N} \frac{\pi^{\mathrm{o}j,nj}_{t+1} X^{\mathrm{o}j}_{t+1}}{1+\tau^{\mathrm{o}j,nj}_{t+1}}, \quad s \in \{1,2,3\} & (16)\\
\dot{r}^{nj}_{t+1} &= \dot{w}^{njs}_{t+1} \dot{L}^{njs}_{t+1}, \quad s \in \{1,2,3\} & (17)
\end{aligned}
$$

where $\chi_{t+1} = \sum_{n=1}^{N} \sum_{j=1}^{J} \frac{\xi^n}{1-\xi^n} \frac{\dot{w}^{nj1}_{t+1} \dot{L}^{nj1}_{t+1} w^{nj1}_t L^{nj1}_t}{\zeta^{nj1}}$.

This is the multi-skill version of CDP's Proposition 1, with the main difference that workers are differentiated by their skills, and skill intensity differs across sectors. Thus for each economy we have $2J$ additional variables to solve, and we also have $2J$ additional labor market clearing conditions. Note that given the Cobb-Douglas production function, the relative changes in labor expenditure $w^{njs}_t L^{njs}_t$ over time for all skill types are identical to the relative change in rental income $r^{nj}_t H^{nj}$ over time. Proposition 1 implies that given $\left\{L^{njs}_t, \pi^{nj}_t, X^{nj}_t, \dot{L}^{njs}_{t+1}, \dot{\Theta}_{t+1}\right\}$ for all $\{n, j, s\}$, one can solve for the change in the allocation of the temporary equilibrium between t and $t+1$, and in the real wages based on $\left\{\dot{w}^{njs}_{t+1}, \dot{P}^{nj}_{t+1}\right\}$. The next proposition then characterizes the changes $\dot{L}^{njs}_{t+1}$ that are consistent with the sequential equilibrium in time differences.

Proposition 2. *Define* $u^{njs}_t \equiv e^{V^{njs}_t}$. *Conditional on an initial allocation of the economy* $(L_0, \pi_0, X_0, \mu_{-1})$, *given an anticipated convergent sequence of changes in fundamentals*

$\left\{\dot{\Theta}_t\right\}_{t=1}^{\infty}$, *the solution to the sequential equilibrium in time differences satisfies the following equations and requires no information on the level of fundamentals* $(\{\Theta_t\}_{t=0}^{\infty}, \overline{\Theta})$*:*

$$\mu_{t+1}^{njs,nki} = \frac{\mu_t^{njs,nki}\left(\dot{u}_{t+2}^{nki}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_t^{njs,n\mathrm{KI}}\left(\dot{u}_{t+2}^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}} \tag{18}$$

$$\dot{u}_{t+1}^{njs} = \dot{\omega}_{t+1}^{njs}\left[\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_t^{njs,n\mathrm{KI}}\left(\dot{u}_{t+2}^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}\right]^{\nu} \tag{19}$$

$$L_{t+1}^{njs} = \delta\sum_{k=0}^{J}\sum_{i\leq s}^{3}\mu_t^{nki,njs}L_t^{nki},\ js\neq 01 \tag{20}$$

$$L_{t+1}^{n01} = \delta\sum_{k=0}^{J}\mu_t^{nk1,n01}L_t^{nk1}+(1-\delta)L^n \tag{21}$$

where $\left\{\dot{\omega}_t^{njs}\right\}$ *is the solution to the temporary equilibrium given* $\left\{\dot{L}_t,\dot{\Theta}_t\right\}$ *characterized in Proposition 1.*

In sum, with Propositions 1 and 2 combined, one can solve the baseline economy in time differences, for a given sequence of changes in fundamentals, using data on initial labor allocation L_0 and transition matrix μ_{-1} alone.

Proposition 3. *Consider a counterfactual convergent sequence of changes in fundamentals relative to the baseline change* $\left\{\widehat{\Theta}_t\right\}_{t=1}^{\infty}$*. Given the allocation under the baseline fundamentals* $\{L_t,\mu_{t-1},\pi_t,X_t\}_{t=0}^{\infty}$*, the counterfactual sequential allocation* $\left\{L'_t,\mu'_{t-1},\pi'_t,X'_t\right\}_{t=0}^{\infty}$ *satisfies the following equations and does not require information on the baseline fundamentals* $(\{\Theta_t\}_{t=0}^{\infty}, \overline{\Theta})$*:*

$$\mu_{t+1}^{\prime njs,nki} = \frac{\mu_t^{\prime njs,nki}\dot{\mu}_{t+1}^{njs,nki}\left(\widehat{u}_{t+2}^{nki}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_t^{\prime njs,n\mathrm{KI}}\dot{\mu}_{t+1}^{njs,n\mathrm{KI}}\left(\widehat{u}_{t+2}^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}} \tag{22}$$

$$\widehat{u}_{t+1}^{njs} = \widehat{\omega}_{t+1}^{njs}\left[\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_t^{\prime njs,n\mathrm{KI}}\dot{\mu}_{t+1}^{njs,n\mathrm{KI}}\left(\widehat{u}_{t+2}^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}\right]^{\nu} \tag{23}$$

$$L_{t+1}^{\prime njs} = \delta\sum_{k=0}^{J}\sum_{i\leq s}^{3}\mu_t^{\prime nki,njs}L_t^{\prime nki},\ js\neq 01 \tag{24}$$

$$L_{t+1}^{\prime n01} = \delta\sum_{k=0}^{J}\mu_t^{\prime nk1,n01}L_t^{\prime nk1}+(1-\delta)L^n. \tag{25}$$

where $\widehat{\omega}^{njs}_{t+1}$ *is the solution to the temporary equilibrium given* $\left(\widehat{L}_{t+1}, \widehat{\Theta}_{t+1}\right)$ *at each* t*:*

$$\widehat{x}^{nj}_{t+1} = \left(\widehat{r}^{nj}_{t+1}\right)^{\xi^n \gamma^{nj}} \prod_{s=1}^{3} \left(\widehat{w}^{njs}_{t+1}\right)^{\zeta^{njs}(1-\xi^n)\gamma^{nj}} \prod_{k=1}^{J} \left(\widehat{P}^{nk}_{t+1}\right)^{\gamma^{nj,nk}} \tag{26}$$

$$\widehat{P}^{nj}_{t+1} = \left[\sum_{o} \pi'^{nj,oj}_{t} \dot{\pi}^{nj,oj}_{t+1} \left(\widehat{\kappa}^{nj,oj}_{t+1} \widehat{x}^{oj}_{t+1}\right)^{-\theta^j} \left(\widehat{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\right]^{-\frac{1}{\theta^j}} \tag{27}$$

$$\pi'^{nj,oj}_{t+1} = \pi'^{nj,oj}_{t} \dot{\pi}^{nj,oj}_{t+1} \left(\frac{\widehat{\kappa}^{nj,oj}_{t+1} \widehat{x}^{oj}_{t+1}}{\widehat{P}^{nj}_{t+1}}\right)^{-\theta^j} \left(\widehat{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j} \tag{28}$$

$$\begin{aligned} X'^{nj}_{t+1} &= \sum_{k=1}^{J} \gamma^{nk,nj} \sum_{\text{o}=1}^{N} \frac{\pi'^{\text{o}k,nk}_{t+1} X'^{\text{o}k}_{t+1}}{1+\tau^{\text{o}k,nk}_{t+1}} \\ &+ \alpha^j \left(\sum_{k=1}^{J} \sum_{s=1}^{3} \widehat{w}^{nks}_{t+1} \widehat{L}^{nks}_{t+1} w'^{nks}_{t} L'^{nks}_{t} \dot{w}^{nks}_{t+1} \dot{L}^{nks}_{t+1} + \iota^n \chi'_{t+1} + \sum_{k=1}^{J} \sum_{\text{o}=1}^{N} \tau^{nk,\text{o}k}_{t+1} \frac{\pi'^{nk,\text{o}k}_{t+1} X'^{nk}_{t+1}}{1+\tau^{nk,\text{o}k}_{t+1}}\right) \end{aligned} \tag{29}$$

$$\widehat{w}^{njs}_{t+1} \widehat{L}^{njs}_{t+1} = \frac{\zeta^{njs}(1-\xi^n)\gamma^{nj}}{w'^{njs}_{t} L'^{njs}_{t} \dot{w}^{njs}_{t+1} \dot{L}^{njs}_{t+1}} \sum_{\text{o}=1}^{N} \frac{\pi'^{\text{o}j,nj}_{t+1} X'^{\text{o}j}_{t+1}}{1+\tau^{\text{o}j,nj}_{t+1}}, \quad s \in \{1,2,3\} \tag{30}$$

$$\widehat{r}^{nj}_{t+1} = \widehat{w}^{njs}_{t+1} \widehat{L}^{njs}_{t+1}, \quad s \in \{1,2,3\} \tag{31}$$

where $\chi'_{t+1} = \sum_{n=1}^{N} \sum_{j=1}^{J} \frac{\xi^n}{1-\xi^n} \frac{\widehat{w}^{nj1}_{t+1} \widehat{L}^{nj1}_{t+1} w'^{nj1}_{t} L'^{nj1}_{t} \dot{w}^{nj1}_{t+1} \dot{L}^{nj1}_{t+1}}{\zeta^{nj1}}$.

In Appendix A, we provide the derivations of the above propositions.

4 Calibration

This section provides a summary of the parameter values and data used in the quantitative model underlying our counterfactual analysis. Further details about the data sources and measurements are documented in Appendix B.

4.1 Trade, Tariffs, and Production Parameters

Data on international trade, input-output coefficients, value-added shares and final consumption expenditure shares were compiled based on the OECD TiVA ICIO Tables (2016 edition). We use tariff data from the World Integrated Trade Solution (WITS) database. The labor shares in value added were obtained from Karabarbounis and Neiman (2014). We obtained the skill shares in the value-added of labor from the World Input-Output (WIOD) Database Socioeconomic Account. The trade elasticities at the sector level were taken from

Caliendo and Parro (2015, Table A2, Column 1).[6]

In sum, for the simulations we include 60 individual economies and a residual Rest-of-World (ROW), 22 sectors (agriculture plus 11 manufacturing sectors and 10 service sectors) and non-employment, and three skill groups (low, middle, and high). Table A.1 explains the classification of the sectors and Table A.2 provides the summary statistics for the key parameters and variables.

4.2 Labor Market Parameters and Sector-Skill Transition

For Taiwan, the low-skilled, middle-skilled, and high-skilled workers are defined as, respectively, those with highest education attainment less than or equal to junior high school; those with a highest education attainment equal to senior high school or vocational school diploma; and those with a highest education attainment equal to a college degree (bachelor, master or doctorate degree). We compile the data on the allocation of labor by sector-skill during the period 1995–2007 and on the transition statistics across sector-skill combinations at annual frequency, based on the *Manpower Utilization Quasi-longitudinal Data* from the Survey Research Data Archive (SRDA) of Academia Sinica, Taiwan.

For economies other than Taiwan, the dynamics of labor market transition is not explicitly studied, so the skill group definition only matters in the measure of the three skill groups' shares in total labor value added. These measures are compiled from the WIOD Socioeconomic Account as documented above. The skill groups in this case are defined according to each economy's underlying education system; but the criteria are generally equivalent in terms of the years of schooling, and in line with our definition of low-, middle-, and high-skilled workers.

We use an annual discount factor β of 0.97, à la Artuç and McLaren (2015) and Caliendo, Parro, Opromolla and Sforza (2021). We set the mortality rate for Taiwan at 0.6% for the period studied, which implies $\delta \backsimeq 0.994$.[7] We estimate the labor market transition elasticity (here corresponding to $\beta\delta/\nu$), based on the 2-stage approach proposed by Artuç and McLaren (2015) but adapted for the utility function specified in equation (1).[8] Since the

[6] When a manufacturing sector in our classification corresponds to multiple manufacturing sectors in Caliendo and Parro (2015), we take the simple average of the elasticities of the matched sectors. We drop the extreme elasticity estimates of Caliendo and Parro (2015) for mining and quarrying, wood, and petroleum, before calculating the elasticity for each of the 11 aggregate manufacturing sectors. We adopt a value of 10 for the service sector's productivity dispersion parameter, basically assuming that trade in services is more sensitive to trade costs than trade in agriculture and manufacturing.

[7] The mortality rate is available from the National Development Council, Taiwan, at `https://pop-proj.ndc.gov.tw/chart.aspx?c=1&uid=61&pid=60`. We take the average of the mortality rates across 1995–2007. The rate is the same up to three decimal points if instead we take the average of the mortality rates during 2001–2007.

[8] The original framework's utility function depends on wage income linearly. In the current context, we

labor-market transition dynamics are only studied for the Taiwanese economy, we omit the economy superscript in this section. In particular, in the first stage we estimate by PPML the following sector-skill-transition equation:

$$L_t^{js,ki} = \exp\left(\alpha_t^{js} + \lambda_t^{ki} - \rho^{js,ki}/\nu\right) + \xi_t^{js,ki} \tag{32}$$

where $L_t^{js,ki}$ is the flow of workers switching from sector-skill combination js to combination ki, measured by $L_t^{js} \times \mu_t^{js,ki}$. It can be shown that $L_t^{js,ki}$ depends on origin-cell-specific fixed effects α_t^{js}, destination-cell-specific fixed effects λ_t^{ki}, and the transition cost $\rho^{js,ki}$, subject to measurement/sampling errors $\xi_t^{js,ki}$, based on similar proofs as in Artuç and McLaren (2015). The transition cost function is empirically implemented in the current study as:

$$\begin{aligned} \rho^{js,ki} &= 0 \text{ if } k = j, i = s; \\ &= \rho_1^{s,i} \text{ if } k = j, i \neq s; \\ &= \rho_2^{j,k} \text{ if } k \neq j, i = s; \\ &= \rho_1^{s,i} + \rho_2^{j,k} + \rho_3 \text{ if } k \neq j, i \neq s. \end{aligned} \tag{33}$$

where $\rho_1^{s,i}$ is the cost for workers to upgrade skill from s to i (from s=low-skill to i=middle-skill or from s=middle-skill to i=high-skill), $\rho_2^{j,k}$ is the cost for workers to switch from sector j to sector k, and ρ_3 ($\gtreqless 0$) captures the possibility that the cost of switching both sector and skill is different from the sum of the cost of switching sector and the cost of upgrading skill, i.e., that there may be some non-linearity in the cost of joint switching.

Furthermore, it can be shown using the Bellman equation (1) and the transition probability equation (3) that the following holds:

$$\phi_t^{js} = \zeta_t + \frac{\beta\delta}{\nu} \ln w_{t+1}^{js} + \xi_t^{js} \tag{34}$$

where $\phi_t^{js} \equiv \lambda_t^{js} + \beta\delta\alpha_{t+1}^{js} - \beta\delta \log\left(L_{t+1}^{js}\right)$ can be imputed given the first-stage estimates of the fixed effects $(\lambda_t^{js}, \alpha_{t+1}^{js})$ and the observed labor allocation L_{t+1}^{js}, while $\zeta_t \equiv -\frac{\beta\delta}{\nu} V_{t+1}^{oo} + \frac{(\beta\delta)^2}{\nu} V_{t+2}^{oo}$ corresponds to the difference in the discounted expected utilities (V_{t+1}, V_{t+2}) for a chosen omitted sector-skill category (oo), and will be captured by time fixed effects. We estimate (34) as an IV regression, using two-period lagged values of the right-hand-side variable ($\ln w_{t+1}^{js}$) as instruments, as in Artuç and McLaren (2015). In addition to the baseline controls specified in (34), we also control for extra fixed effects: $\eta_{t+1}^s \equiv \eta_1^s + \eta_2^s \times t$, which

follow Caliendo, Dvorkin and Parro (2019) such that the per period utility function depends on $\ln C_t^{njs} = \ln w_t^{njs} - \ln P_t^n$.

correspond to the origin-skill fixed effects and origin-skill-specific time trends. This can be interpreted as non-pecuniary benefits associated with each skill category (not captured by market wages). This is in line with Artuç and McLaren (2015), by including controls for non-pecuniary benefits.[9]

The estimation results are reported in Table 3. In Stage 1, based on estimations of equation (32) and the switching-cost specification in equation (33), we find that the skill-upgrading cost is higher from low to middle skill than from middle to high skill, although the difference is not statistically significant. Figure 9 summarizes the sector-to-sector switching costs (origin-sectors in the rows and destination-sectors in the columns), where the magnitudes reported reflect the average sector-switching costs with or without skill upgrading ($k \neq j, i \geq s$). Overall, the switching costs are the largest to switch from service to manufacturing sectors, followed by the costs to switch from manufacturing to service sectors, then the costs to switch across sectors within manufacturing, and the lowest are across sectors within services. Column (2) of Table 3 then reports the Stage-2 estimation results. The estimate of the labor market transition elasticity (corresponding to $\beta\delta/\nu$) is 0.738 and significant at 1%.[10] Given the values of β and δ (as indicated above in this section), this implies an estimate of $\nu \backsimeq 1.306$, which we use in the quantitative simulations.

In Online Appendix A, we report results when we allow the sector-to-sector switching costs to differ conditional on the origin-skill type. The alternative estimate of the labor market transition elasticity is larger at 1.284 and implies a correspondingly smaller estimate of $\nu \backsimeq 0.751$. This set of estimates of transition elasticity and ν is closer to that of Artuç and McLaren (2015), where $\nu = 0.62$. Given smaller ν, the labor market will tend to be more responsive to economic shocks and hence we can expect greater quantitative effects for given simulated shocks with this alternative value of ν.

5 Counterfactual Simulation Results

In this section, we conduct counterfactual simulations to assess the quantitative effect of Taiwan's WTO accession on its own labor markets. In particular, we examine how workers transit across sectors and skills in response to the changes in tariffs and trade, and the implied welfare effects of such changes on the local workers conditional on their sector-skill

[9]The utility function in (1) can be modified to include this extra term, without affecting the counterfactual analysis presented in Section 5. The counterfactual equilibrium conditions in Section 3.7 remain intact, except that the counterfactual utilities $\widehat{u}^{njs}_{t+1}$ in (23) need to be scaled by $\widehat{\vartheta}^{njs}_{t+1}$, where $\vartheta^{njs}_{t+1} = exp(\eta^{ns}_{t+1})$.

[10]This annual rate is larger than the implied quarterly elasticity (0.185) of Caliendo, Dvorkin and Parro (2019), and in the same order of magnitude as the annual elasticity estimate (0.50) of Caliendo, Parro, Opromolla and Sforza (2021).

combinations. We also report the general pattern of welfare effects on the other economies at the aggregate and across sectors. In this quantitative exercise, the baseline economy consists of the actual changes in fundamentals for 1995–2007 (the data period) and constant fundamentals after 2007. The counterfactual economy is the same except that Taiwan's tariffs on imports and foreign tariffs on Taiwan's exports are set to their levels in 1995. We simulate the model for both the baseline and the counterfactual economy until year 3000.[11] The effect in each period is calculated as the difference between the baseline economy (with WTO accession) and the counterfactual economy (without WTO accession). We focus on the period 1995–2020 when reporting the cumulative effects on the variables of interest. Statistics for longer-run effects are available upon request.

5.1 Transition Dynamics in Taiwanese Labor Markets

We start by presenting the transition dynamics of the employment shares for the Taiwanese labor market during 1995–2050 in the baseline economy versus the counterfactual economy. Figure 10 summarizes the pattern by broad sector categories (the simulation is nonetheless conducted at the disaggregate sector level detailed in Section 4). It shows that Taiwan's accession to WTO led to decreases in employment in the agricultural sector, while employment increased in the manufacturing and service sectors. In particular, agricultural employment declined substantially as a result of WTO accession, accounting for about 0.37% of the total population (measured as the sum of employed, unemployed, and not-in-labor-force, as elaborated in Appendix B.1). This is relative to an initial employment size of 9.3% of the total population in the sector in 1995. Meanwhile, manufacturing and service employment shares increased by about 4.4% and 1.3% of the total population, respectively. The decrease in agricultural employment took place mainly during the data period of 1995–2007, and the effect stabilized soon afterwards. In contrast, the increase in manufacturing and service employment continued after the data period and only slowly converged after 2020.

These effects are quantitatively large, in comparison with the literature such as CDP (around $\pm 0.3\%$). In addition, the increase in manufacturing and service employment ($\approx$ 5.7% all told) is far larger than the decrease in agricultural employment ($\approx$ 0.37%), which suggests that employment increased overall during this period as a result of WTO accession. Specifically, non-employment (the sum of unemployed and not-in-labor-force) decreased by about 5.3% of the total population up to 2020.

These patterns are consistent with our priors. As set out in the stylized facts, Taiwan lowered tariffs on agricultural imports from other economies during the period, in exchange

[11] This sufficiently large simulation terminal period is chosen such that the effects of the trade shocks under study are likely to have reached steady states by then.

for reduced foreign tariffs on its manufacturing exports. Hence, Taiwanese farmers were hit with increased import competition from abroad, which led to labor transition out from the agricultural sector. In contrast, manufacturing sectors expanded significantly due to improved access to foreign markets, while service sectors benefited as a result of input-output linkages and spillover from the manufacturing sectors. The difference in transition dynamics and convergence timing suggests that the outflow of farmers from the agricultural sector took place rather quickly and the adjustment was basically completed by the time Taiwan finished all tariff changes. However, the gain in manufacturing and service employment was a long and slow-moving process that continued to the present decade. This was especially true for the service sectors. The fact that these effects are quantitatively larger than the existing literature based on developed economies such as the US can be attributed to the export-oriented, small and open nature of the Taiwanese economy.

We further decompose the employment dynamics by skill groups in Figure 11. The upper panel shows that the decrease in agricultural employment was almost entirely driven by the low-skilled workers, which can be explained by the low-skill nature of the sector. The middle and lower panels show that both the manufacturing and service sectors saw an increase of high-skill employment (by about 1.5% and 0.9%, respectively). In comparison, the middle-skill employment increased by more in manufacturing (about 1.6%) than in the service sectors (0.3%). Furthermore, while there was a positive inflow of low-skilled workers into manufacturing sectors, the service sectors saw a decline in low-skill employment. This implies there was a trend to upgrade skills in the service sectors, and low-skill jobs were gradually replaced by high-skill employment. In the meantime, the manufacturing sectors helped absorb some of the displaced agricultural workers with low skills.

5.2 Effects on Sectoral Employment Shares

In this section, we further break down the effects by sectors and discuss the importance of particular sectors. Figure 12 suggests that among manufacturing sectors, the positive effect on employment due to Taiwan's WTO entry was mainly driven by the MCEE (Machinery, Computer, Electronics & Electrical) sectors, whose employment increased by about 1.3% of the total population (cf. 4.4% across all manufacturing sectors). This was followed by "Basic & Fabricated Metals" (0.67%) and "Textiles, Leather, Footwear" (0.5%). In Figure 13, we normalize these changes relative to the initial employment share of the sector in 1995 (of the total population). The importance of MCEE sectors and the sectors of "Petroleum, Chemicals, Plastics, Metals" continued to stand out and that of "Textiles, Leather, Footwear" reduced relative to Figure 12. Thus, the pattern of comparative advantage tilted toward the first two broad sectors that are more skill-intensive and capital-intensive in nature and that expanded the most in their exports among other sectors in the stylized facts.

Figures 14–15 report the counterpart for the service sectors. Among the service sectors, employment in the "Other Business Services" sector (including activities such as R&D, law, accounting, business consulting, architecture, engineering, advertising and other business activities, cf. Table A.1) increased the most by more than 0.5% of the total population, followed by "Construction", "Financial Intermediation", and "Hotels, Restaurants" (by about 0.3% each). In contrast, employment in the "Wholesale, Retail" and "Education, Public Service" sectors decreased. The rates of expansion were especially pronounced in "Financial Intermediation" and "Other Business Services", when normalized by the initial employment size, as indicated in Figure 15. Our interpretations are that these two sectors benefitted from expansion of manufacturing sectors through input-output linkages, especially since the biggest export expansions in manufacturing stemmed from the skill-intensive MCEE sectors, which tended to source from the downstream business service sectors.

We further show how employment shares of different skill groups changed in individual sectors in Figures 16–17. In terms of skill groups, the employment shares of high-skilled and middle-skilled workers grew the most in the MCEE sectors among other manufacturing sectors, and that of high-skilled workers mostly in the "Other Business Services" sector among services. These sectors also had the largest overall employment gains, as discussed above, which suggests that when these sectors expanded due to export shock and input-output linkages, they tended to hire more skilled workers.

With regard to the employment of low-skilled workers, the "Textiles, Leather, Footwear" sector experienced the largest gain of such workers among manufacturing sectors, while the changes of low-skilled employment shares across service sectors were not as uniformly positive as in manufacturing sectors, and saw large decreases in some sectors, such as "Wholesale, Retail". Interestingly, the "Other Business Services" sector, which expanded its employment of high-skilled workers, also increased its employment of low-skilled workers, albeit less proportionally. This could be due to the heterogeneous nature of the sector, with a wide variety of service activities included in the category.

5.3 Welfare Effects on Taiwanese Workers

Table 4 reports the aggregate welfare effect of WTO accession on Taiwanese labor markets over the period of 1995–2020. The welfare effect for a worker in location n of sector-skill-level js is measured in terms of changes in his/her total discounted consumption equivalent during the period:

$$\widehat{W}^{njs} = \sum_{t=1995}^{2020} (\beta\delta)^{t-1995} \ln \left(\frac{\widehat{\omega}_t^{njs}}{\left(\widehat{\mu}_t^{njs,njs}\right)^{\nu}} \right). \tag{35}$$

In particular, the change in welfare due to the WTO accession is given by the present discounted value of the expected change in real consumption and the change in the option value. The change in the option value is summarized by the change in the fraction of workers that are not reallocated, $\widehat{\mu}_t^{njs,njs}$, and the variance of the taste shocks ν. A higher $\widehat{\mu}_t^{njs,njs}$ implies lower welfare gain, as workers in the cell have lower expected gains from switching out of the current cell. The aggregate welfare effects across all sectors and skills are computed using sector-skill employment shares in 1995 as weights.

In the aggregate, Taiwanese workers experienced a 2.40% welfare gain during the period 1995–2020, as a result of Taiwan's WTO accession. This welfare effect is large in comparison with the findings of the literature based on similar analytical frameworks for different economies (Caliendo, Dvorkin and Parro, 2019; Caliendo, Parro, Opromolla and Sforza, 2021). We attribute this difference to the fact that Taiwan is a small and open export-oriented economy, and hence stood to gain more from multilateral trade liberalization relative to larger economies.

We also calculate the welfare effects specific to each skill group, using sector-skill employment shares (conditional on each skill's employment share) in 1995 as weights. Table 4 indicates that the aggregate welfare gains for low-, middle, and high-skilled workers are 2.14%, 2.59%, and 2.69%, respectively, with the high-skilled workers experiencing the largest welfare gains. This suggests that Taiwan is relatively skill-abundant with respect to the majority of the other economies, and the high-skilled Taiwanese workers benefitted the most from trade liberalization via the Stolper-Samuelson mechanisms.

We further decompose the welfare effects by the broad sector categories of agriculture/manufacturing/service, where the welfare effects of workers are weighted by sector-skill employment shares and normalized by each broad sector's employment share in 1995. Consistent with the effects on employment shares discussed above, Taiwan's WTO entry led to the largest welfare gains for workers in manufacturing sectors (3.07%), followed by service sectors (2.22%), with the smallest gains being for workers in agriculture (1.76%).

5.4 Welfare Effects on other Economies

Figures 18–21 present the welfare effects of Taiwan's WTO entry on the other economies. Recall that in the setup, the dynamic of labor market transition is not explicitly studied for the other economies. This implies constant skill allocation and the same wage (welfare) effects across skill groups in the other economies, by the Cobb-Douglas production function. The wage (welfare) effects are nonetheless sector-specific in each of the other economies. In presenting the welfare effects, we aggregate the effects across sectors, using sectoral labor value-added in 1995 as weights.

Figure 18 indicates that all told, Taiwan's WTO accession led to general welfare gains across the 60 other economies (with the exception of six economies). The magnitudes of welfare changes are between -0.06% and 0.15%, which are in similar ranges of welfare effects reported by the quantitative trade literature for alternative episodes of trade liberalization. Among the economies that experienced welfare gains, Philippines, China, and Saudi Arabia benefitted the most. These countries were either closely linked to the Taiwanese economy in terms of geographical proximity (China and Philippines) or via the global value chain (Saudi Arabia, a major material supplier for the Petro-Chemicals industry). On the other hand, Southeast Asian economies tended to experience welfare losses: e.g., Cambodia, Malaysia, Thailand, and Vietnam. We now further look at the welfare effects by sectors (agriculture, manufacturing, and service sectors), which might shed light on the reasons behind the negative welfare effects.

Figures 19–21 indicate that Taiwan's WTO accession led to: (1) welfare gains in the agricultural sector; (2) welfare losses in the manufacturing sectors; and (3) welfare gains in the service sectors, across almost all the other economies. This is consistent with the previous discussion that Taiwan opened its agricultural market in exchange for foreign tariff reductions on its manufacturing exports. Hence, faced with increased competition from Taiwanese exports, the workers in the manufacturing sectors of the other economies experienced welfare losses. In contrast, workers in the service sectors in the other economies did not face direct competition from Taiwanese exports (recall that there was no labor reallocation in the other economies), and thus tended to experience welfare gains given the lower general price index (as a result of increased market competition in the manufacturing sectors).

In Figure 22, we present the welfare effects across all labor markets (22 sectors in 60 other economies) by means of histograms. The welfare effects are heterogeneous, and range from -0.4% to 0.3% across individual labor markets. In general, the distribution is skewed towards the positive range, although there are substantial numbers of labor markets that experienced welfare losses. We further plot the histograms by agriculture, manufacturing, and service sectors. Even though previously we observed almost uniform welfare losses for the aggregate manufacturing sectors, a non-negligible number of economy-sector pairs in manufacturing still benefitted. This suggests that competition from Taiwanese exports might have been concentrated in certain sectors such as MCEE and PCPM sectors. Hence, it is mainly workers in these sectors in the other economies that tended to suffer the most and experience welfare loss. For services, the distribution is skewed to the positive range, but there are also certain economy-sector pairs that experienced welfare losses. The service sectors that experienced welfare losses were likely sectors with strong input-output linkages with the manufacturing sectors that were in direct competition with Taiwan's exports. When Taiwan joined the WTO, and the production in those manufacturing sectors shrank in the other economies, the nominal wages in their key downstream service sectors declined as a result, and led to welfare loss for workers in these service sectors if the decline in nominal wages outpaced the drop in the overall price index.

6 Anatomy of the Effects of Taiwan's WTO Accession

6.1 The Role of China

In Section 2 on the stylized facts, we documented that China had a strong influence on the trade pattern of Taiwan during the period studied (1995–2007). China also entered the WTO at about the same time as Taiwan. In this section, we analyze three more counterfactual scenarios to assess the interaction of the Chinese economy with Taiwan in international markets. In the first scenario, we assess the effects of China's WTO accession on Taiwan's labor market dynamics: in the counterfactual, China's import tariffs and foreign tariffs on China's exports are rolled back to their levels in 1995. In the second scenario, we study the combined effects of WTO accession by both Taiwan and China: in the counterfactual, both Taiwan's and China's import tariffs and foreign tariffs on Taiwan's and China's exports are set to their levels in 1995. In the third scenario, we evaluate the effects of the tariff concessions between Taiwan and China during this period. In particular, in the counterfactual, only the bilateral tariff concessions between the two economies are rescinded and set to their levels in 1995. We summarize the findings in Tables 5 and 6. The full set of results can be found in the Online Appendix.

Table 5 reports the effects on the employment shares across sectors and skill types in the Taiwanese labor market under the alternative scenarios of tariff concessions introduced above. We repeat the simulation results for the benchmark case (WTO accession by Taiwan) in column (1) for the ease of comparison. Panel A (reporting effects at the aggregate sector level) indicates that WTO accession by Taiwan had larger negative effects on Taiwan's agriculture employment, and larger positive effects on manufacturing and service employment, in comparison with bilateral tariff concessions between only Taiwan and China, in column (4). This suggests that additional tariff concessions offered by Taiwan to the other economies and its additional access to the other economies' markets beyond China heightened the import competition in the agricultural sector, but increased its exports to the rest of the world in the manufacturing sector, which in turn benefitted the service sectors via the domestic input-output linkages. Note, however, that the negative effect on agriculture of Taiwan's WTO accession was driven almost entirely by import competition from foreign economies other than China, while the positive effects of WTO accession by Taiwan on manufacturing/service employment was largely driven by the increased access to the Chinese market in the manufacturing sector. As illustrated by Figure 7 and discussed under Stylized Fact 2(d), China was a negligible trading partner of Taiwan in the agricultural sector in terms of both exports and imports. Instead, Japan (on the export side) and the US, ASEAN, and the ROW (on the import side) were the main destination of Taiwan's agricultural exports, and respectively, the sources of imports. Thus, the drop in agricultural employment in Taiwan was mainly due to its tariff concessions with respect to these economies (and not due to those with respect to China).

Next, comparing the results in column (2) and column (4), we find that the effects of WTO accession by China were less positive for manufacturing/service employment in Taiwan than the scenario of bilateral tariff concessions between Taiwan and China. This indicates that the additional tariff concessions between China and the other economies in the scenario of WTO accession by China (relative to bilateral tariff concessions) increased the market competition that Taiwanese exports faced in the Chinese market from the other economies, and in the foreign markets from China, hence the smaller positive push to the manufacturing/service sectors in Taiwan. It is not clear why the effects of WTO accession by China were less negative (indeed they were positive) for agricultural employment in Taiwan than the scenario of bilateral concessions only. Likely, the general equilibrium positive income effect of increased openness in China led to increased imports in the agricultural sector, and that more than offset potential negative effects of trade diversion from Taiwan toward the other sources with its WTO accession (compared to bilateral concessions only).

Similarly, comparing column (1) for the scenario of WTO accession by Taiwan, and column (3) for the scenario of WTO accession by both Taiwan and China, we find the effects of the latter to be milder than the former. This is akin to the mechanisms discussed above. The additional tariff reductions between China and the other economies in column (3) compared to column (1) created an additional "competition effect" for Taiwanese exports in the third countries and in China's local market. This dampened the positive employment effects for manufacturing and services in Taiwan, although again China's multilateral tariff concessions appeared to have helped cushion the negative employment effects on agriculture in Taiwan.

Panel B of Table 5 presents the employment effects for key sectors that experienced the large employment changes identified in Section 5.2. The difference between scenarios in the employment effects on manufacturing (e.g., between 4.36% in column (1) and 3.68% in column (2)) can be almost entirely explained by those of "Computer, Electronics", "Basic & Fabricated Metals", and "Textiles, Leather, Footwear" combined. In particular, "Computer, Electronics" played a pivotal role. These findings reiterate the importance of key manufacturing sectors in determining the aggregate employment effects in the Taiwanese labor market. Among large service sectors, however, we do not observe significant variations across scenarios. This suggests that the effects on service employment were more diffused across sectors, in contrast to the concentration of employment effects in key manufacturing sectors. "Wholesale, Retail" was an exception. It stood out as one service sector that lost a significant portion of employment (−0.30% of the total population) in the scenario of bilateral tariff concessions, but fared much better (−0.24%) if Taiwan acceded to the WTO and did not rely solely on access to the Chinese market. The WTO accession by China did not exert much additional impact on this sector as well as on other service sectors, as indicated by comparing column (3) with column (1), except "Hotels, Restaurants", which experienced less positive employment gain with China's multilateral trade liberalization in addition.

Panel C of Table 5 reports the employment effects by skill type. The high-skilled workers experienced the largest positive employment effects, followed by middle-skilled workers, while the low-skilled workers experienced negative employment effects. This pattern holds across all four scenarios of tariff concessions studied. This reflects the general comparative advantage of Taiwan in skill-intensive sectors. The ranking of the quantitative effects across scenarios remains the same as highlighted above. That is, the effects on Taiwanese employment by skill type are stronger with Taiwan's WTO accession than bilateral tariff concessions between Taiwan and China only, which in turn are stronger than the effects of China's WTO accession. Combined WTO accession by Taiwan and China has weaker effects on the Taiwanese labor market than accession by Taiwan alone, but stronger effects than accession by China alone, consistent with the mechanisms discussed above.

Table 6 summarizes the welfare effects on Taiwanese workers by skill type and sector, under alternative scenarios of tariff concessions. The pattern of the welfare effects largely reflects the ranking of the employment effects across sectors and skill types discussed above. In particular, the welfare effects are stronger for high-skilled workers (than middle-skilled and low-skilled workers) and for manufacturing workers (than service and agricultural workers). Across skill types and aggregate sectors, the effects are most pronounced (and positive) in the scenario of WTO accession by Taiwan, followed by WTO accession by both, and then by accession of China alone. Similarly, the positive effects are stronger with WTO accession by Taiwan than its bilateral concessions with China, and further stronger than

WTO accession by China alone. The exception is again the agricultural sector, where workers could potentially benefit from China's further trade liberalization with the rest of the world.

Finally, we summarize the effects of these alternative scenarios on the welfare of the other economies. The figures for these other scenarios can be found in Online Appendix B. As discussed above, while there are quantitatively meaningful differences in the employment and welfare effects in Taiwan under different scenarios of tariff concessions, the effects are in similar ranges. This can be attributed to the fact that bilateral tariff concessions between Taiwan and China were present in all scenarios, and these bilateral tariff concessions played the most important role quantitatively in determining the labor market dynamics in Taiwan. In contrast, the quantum of the welfare effects for the rest of the world differed substantially across scenarios. In the aggregate, the welfare effects of China's WTO entry had much larger effects on the other economies (from -1% to $+0.7\%$), in comparison with Taiwan's WTO entry (where the majority of the welfare effects were smaller than 0.05%). Similarly, across economy-sector pairs, while the distribution of the welfare effects of Taiwan's WTO entry on the other economy-sector pairs ranges from -0.4% to 0.3% (cf. Figure 22), the distribution of the welfare effects of WTO accession by China on the rest of the world ranges from -3% to $+1.6\%$ at the economy-sector level. This basically reflects the much larger market size of China relative to Taiwan from the other economies' perspectives.

6.2 Skill-upgrade Mechanism

In this section, we demonstrate the relevance of the skill-upgrade mechanism in quantifying the employment effect of WTO accession by Taiwan. To do so, we generalize the model introduced in Section 3 to allow for time-varying sector-skill transition costs. This basically extends the expressions for the utility function and the sector-skill transition probability by $\left(\varrho_t^{njs,nki}\right)^{-\frac{1}{\nu}} \equiv \left(e^{\rho_t^{njs,nki}}\right)^{-\frac{1}{\nu}}$, where $\rho_t^{njs,nki}$ indicate the time-varying sector-skill transition costs. The sequential and counterfactual equilibrium conditions are otherwise identical to the benchmark presented in Section 3.7. Online Appendix C provides further details. With this extension, we conduct a counterfactual exercise where the cost of skill upgrading (from low to middle or from middle to high) is raised to a prohibitive level from 1996 onwards relative to 1995. Specifically, the sector-skill transition costs $\rho_t^{njs,nki}$ if involving skill upgrade are set to be 10-fold in 1996 onwards relative to the level in 1995 (before making the exponential transformation). This quantitative exercise effectively shuts down the mechanism of transition across skill types over time. We then use the equilibrium path of changes from this exercise as the baseline. Conditional on this baseline, we roll back Taiwan's tariffs on imports and foreign tariffs on Taiwan's exports to their levels in 1995. Hence, we obtain a baseline where skill upgrading is absent, but WTO accession is present; and a counterfactual economy where both skill upgrading and WTO accession are eliminated. We simulate both models from 1995 to 3000. The difference between the two simulations then measures the quantitative effect of WTO accession by Taiwan in an environment where skill upgrading is prohibitive. This is then compared to the effect of WTO accession by Taiwan where the skill-upgrade mechanism is present (as in Section 5).

Figure 23 illustrates the results of these quantitative exercises by aggregate sectors and skill groups, where the effects are calculated for the period of 1995–2020. We find that the employment effects of WTO accession in the presence of skill upgrading are in general much more pronounced than the scenario where skill upgrading is absent. This suggests the existence of strong complementarity between skill upgrading and tariff concessions by Taiwan during the period studied. The difference between the two scenarios is quantitatively large, thus highlighting the importance of the supply-side adjustment mechanism. Furthermore, the inclusion of the skill-upgrade mechanism is also pivotal to the qualitative findings of employment effects across sectors. In particular, WTO accession by Taiwan tends to increase high-/middle-skilled employment in both manufacturing and service sectors when the skill-upgrade mechanism is present. In contrast, when skill upgrading is prohibitive, WTO accession increases the employment of high-/middle-skilled workers only in the manufacturing sector and decreases skilled employment in the service sector. To understand these findings, note that when skill upgrading is an option, workers upgrade their skills in response to the larger demand for skills from the manufacturing sector as a result of WTO accession. In the process, the service sector also benefits from the input-output linkages and the larger pool of skilled labor. In contrast, when skill upgrading is prohibitive, the supply-side adjustment is eliminated, which rules out inflows of new skilled workers. In this case, the sectoral distribution of each skill type is entirely driven by within-skill-type reallocation of workers (subject to birth/death) since skill upgrading is prohibited. As a result, WTO accession results in reallocation of skilled workers from the agriculature/service sectors (and non-employment) toward the expanding manufacturing sectors.

Next, we further examine the employment effects by individual manufacturing sectors in Figure 24. Several patterns emerge. First, the gap between the two scenarios is proportionally very large for most of the manufacturing sectors. Without skill upgrading, most manufacturing sectors would experience very small increases in high-/middle-skilled employment. Second, the "Computer, Electronics" sector stands out in the sense that its skilled employment still increases substantially even when the skill-upgrade mechanism is eliminated. As suggested in the previous section, "Computer, Electronics" is the sector of comparative advantage in Taiwan. Thus, even when skill upgrading is inoperative, Taiwan's WTO accession still induces skilled labor to reallocate to the "Computer, Electronics" sector from the other non-manufacturing sectors. Third, because the difference in employment effects for the other manufacturing sectors (other than "Computer, Electronics") is particularly large, this implies that skill upgrading on the supply side helped increase skilled employment proportionally more in these sectors. In sum, skill upgrading on the supply side helped complement the pull factor for skilled labor on the demand side due to Taiwan's WTO accession and moderated the increased costs of skilled workers, such that manufacturing sectors across the board increased their employment of skilled workers.

The important role played by the skill-upgrade mechanism is closely linked to the finding above that bilateral tariff concessions with China accounted for the bulk of the effects of Taiwan's WTO accession, wherein Taiwan re-oriented its sectoral specializations and repositioned itself in the global value chain. These changes demanded higher skills relative to China (and much of the rest of the world). If the labor supply of each skill type were fixed, a standard Stolper-Samuelson argument would imply that wages for higher skills in Taiwan would increase. The large size of China implies that such increase in skill premiums in Taiwan would be sharp. However, the skill-upgrade mechanism allowed the supply side to respond to the increased demand for higher skills and helped mitigate the upward pressure on the skill premiums. As discussed, this increased supply of skilled labor spilled over into the service industries and other manufacturing industries. As a result, we observe significantly larger responses in employment following Taiwan's WTO accession.[12]

7 Conclusion

This paper studies the evolution of the Taiwanese labor markets (disaggregated by sectors and skills) during 1995–2007, a time when the Taiwanese import tariffs and other economies' tariffs against Taiwanese exports fell significantly due to Taiwan's accession to the GATT/WTO. We document a rich set of stylized facts on changes in tariffs, trade flows, and labor market dynamics of Taiwan during this period. We extend the CDP framework to allow for skill-upgrade mechanisms, and conduct quantitative analyses to examine the dynamic adjustments of Taiwanese workers' sector-skill choices in this period, due to Taiwan's WTO accession. The quantitative effects and qualitative patterns are compared with those of China's WTO accession alone, combined accession by both Taiwan and China, or mere

[12]We can also calculate the welfare effects of "WTO Accession by Taiwan (without the skill-upgrade mechanism)". The welfare effects for low-, middle-, and high-skilled workers are, respectively, around 0.06%, 0.40%, and 0.74%. This is in comparison with the benchmark effects (with the skill-upgrade mechanism) of 2.14%, 2.59%, and 2.69% reported in Section 5.3. Thus, a framework without the skill-upgrade mechanism leads to much more muted—yet much more unequal—welfare effects across workers of different skill types.

bilateral tariff concessions between the two economies. We summarize the main takeaways as follows.

First and foremost, we find that Taiwan's accession to the WTO explains much of the observed patterns of Taiwan's trade and labor-market outcomes during this period, demonstrating the important roles played by tariff concessions. In turn, much of the impacts can be attributed to the bilateral tariff concessions extended by Taiwan and China toward each other. This highlights the weight the Chinese economy has on the island. China's accession to the WTO (relative to bilateral concessions) or combined accession (relative to Taiwan's accession alone) introduced additional competition in third countries and in China's local market for Taiwanese exports, and moderated the impacts downward.

At the sector-skill level, the "star" manufacturing sectors (the MCEE in particular) basically drove the changes in trade and labor market patterns, and the effects spilled over to service sectors (mainly financial intermediation and other business services) through input-output linkages. The expanding sectors, the MCEE and service sectors, also were the sectors that propelled the skill upgrading seen in both the data and counterfactual analyses. As a result, the high-skilled workers and the star manufacturing/service sectors enjoyed the most welfare gains from Taiwan's trade liberalization during 1995–2007. This is in contrast with the low-skilled workers and the agricultural sector, which suffered from increased import competition, lost employment shares, and enjoyed the smallest gains.

We also evaluate the WTO accession effect in a counterfactual baseline economy where the skill-upgrade mechanism is eliminated. Compared with the benchmark case where the mechanism is present, the exercise demonstrates the importance of the supply-side adjustment that accommodated the increased demand for skilled labor due to the trade shocks experienced by Taiwan during this period. Without the skill-upgrade mechanism, the quantitative magnitudes of the employment effects and changes in the production/trade volumes would have been substantially muted. The positive employment/trade effects would in turn have been concentrated only in a few star sectors. In sum, the skill-upgrade mechanism allowed the much needed structural transformation of the economy during the period of its WTO accession, and allowed the welfare gains to spill over to a broader spectrum of the economy.

The benchmark analytical framework can potentially be extended methodologically to address alternative policy questions of interest. First, as shown in Online Appendix C, the dynamic hat algebra can be generalized to allow for time-varying sector-skill transition costs. This alternative framework can be used to accommodate changes to the sector-skill transition costs in a counterfactual such as that analyzed in Section 6.2. In general, it can also be used to study the effects of supply-side shocks such as education reforms that change the costs of skill upgrading. Second, in the benchmark, jobs and skills are paired perfectly, such that a worker with a given skill level always does a job that requires exactly the skill level. Therefore, a high-skilled worker is always assigned to an occupation that requires a high skill level. In Online Appendix D, we generalize the model by allowing workers to undertake jobs with lower skill requirement than the worker's current skill level. The empirical implementation of the alternative framework, however, requires additional data and measurement of skill requirements for occupations in each sector and the mass of workers engaged in the corresponding occupations and sectors, in addition to the education attainments of workers and their sectors of employment. We leave these potential analyses for future research.

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A Theoretical Proofs

Proofs for Proposition 1. Replacing $\sum_{\text{o}=1}^{N} \frac{\pi_t^{oj,nj} X_t^{oj}}{1+\tau_t^{oj,nj}}$ in (11) with (10) yields (17). Note that it holds for all $s \in \{1,2,3\}$. Applying the definition of $\dot{x}_{t+1}$ to (6) yields (12). Applying the definition of $\dot{x}_{t+1}$ to (7) and using (8) yields:

$$\begin{aligned}
\dot{P}_{t+1}^{nj} &= \left[\frac{\sum_o \left(\kappa_{t+1}^{nj,oj} x_{t+1}^{oj}\right)^{-\theta^j} \left(A_{t+1}^{oj}\right)^{\gamma^{oj}\theta^j}}{\sum_o \left(\kappa_t^{nj,oj} x_t^{oj}\right)^{-\theta^j} \left(A_t^{oj}\right)^{\gamma^{oj}\theta^j}} \right]^{-\frac{1}{\theta^j}} \\
&= \left[\sum_o \frac{\left(\kappa_{t+1}^{nj,oj} x_{t+1}^{oj}\right)^{-\theta^j} \left(A_{t+1}^{oj}\right)^{\gamma^{oj}\theta^j}}{\sum_{\text{o}} \left(\kappa_t^{nj,\text{o}j} x_t^{\text{o}j}\right)^{-\theta^j} \left(A_t^{\text{o}j}\right)^{\gamma^{\text{o}j}\theta^j}} \right]^{-\frac{1}{\theta^j}} \\
&= \left[\sum_o \left(\dot{\kappa}_{t+1}^{nj,oj} \dot{x}_{t+1}^{oj}\right)^{-\theta^j} \left(\dot{A}_{t+1}^{oj}\right)^{\gamma^{oj}\theta^j} \pi_t^{nj,oj} \right]^{-\frac{1}{\theta^j}},
\end{aligned}$$

which is (13). Combining the definition of $\dot{x}_{t+1}$ with (8) yields:

$$\begin{aligned}
\dot{\pi}_{t+1}^{nj,oj} &= \left(\dot{\kappa}_{t+1}^{nj,oj} \dot{x}_{t+1}^{oj}\right)^{-\theta^j} \left(\dot{A}_{t+1}^{oj}\right)^{\gamma^{oj}\theta^j} \frac{\sum_{\text{o}} \left(\kappa_t^{nj,\text{o}j} x_t^{\text{o}j}\right)^{-\theta^j} \left(A_t^{\text{o}j}\right)^{\gamma^{\text{o}j}\theta^j}}{\sum_{\text{o}} \left(\kappa_{t+1}^{nj,\text{o}j} x_{t+1}^{\text{o}j}\right)^{-\theta^j} \left(A_{t+1}^{\text{o}j}\right)^{\gamma^{\text{o}j}\theta^j}} \\
&= \left(\dot{\kappa}_{t+1}^{nj,oj} \dot{x}_{t+1}^{oj}\right)^{-\theta^j} \left(\dot{A}_{t+1}^{oj}\right)^{\gamma^{oj}\theta^j} \left[\frac{\sum_{\text{o}} \left(\kappa_{t+1}^{nj,\text{o}j} x_{t+1}^{\text{o}j}\right)^{-\theta^j} \left(A_{t+1}^{\text{o}j}\right)^{\gamma^{\text{o}j}\theta^j}}{\sum_{\text{o}} \left(\kappa_t^{nj,\text{o}j} x_t^{\text{o}j}\right)^{-\theta^j} \left(A_t^{\text{o}j}\right)^{\gamma^{\text{o}j}\theta^j}} \right]^{-1},
\end{aligned}$$

which yields (14) by using (13).

For (15), we simply use (9) and replace $w_{t+1}^{nks} L_{t+1}^{nks}$ with $\dot{w}_{t+1}^{nks} \dot{L}_{t+1}^{nks} w_t^{nks} L_t^{nks}$. Rearranging (10) for each s and replacing $w_{t+1}^{nks} L_{t+1}^{nks}$ with $\dot{w}_{t+1}^{nks} \dot{L}_{t+1}^{nks} w_t^{nks} L_t^{nks}$ gives us (16). □

Proofs for Proposition 2. Equations (20) and (21) simply restate the laws of motion as in (4) and (5). We start from time $t = -1$ and $t + 1 = 0$. Applying the definitions of $\dot{x}_{t+1}$ and

u to (3) yields the following:

$$
\begin{aligned}
\dot{\mu}_0^{njs,nki} &= e^{\frac{\beta\delta\left(V_1^{nki}-V_0^{nki}\right)}{\nu}} \frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_1^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}} \\
&= e^{\frac{\beta\delta\left(V_1^{nki}-V_0^{nki}\right)}{\nu}} \frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_1^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}} \frac{e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}} \\
&= \frac{e^{\frac{\beta\delta\left(V_1^{nki}-V_0^{nki}\right)}{\nu}}}{\frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_1^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}} \frac{e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}} \\
&= \frac{e^{\frac{\beta\delta\left(V_1^{nki}-V_0^{nki}\right)}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} \frac{e^{\frac{\beta\delta\left(V_1^{n\text{KI}}-V_0^{n\text{KI}}\right)}{\nu}} e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_0^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}} \\
&= \frac{\left(\dot{u}_1^{nki}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} \left(\dot{u}_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} \mu_{-1}^{njs,n\text{KI}}},
\end{aligned}
$$

which is (18) at $t=-1$. For a general t, we simply change the timing subscript. The above also implies that:

$$
\frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_{t+1}^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_{t+2}^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}} = \left[\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} \left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} \mu_t^{njs,n\text{KI}}\right]^{-1}.
$$

Using (2) and the above equation, we have for $t=0$ and $t+1=1$:

$$
\begin{aligned}
V_1^{njs} - V_0^{njs} &= \ln \dot{\omega}_1^{njs} + \nu \ln \frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_2^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} e^{\frac{\beta\delta V_1^{n\text{KI}}-\rho^{njs,n\text{KI}}}{\nu}}} \\
&= \ln \dot{\omega}_1^{njs} + \nu \ln \sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3} \left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} \mu_0^{njs,n\text{KI}}.
\end{aligned}
$$

Applying the definition of u to the above equation yields (19) for $t=0$. For general t, we simply replace the timing subscripts. □

Proofs for Proposition 3. Equations (20) and (21) are simply the counterfactual versions of the laws of motion (4) and (5). Equations (26), (28), and (31) are obtained by simply applying the definition of $\widehat{y}_{t+1}$ to (12), (14), and (17), respectively. To derive (27), first note that we can write the counterfactual version of (13) as:

$$\begin{aligned}
\dot{P}'^{nj}_{t+1} &= \left[\sum_o \left(\dot{\kappa}'^{nj,oj}_{t+1}\dot{x}'^{oj}_{t+1}\right)^{-\theta^j}\left(\dot{A}'^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\pi'^{nj,oj}_t\right]^{-\frac{1}{\theta^j}} \\
&= \left[\sum_o \left(\widehat{\kappa}^{nj,oj}_{t+1}\widehat{x}^{oj}_{t+1}\right)^{-\theta^j}\left(\widehat{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\pi'^{nj,oj}_t\left(\dot{\kappa}^{nj,oj}_{t+1}\dot{x}^{oj}_{t+1}\right)^{-\theta^j}\left(\dot{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\right]^{-\frac{1}{\theta^j}} \\
&= \left[\sum_o \left(\widehat{\kappa}^{nj,oj}_{t+1}\widehat{x}^{oj}_{t+1}\right)^{-\theta^j}\left(\widehat{A}^{oj}_{t+1}\right)^{\gamma^{oj}\theta^j}\pi'^{nj,oj}_t\left(\dot{P}^{nj}_{t+1}\right)^{-\theta^j}\dot{\pi}^{nj,oj}_{t+1}\right]^{-\frac{1}{\theta^j}},
\end{aligned}$$

where we use (14) in the last step. Then, we can obtain (27) by rearranging the terms. For (29), we simply use the counterfactual version of (15) and replace $\dot{w}'^{nks}_{t+1}\dot{L}'^{nks}_{t+1}w'^{nks}_t L'^{nks}_t$ with $\widehat{w}^{nks}_{t+1}\widehat{L}^{nks}_{t+1}w'^{nks}_t L'^{nks}_t\dot{w}^{nks}_{t+1}\dot{L}^{nks}_{t+1}$. Using the counterfactual version of (16) for each s and rearranging yields (30). To obtain (22), using the definition of $\widehat{y}_{t+1}$ and (18), we have:

$$\begin{aligned}
\widehat{\mu}^{njs,nki}_{t+1} &= \left(\widehat{u}^{nki}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\frac{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(\dot{u}^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu^{njs,n\mathrm{KI}}_t}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(\dot{u}'^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu'^{njs,n\mathrm{KI}}_t} \\
&= \frac{\left(\widehat{u}^{nki}_{t+2}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\frac{\left(\dot{u}'^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu'^{njs,n\mathrm{KI}}_t}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(\dot{u}^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu^{njs,n\mathrm{KI}}_t}} \\
&= \frac{\left(\widehat{u}^{nki}_{t+2}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\frac{\left(\dot{u}^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\left(\dot{u}'^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu'^{njs,n\mathrm{KI}}_t\left(\dot{u}^{n\mathrm{KI}}_{t+2}\right)^{-\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(\dot{u}^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}\mu^{njs,n\mathrm{KI}}_t}}.
\end{aligned}$$

Applying the actual version of (18) to the denominator yields:

$$\widehat{\mu}^{njs,nki}_{t+1} = \frac{\left(\widehat{u}^{nki}_{t+2}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\dot{\mu}^{njs,n\mathrm{KI}}_{t+1}\mu'^{njs,n\mathrm{KI}}_t\left(\widehat{u}^{n\mathrm{KI}}_{t+2}\right)^{\frac{\beta\delta}{\nu}}},$$

which is exactly (22). Finally, for (23), we use (19) and the definition of $\widehat{y}_{t+1}$ to obtain:

$$\begin{aligned}\widehat{u}_{t+1}^{njs} =& \widehat{\omega}_{t+1}^{njs}\left[\frac{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_t^{\prime njs,n\text{KI}}\left(\dot{u}_{t+2}^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_t^{njs,n\text{KI}}\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right]^{\nu} \\ =& \widehat{\omega}_{t+1}^{njs}\left[\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\mu_t^{njs,n\text{KI}}\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_t^{njs,n\text{KI}}\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\frac{\mu_t^{\prime njs,n\text{KI}}}{\mu_t^{njs,n\text{KI}}}\frac{\left(\dot{u}_{t+2}^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right]^{\nu}.\end{aligned}$$

Plugging the actual version of (18) into the above equation yields:

$$\begin{aligned}\widehat{u}_{t+1}^{njs} =& \widehat{\omega}_{t+1}^{njs}\left[\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_{t+1}^{njs,n\text{KI}}\frac{\mu_t^{\prime njs,n\text{KI}}}{\mu_t^{njs,n\text{KI}}}\frac{\left(\dot{u}_{t+2}^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right]^{\nu} \\ =& \widehat{\omega}_{t+1}^{njs}\left[\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\mu_{t+1}^{njs,n\text{KI}}}{\mu_t^{njs,n\text{KI}}}\mu_t^{\prime njs,n\text{KI}}\frac{\left(\dot{u}_{t+2}^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(\dot{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right]^{\nu} \\ =& \widehat{\omega}_{t+1}^{njs}\left[\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\dot{\mu}_{t+1}^{njs,n\text{KI}}\mu_t^{\prime njs,n\text{KI}}\left(\widehat{u}_{t+2}^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}\right]^{\nu},\end{aligned}$$

which is exactly (23).

The above equations handle the change of endogenous variables between t and $t+1$ in general. However, we need to solve for $\mu_1^{\prime njs,nki}$ and $\widehat{u}_1^{njs}$ differently. This is because the path of counterfactual fundamentals is observed only at $t=1$ and the decisions made at $t=0$ by agents are exogenously given. More precisely, the allocations at $t=0$ are such that $\widehat{u}_0^{njs}=1$, $\mu_0^{\prime njs,nki}=\mu_0^{njs,nki}$, and $L_1^{\prime njs}=L_1^{njs}$. To start, given (2) and the definition of u, we have:

$$\begin{aligned}u_0^{njs} &= \omega_0^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}\right)^{\nu}, \\ u_1^{\prime njs} &= \omega_1^{\prime njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\left(u_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}\right)^{\nu}.\end{aligned}$$

Because there is no counterfactual at $t=0$, it follows that $u_0^{njs}=u_0^{\prime njs}$ and $\omega_0^{njs}=\omega_0^{\prime njs}$; thus $\dot{u}_1^{\prime njs}=\frac{u_1^{\prime njs}}{u_0^{njs}}$ and $\dot{\omega}_1^{\prime njs}=\frac{\omega_1^{\prime njs}}{\omega_0^{njs}}$. Define $\phi_1^{n\text{KI}}\equiv\left(\frac{u_1^{n\text{KI}}}{u_1^{\prime n\text{KI}}}\right)^{\frac{\beta\delta}{\nu}}$; we can combine the above observations to obtain:

$$\dot{u}_1^{\prime njs} = \frac{u_1^{\prime njs}}{u_0^{njs}} = \dot{\omega}_1^{\prime njs} \left(\frac{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \left(u_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}} \right)^{\nu}$$

$$= \dot{\omega}_1^{\prime njs} \left(\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \frac{\left(u_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \phi_1^{n\text{KI}} \left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}} \right)^{\nu}.$$

Turn to $\mu_0^{njs,nki}$. Given (3) and the definition of u and ϕ, we have:

$$\mu_0^{njs,nki} = \frac{\left(u_1^{nki}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,nki}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}$$

$$= \frac{\phi_1^{nki} \left(u_1^{\prime nki}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,nki}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \phi_1^{n\text{KI}} \left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}.$$

Combining $\mu_0^{njs,nki}$ and $\dot{u}_1^{njs}$ yields:

$$\dot{u}_1^{\prime njs} = \dot{\omega}_1^{\prime njs} \left(\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \frac{\frac{\phi_1^{n\text{KI}}}{\left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}} \frac{\left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\phi_1^{n\text{KI}}} \left(u_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \phi_1^{n\text{KI}} \left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}} \right)^{\nu}$$

$$= \dot{\omega}_1^{\prime njs} \left(\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \frac{\phi_1^{n\text{KI}} \left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \phi_1^{n\text{KI}} \left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}} \frac{\left(u_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_1^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}} \frac{1}{\phi_1^{n\text{KI}}} \right)^{\nu}$$

$$= \dot{\omega}_1^{\prime njs} \left(\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \frac{\mu_0^{njs,n\text{KI}}}{\phi_1^{n\text{KI}}} \left(\dot{u}_2^{\prime n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} \right)^{\nu}.$$

Note that at $t = 0$, (19) gives us:

$$\dot{u}_1^{njs} = \dot{\omega}_1^{njs} \left[\sum_{\text{K}=0}^{J} \sum_{\text{I}\geq s}^{3} \mu_0^{njs,n\text{KI}} \left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}} \right]^{\nu}.$$

Using the definition of $\mu_0^{njs,n\text{KI}}$, we therefore have:

$$
\begin{aligned}
\widehat{u}_1^{njs} &= \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\frac{\mu_0^{njs,n\text{KI}}}{\phi_1^{n\text{KI}}}\left(\dot{u}_2'^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_0^{njs,n\text{KI}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right)^{\nu} \\
&= \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\phi_1^{n\text{KI}}}\frac{1}{\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\frac{\mu_0^{njs,n\text{KI}}\left(\dot{u}_2'^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_0^{njs,n\text{KI}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right)^{\nu} \\
&= \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\left(\widehat{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\phi_1^{n\text{KI}}}\frac{\mu_0^{njs,n\text{KI}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\mu_0^{njs,n\text{KI}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right)^{\nu} \\
&= \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\left(\widehat{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\phi_1^{n\text{KI}}}\frac{\frac{\left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\left(u_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}\left(\dot{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}\right) \\
&= \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\frac{\left(\widehat{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\phi_1^{n\text{KI}}}\frac{\left(u_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}{\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\left(u_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}e^{-\frac{\rho^{njs,n\text{KI}}}{\nu}}}\right)^{\nu}.
\end{aligned}
$$

Plugging the definition of $\mu_1^{njs,nki}$ into the above equation yields:

$$\widehat{u}_1^{njs} = \widehat{\omega}_1^{njs}\left(\sum_{\text{K}=0}^{J}\sum_{\text{I}\geq s}^{3}\upsilon_0^{njs,n\text{KI}}\left(\widehat{u}_2^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}}\right)^{\nu},$$

where $\upsilon_0^{njs,n\text{KI}} \equiv \frac{\mu_1^{njs,n\text{KI}}}{\phi_1^{n\text{KI}}}$. Because $u_0^{njs} = u_0'^{njs}$, it follows that:

$$\upsilon_0^{njs,n\text{KI}} = \frac{\mu_1^{njs,n\text{KI}}}{\phi_1^{n\text{KI}}} = \mu_1^{njs,n\text{KI}}\left(\frac{u_1'^{n\text{KI}}}{u_1^{n\text{KI}}}\right)^{\frac{\beta\delta}{\nu}} = \mu_1^{njs,n\text{KI}}\left(\widehat{u}_1^{n\text{KI}}\right)^{\frac{\beta\delta}{\nu}},$$

which leads to the expression used in (38).

Next, we examine the sector-skill transition probability. Given (3), we have:

$$
\begin{aligned}
\frac{\mu_1^{\prime njs,nki}}{\mu_1^{njs,nki}} &= \frac{\dfrac{\left(u_2^{\prime nki}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,nki}}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(u_2^{\prime n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\mathrm{KI}}}{\nu}}}}{\dfrac{\left(u_2^{nki}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,nki}}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\left(u_2^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}} e^{-\frac{\rho^{njs,n\mathrm{KI}}}{\nu}}}} \\
&= \frac{\dfrac{\left(u_2^{\prime nki}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_2^{nki}\right)^{\frac{\beta\delta}{\nu}}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_1^{njs,n\mathrm{KI}}\dfrac{\left(u_2^{\prime n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_2^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}} \\
&= \frac{\left(\widehat{u}_2^{nki}\right)^{\frac{\beta\delta}{\nu}}\dfrac{\left(u_1^{\prime nki}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_1^{nki}\right)^{\frac{\beta\delta}{\nu}}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_1^{njs,n\mathrm{KI}}\left(\widehat{u}_2^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}\dfrac{\left(u_1^{\prime n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_1^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}} \\
\Rightarrow \mu_1^{\prime njs,nki} &= \frac{\mu_1^{njs,nki}\left(\widehat{u}_2^{nki}\right)^{\frac{\beta\delta}{\nu}}\dfrac{\left(u_1^{\prime nki}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_1^{nki}\right)^{\frac{\beta\delta}{\nu}}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_1^{njs,n\mathrm{KI}}\left(\widehat{u}_2^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}\dfrac{\left(u_1^{\prime n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}{\left(u_1^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}}}
\end{aligned}
$$

Recall that $\upsilon_0^{njs,n\mathrm{KI}} = \mu_1^{njs,n\mathrm{KI}}\left(\widehat{u}_1^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}$; we thus have:

$$
\mu_1^{\prime njs,nki} = \frac{\upsilon_0^{njs,nki}\left(\widehat{u}_2^{nki}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\upsilon_0^{njs,n\mathrm{KI}}\left(\widehat{u}_2^{n\mathrm{KI}}\right)^{\frac{\beta\delta}{\nu}}},
$$

which corresponds to the expression used in (36). □

B Data

B.1 Sector-Skill Movement in Taiwan

We construct the transition statistics across sector-skill combinations for the Taiwanese labor market in the period 1995–2007, based on the *Manpower Utilization Quasi-longitudinal Data* from the Survey Research Data Archive (SRDA), Academia Sinica, Taiwan. The dataset is further a compilation of the data gleaned from the *Manpower Utilization Survey* conducted by the Taiwanese Directorate General of Budget, Accounting and Statistics (DGBAS). Given the original surveys (in May) of two consecutive years, the SRDA performed matching of observations across years based on household IDs and individual characteristics. About 50% of the individuals remain in the survey sample across every two consecutive years. Hence, the compiled survey sample by the SRDA is quasi-longitudinal. We combine the SRDA data for 1995–1996, 1996–1997, ..., and 2006–2007, to obtain the transition matrix for the whole period.

The *Manpower Utilization Survey* samples all members above age 15 in the surveyed households, and provides detailed information on the education attainment, sector employed, and sampling weight of each observation. The quasi-longitudinal data thus allow us to trace the above characteristics for each individual surveyed across every two consecutive years. The quasi-longitudinal dataset contains approximately 25000 observations (individuals) in each two-year cycle.

We characterize the skill level of an individual by his/her education attainment. The education attainment in the data is defined by the highest level reached, which includes illiteracy, self-educated, primary, junior high, senior high and vocational, and college (bachelor, master and doctorate degrees). Because primary and junior high education is compulsory in Taiwan, we group these two levels together with illiteracy and self-educated as low-skill attainment. We label the senior high and vocational diplomas as middle-skill attainment, and college degrees as high-skill attainment.

We screen the observations and classify them into "not-in-our-sample" (NIOS), "not-in-labor-force" (NILF), unemployed, and employed as follows.

(1) Check the survey question "work_t". Classify as "not-in-our-sample" (NIOS) the following respondents who:

  (1a) Reported 9, 10, and 11 before 2007. This includes "Old (65+) and Disabled", "Military Personnel and Jailed", and "Others".

  (1b) Reported 9, 10, 11, 12, and 13 after 2007. This includes "Old (65+) and Disabled", "Retired", "Major Illness", "Military Personnel, Prisoners, and Missing Population", and "Others".

(2) Place "full time students who have never worked before (except for graduate students)" into NIOS. These are respondents who: Reported 7 (students) to the survey question "work_t", and reported less than or equal to 22 to the survey question "age_t", where age 22 is the typical age when a university student obtains a bachelor's degree in Taiwan. The above steps give us: Population 15+ = NIOS + SP, where SP = Labor Force + Not-in-Labor-Force.

(3) For observations in SP, check the survey question "primaryworker_t". Classify the respondents as unemployed (unemp) if their response to the question is not "NA". The rationale for using this question to identify unemployment is because of the questionnaire design. This question is the follow-up question after the main question "How long have you been searching for a job, or waiting to return to work, while being jobless". Therefore, the sub-question "primaryworker_t" is answered specifically by unemployed respondents. This is also the official way that DGBAS identifies the unemployed.

(4) For remaining observations in SP, check "workstus_t". Classify respondents as "not-in-labor-force" (NILF) if the response is "NA". Also classify respondents as NILF if the response to "workstus_t" is 5 (unpaid home worker) and the response to "workhour_t" (as full-time) and "a8_1b_t" (as part-time) are below 15 hours.

(5) The remaining respondents are classified as employed. Use the survey question "indu_t" to identify the sector of employment.

We drop from the study the NIOS observations (mainly those above age 65, non-civilians, and those reporting to be students and with age below 22), because they do not reflect the demographic group that makes the sector-skill switching decisions, the main concern of the model. We use the age of 22 as the cutoff to identify (and keep in the study as part of the NILF) those students who have potential to enter the labor force (postgraduate students) or those who return from the labor force to study.[13] We then combine the NILF and the unemployed as one category under "non-employment". These are individuals who could potentially choose to switch to sectors of employment. We harmonize the Taiwanese sector classification (ROC SIC) used by the DGBAS with ISIC Rev 3. The concordance is provided in Table A.1. The quasi-longitudinal data by tracking individuals in every two consecutive years allow us to construct the transition matrix of sector-skill movement at annual frequency. We weight each observation by the sampling weight variable (attached to each observation).

B.2 Tariffs

The tariff data were downloaded from the World Integrated Trade Solution (WITS) database at the HS 6-digit level for the years 1995–2007. In particular, we select the effectively applied Ad Valorem Equivalent (AVE) tariff rates. We then compute the weighted average tariff rates for the list of sectors and countries reported in our analysis, using the WITS trade value as

[13]Theoretically, we could have kept the respondents who are students below age 22 and had worked in the past. However, the questionnaire design does not allow us to identify this group of respondents.

weights. If the tariff rate for an economy-sector observation is missing for a particular year, we fill in the missing value by using the tariff rate in the subsequent year. If the value in the subsequent year is also not available, we fill in the missing value using the previous year.

B.3 Trade Flows

The trade data are taken from the OECD TiVA ICIO Tables (2016 edition). We aggregate the intermediates trade, the final goods trade, and the discrepancy term to obtain a total trade flow measure at the economy-sector level. The discrepancy term is reported at origin economy-sector to the destination economy level. We divide this term equally among destination sectors of each destination economy.

B.4 Share of Value Added and Input Shares

The data on value added, gross output, and input-output linkages are from the same source as the trade data. The share of value added is computed as the ratio of value added in gross output based on the initial values in 1995. The intermediate input shares are constructed as the share of intermediate trade flow at the origin-destination sector level in gross output for each economy in 1995.

B.5 Share of Labor Compensation in Value Added

The share of labor compensation in value added in 1995 is taken from the database provided by Karabarbounis and Neiman (2014). In particular, we use the variable "TLS", which is the total labor share (compensation of employees divided by GDP), because the "CLS" variable, which measures the corporate labor share, is not available for our main economy of interest, Taiwan. For the economies in our study that are not included in Karabarbounis and Neiman (2014), we use the mean labor shares across the economies available from the Karabarbounis-Neiman dataset.

B.6 Share of Labor Compensation by Skill Group

Our model also requires data on the share of labor compensation by skill group. Ideally, we would want to use the TiVA ICIO database, the same source as for the value added. However, these statistics are not available in TiVA. Thus, we collect them from the World Input-Output (WIOD) Database Socioeconomic Account. The variables that we use are "LABHS", "LABMS", and "LABLS", which are shares of labor compensation to high/middle/low-skilled labor in total labor compensation. We use their values in 1995 at the economy-sector-skill level in the analysis. For economies in our study that are not covered individually by WIOD, we proxy their shares using the average of the 40 economies available from WIOD.

B.7 Mortality Rate

We obtain the information on Taiwanese mortality rate by using the statistics reported by the Taiwanese National Development Council.[14] In particular, we compute the time-series average over the years 1995–2007, which gives a mortality rate of 0.6%.

B.8 Economy and Sector Grouping

We organize our list of economies and sectors based on the TiVA ICIO Tables (2016 edition), which include 64 economies (63 individual economies and a Rest-of-World entity) and 34 industries. Due to data constraints/discrepancies in terms of classifications and coverage for tariffs, trade, and labor market data, we use a more aggregated grouping of economies and sectors.

First, we combine Belgium and Luxembourg as an entity, and merge Singapore and Hong Kong into the ROW. This leads to a set of 61 economies (60 individual economies and a ROW). In particular, the 61 economies are Argentina, Australia, Austria, Belgium-Luxembourg, Bulgaria, Brazil, Brunei, Canada, Switzerland, Chile, China, Colombia, Costa, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Indonesia, India, Ireland, Iceland, Israel, Italy, Japan, Cambodia, South Korea, Lithuania, Latvia, Morocco, Mexico, Malta, Malaysia, Netherlands, Norway, New Zealand, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Slovakia, Slovenia, Sweden, Taiwan, Thailand, Tunisia, Turkey, United States, Vietnam, South Africa, and a residual Rest-of-World.

We then combine 34 industries into 22 sectors. The concordance is documented in Table A.1. In particular, we combine c01t05 and c10t14; c20 and c21t22; c23 and c24; and c71 and c73t74. The sets of 61 economies and 22 sectors are used in our quantitative analyses.

For reporting of the stylized facts, we use larger groupings of economies and sectors to reduce the dimensionality in the figures. The trade flows are aggregated into major economies and regions in the world, including ASEAN+3, China, European Union, Japan, Korea, Latin America, Taiwan, United States, and a residual Rest-of-World. The group ASEAN+3 includes TiVA economies that were ASEAN members in 2007, in addition to three Indo-Pacific economies (India, Australia and New Zealand). European Union includes TiVA economies that were members of the EU in 2007. We further combine the 22 sectors

[14] https://pop-proj.ndc.gov.tw/chart.aspx?c=1&uid=61&pid=60.

into 12 groups. Table A.1's footnote provides the details of the sub-sectors included in each group.

B.9 Dispersion of Productivity

The trade elasticities at the sector level are taken from Caliendo and Parro (2015, Table A2, Column 1). When a manufacturing sector in our classification corresponds to multiple manufacturing sectors in Caliendo and Parro (2015), we take the simple average of the elasticities of the matched sectors. We drop the extreme elasticity estimates of Caliendo and Parro (2015) for mining and quarrying, wood, and petroleum, before calculating the elasticity for each of the 11 aggregate manufacturing sectors. We adopt a value of 10 for the service sector's productivity dispersion parameter, basically assuming that trade in services is more sensitive to trade costs than trade in agriculture and manufactures.

The summary statistics of key variables/parameters are provided in Table A.2.

C Implementation Algorithm

C.1 General Description

We simulate the baseline economy as follows. First, we compute the initial allocations for 1995, in which we discipline the portfolio shares to match the observed trade imbalances, using the temporary equilibrium conditions. The baseline economy for the period 1996–2007 corresponds to the allocations observed in data and reflects the actual time-varying fundamentals. We then take the allocations in 2007 and compute the path of the baseline allocations forward with constant fundamentals until 3000. Hereafter, we refer to the initial data period (1995), the data end period (2007), and the simulation terminal period, in the model time as 0, $\overline{T}$, and T, respectively.

We construct the counterfactuals, given the counterfactual sequence of changes in fundamentals $\{\widehat{\Theta}_t\}_{t=1}^{T}$ as follows. In the case of Taiwan's accession to the WTO, the counterfactual world corresponds to one where the tariffs levied on Taiwan's imports and exports remained at their levels in 1995. This is equivalent to setting $(1+\dot{\tau}_t^{nj,oj})' = 1$ for trading relationships that involve Taiwan as an origin or destination. In particular, given the actual evolution of tariffs, we construct the counterfactual shocks as $(\widehat{1+\tau_t^{nj,oj}}) \equiv (1+\dot{\tau}_t^{nj,oj})'/(1+\dot{\tau}_t^{nj,oj}) = 1/(1+\dot{\tau}_t^{nj,oj})$, where either n or o corresponds to Taiwan. Given the counterfactual shocks, we then use the dynamic hat algebra to compute the counterfactual changes in allocations over time for the period of simulations.

C.2 Detailed Steps for Computing Initial Year Allocation

To compute the initial year allocation, we take the data $(L_0^{njs}, \mu_{-1}^{njs,nki}, \tilde{\pi}_0^{nj,oj}, \tilde{w}_0^{njs}, \tilde{X}_0^{nj})$ in 1995 as given and discipline the portfolio share to match the observed trade imbalances, using the temporary equilibrium conditions. Following this, we obtain an updated set of equilibrium values $(\tilde{\tilde{\pi}}_0^{nj,oj}, \tilde{\tilde{w}}_0^{njs}, \tilde{\tilde{X}}_0^{nj})$ consistent with the model. In sum, the initial year allocation is set at $(L_0^{njs}, \mu_{-1}^{njs,nki}, \pi_0^{nj,oj}, w_0^{njs}, X_0^{nj}) = (L_0^{njs}, \mu_{-1}^{njs,nki}, \tilde{\tilde{\pi}}_0^{nj,oj}, \tilde{\tilde{w}}_0^{njs}, \tilde{\tilde{X}}_0^{nj})$.

C.3 Detailed Steps for Computing Baseline Allocation

We simulate the baseline path for 1996–2007 as follows. First, given the initial labor allocation L_0^{njs}, the path of transition probability $\{\mu_t^{njs,nki}\}$, and the survival rate δ, we compute the path of labor allocation L_t^{njs} using the laws of motion in (20)–(21). Given the path of labor allocation L_t^{njs} for 1996–2007 (model time $t = 1$ to $t = \overline{T}$), we then compute the path of changes in labor allocation $\dot{L}_t^{njs}$. This, together with $\{\tilde{\pi}_t^{nj,oj}, \tilde{w}_t^{njs} L_t^{njs}, \tilde{X}_t^{nj}\}$ imputed from the data for 1996–2007, are used to generate $\{\dot{\pi}_t^{nj,oj}, \dot{w}_t^{njs}, \dot{X}_t^{nj}\}$ consistent with the temporary equilibrium conditions.

Next, we compute the baseline economy from 2007 onwards with constant fundamentals. We extract the variables in 2007, $\{L_{\overline{T}}^{njs}, \mu_{\overline{T}-1}^{njs,nki}, \pi_{\overline{T}}^{nj,oj}, X_{\overline{T}}^{nj}, \tau_{\overline{T}}^{nj,oj}\}$ and solve for the sequential competitive equilibrium with constant fundamentals by employing the following algorithm, which is similar to the implementation in CDP:

1. Initialize the system at $t = \overline{T}$ with a guess for $\{\dot{u}_{t+1}^{njs(0)}\}_{t=\overline{T}}^{T}$, where the superscript (0) indicates that this is an "initial" guess.

2. For $t \geq \overline{T}$, use the guess of $\{\dot{u}_{t+1}^{njs(0)}\}_{t=\overline{T}}^{T}$ and $\mu_{\overline{T}-1}^{njs,nki}$ in the data to solve for the path of $\{\mu_t^{njs,nki}\}_{t=\overline{T}}^{T}$ using equation (18).

3. Given the path of $\{\mu_t^{njs,nki}\}_{t=\overline{T}}^{T}$ and $L_{\overline{T}}^{njs}$, compute $\{L_{t+1}^{njs}\}_{t=\overline{T}}^{T}$ using the laws of motion for labor transitions (20)–(21). Given the path of L_{t+1}^{njs}, compute the path of changes $\dot{L}_{t+1}^{njs}$.

4. For each $t \geq \overline{T}$, with the computed $\dot{L}_{t+1}^{njs}$, solve for the temporary equilibrium by iterating over $\dot{w}_{t+1}^{njs}$ that solves the equilibrium conditions (12)–(15) and clears the markets for labor and structure (16)–(17). The existence and uniqueness of such solution is guaranteed by the fixed point theorem as shown in Alvarez and Lucas (2007). This provides a sequence of $\{\dot{w}_{t+1}^{njs}, \dot{P}_{t+1}^{nj}\}$.

5. For each t, given the computed $(\mu_t^{njs,nki}, \dot{w}_{t+1}^{njs}, \dot{P}_{t+1}^{nj})$ and the initial guess $\dot{u}_{t+2}^{njs(0)}$, solve backward for $\dot{u}_{t+1}^{njs(1)}$ using equation (19) and obtain an updated path for $\{\dot{u}_{t+1}^{njs(1)}\}$.

6. Take the path for $\{\dot{u}_{t+1}^{njs(1)}\}$ as the new set of initial conditions. Repeat the above process until the updated path for $\{\dot{u}_{t+1}^{njs(1)}\}$ converges.

The algorithm above provides the paths for $\{\dot{L}_{t+1}^{njs}, \dot{\mu}_t^{njs,nki}, \dot{\pi}_{t+1}^{nj,oj}, \dot{w}_{t+1}^{njs}\}$ in the baseline economy.

C.4 Detailed Steps for Computing Counterfactuals

Given the counterfactual sequence of changes in fundamentals $\{\widehat{\Theta}_t\}_{t=1}^T$ and the path of changes in the baseline economy $\{\dot{L}_t^{njs}, \dot{\mu}_{t-1}^{njs,nki}, \dot{\pi}_t^{nj,oj}, \dot{w}_t^{njs}\}_{t=1}^T$, solve for the counterfactual economy as follows:

1. Initialize the system at $t = 0$ with a guess for $\{\widehat{u}_{t+1}^{njs(0)}\}_{t=0}^T$, where the superscript (0) indicates that this is an "initial" guess.

2. For $t \geq 0$, use the guess of $\{\widehat{u}_{t+1}^{njs(0)}\}_{t=0}^T$ and $\{\dot{\mu}_t^{njs,nki}\}$ in the baseline economy to solve for the path of $\{\mu_t'^{njs,nki}\}_{t=0}^T$ as follows:

For $t = 0$,

$$\begin{aligned}
&\widehat{u}_0^{nki(0)} = 1, \\
&\mu_0'^{njs,nki} = \mu_0^{njs,nki}, \\
&L_1'^{njs} = L_1^{njs} = \delta \sum_{\mathrm{K}=0}^{J} \sum_{i \leq s}^{3} \mu_0^{njs,nki} L_0^{nki} \\
&L_1'^{n01} = L_1^{n01} = \delta \sum_{k=0}^{J} \mu_t^{nk1,n01} L_0^{nk1} + (1-\delta) L^n.
\end{aligned}$$

For $t = 1$,

$$\mu_1'^{njs,nki} = \frac{\mu_1^{njs,nki} \left(\widehat{u}_1^{nki(0)}\right)^{\frac{\beta\delta}{\nu}} \left(\widehat{u}_2^{nki(0)}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J} \sum_{\mathrm{I} \geq s}^{3} \mu_1^{njs,n\mathrm{KI}} \left(\widehat{u}_1^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}} \left(\widehat{u}_2^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}}}. \tag{36}$$

For $t > 1$,

$$\mu_t'^{njs,nki} = \frac{\mu_{t-1}'^{njs,nki} \dot{\mu}_t^{njs,nki} \left(\widehat{u}_{t+1}^{nki(0)}\right)^{\frac{\beta\delta}{\nu}}}{\sum_{\mathrm{K}=0}^{J} \sum_{\mathrm{I} \geq s}^{3} \mu_{t-1}'^{njs,n\mathrm{KI}} \dot{\mu}_t^{njs,n\mathrm{KI}} \left(\widehat{\mu}_{t+1}^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}}}.$$

3. Given the path of $\{\mu_t'^{njs,nki}\}_{t=0}^T$, L_0^{njs}, and the laws of motions in (24)–(25), compute the counterfactual path of labor allocation $\{L_{t+1}'^{njs}\}$ and the changes over time of the counterfactual relative to factual allocation $\{\widehat{L}_{t+1}^{njs}\}$.

4. For each $t \geq 0$, with the computed $\{\widehat{L}_{t+1}^{njs}\}$ and the path of changes $\{\dot{L}_t^{njs}, \dot{\pi}_t^{nj,oj}, \dot{w}_t^{njs}\}$ in the baseline economy, solve for the temporary equilibrium by iterating over $\{\widehat{w}_{t+1}^{njs}\}$ that solves the equilibrium conditions (26)–(29) and clears the markets for labor and structure (30)–(31). This provides a sequence of $\{\widehat{w}_{t+1}^{njs}, \widehat{P}_{t+1}^{nj}\}$.

5. For each t, given $\dot{\mu}_{t+1}^{njs,nki}$ in the baseline economy, the computed $(\mu_t'^{njs,nki}, \widehat{w}_{t+1}^{njs}, \widehat{P}_{t+1}^{nj})$,

and the initial guess $\widehat{u}_{t+2}^{njs(0)}$, solve backward for $\{\widehat{u}_{t+1}^{njs(1)}\}$ with the following equations:

$$\widehat{u}_{t+1}^{njs(1)} = \widehat{\omega}_{t+1}^{njs}\left[\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_t^{\prime njs,n\mathrm{KI}}\dot{\mu}_{t+1}^{njs,n\mathrm{KI}}\left(\widehat{u}_{t+2}^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}}\right]^{\nu}, \text{ for } t \geq 1, \tag{37}$$

$$\widehat{u}_{1}^{njs(1)} = \widehat{\omega}_{1}^{njs}\left[\sum_{\mathrm{K}=0}^{J}\sum_{\mathrm{I}\geq s}^{3}\mu_1^{njs,n\mathrm{KI}}\left(\widehat{u}_{1}^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}}\left(\widehat{u}_{2}^{n\mathrm{KI}(0)}\right)^{\frac{\beta\delta}{\nu}}\right]^{\nu}. \tag{38}$$

6. Take the path for $\{\widehat{u}_{t+1}^{njs(1)}\}$ as the new set of initial conditions. Repeat the above process until the updated path for $\{\widehat{u}_{t+1}^{njs(1)}\}$ converges.

Table 1: Changes in tariffs on Taiwanese imports and exports (1995–2007)

Year	1995–2001		2002–2007	
Sector	Agriculture	Manufacturing	Agriculture	Manufacturing
Foreign Tariffs on Taiwan's Exports	0.07%	−2.54%	−3.10%	−1.75%
Taiwan's Import Tariffs	−0.42%	−1.25%	−4.42%	−1.31%

Notes: The table reports the changes (in percentage points) in average tariffs (across products and trading partners of Taiwan) in agriculture and in manufacturing, before and after its WTO accession. Ad-valorem equivalent tariff rates are obtained from the WITS database. The average tariff rates are computed across 6-digit HS sectors of agriculture and of manufacturing, respectively, weighted by the corresponding WITS trade value. Trading partners include all economies available in the WITS database. The 6-digit HS codes are first concorded to the 2-digit ISIC Rev.3 sectors, and are then aggregated to the agriculture and manufacturing categories. The agricultural sector includes 2-digit ISIC Rev.3 sectors of 01, 02, and 05 (agriculture, forestry, and fishing). The manufacturing includes 2-digit ISIC Rev.3 sectors of 15–37.

Table 2: Labor transition across sectors in Taiwan, 1995–2007

Sectors	From/To	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	School	ΔEmp.
Agriculture, Mining	(1)	85.9	0.4	0.6	0.9	0.3	0.3	0.0	2.4	2.1	0.4	1.5	5.2	7.2	−5.3
Food, Beverages, Tobacco	(2)	1.8	77.2	0.7	1.6	1.3	0.3	0.0	0.6	8.5	0.7	1.9	5.4	10.9	+0.0
Textiles, Wood, Paper	(3)	0.5	0.2	80.7	2.5	1.3	0.8	0.0	0.4	2.9	0.4	2.3	7.9	10.6	−1.9
Petroleum, Chemicals, Plastics, Metals	(4)	0.8	0.4	1.7	80.2	4.3	1.6	0.0	1.6	2.5	0.4	1.3	5.2	11.0	+0.2
MCEE	(5)	0.2	0.2	0.7	3.8	82.7	1.1	0.0	0.7	3.0	0.2	2.1	5.3	12.5	+3.5
Motor, Transport Equipment	(6)	0.8	0.3	1.8	4.8	3.9	75.8	0.0	1.1	3.1	0.7	1.7	5.9	10.9	+0.0
Electricity, Water, Gas	(7)	0.1	0.0	0.1	0.6	0.5	0.1	92.1	1.9	1.7	0.2	1.8	0.9	13.5	−0.1
Construction	(8)	2.2	0.1	0.4	1.9	1.2	0.5	0.1	81.3	2.8	0.7	2.8	6.1	10.0	−1.7
Wholesale, Retail, Hotels, Restaurants	(9)	0.7	0.6	0.6	1.0	1.3	0.4	0.0	0.8	84.4	0.5	3.3	6.4	11.2	+2.9
Transport, Storage	(10)	0.9	0.2	0.3	1.0	0.6	0.4	0.1	1.0	2.8	86.9	2.6	3.2	11.3	−0.2
Business Services	(11)	0.3	0.1	0.5	0.4	0.9	0.2	0.0	0.9	2.8	0.4	88.8	4.7	13.5	+4.6
Non-employment	(12)	1.2	0.3	1.2	1.3	1.9	0.4	0.0	1.6	5.4	0.5	5.0	81.3	9.6	−1.8

Notes: Statistics are computed based on the *Manpower Utilization Quasi-longitudinal Data* from 1995 to 2007. The numbers reported are time-series-average transition rates in percentage during the period 1995–2007, measuring the proportion of labor transitioning out from a row-origin sector into a column-destination sector during a year. The "School" column measures the average years of schooling in each sector for the period 1995–2007. The top five destination cells of each row-origin sector are highlighted in color. The cells highlighted in blue are the diagonal cells, which measure the proportions of labor that stay in the same sector. The cells highlighted in yellow are the cells that measure the proportions of labor that transit into a different sector among the top four destinations. Sectors for this table are defined at a more aggregate level than used in the quantitative exercises to reduce dimensionality. We first concord the labor survey data from Taiwanese classifications to 2-digit ISIC Rev.3 sectors. We then aggregate further the 2-digit ISIC Rev.3 sectors to the sectors shown in the table. See Table A.1 and its footnote for the sector definitions.

Table 3: Estimation of labor market transition elasticity $\beta\delta/\nu$

	(1) Stage 1 Estimation $L_t^{js,ki}$		(2) Stage 2 Estimation ϕ_t^{js}
$\rho_1^{low,mid}$	4.909***	$\ln w_{t+1}^{js}$	**0.738*****
	(0.110)		(0.0324)
$\rho_1^{mid,high}$	4.468***	$\eta_2^{middle} \times t$	-0.0109***
	(0.135)		(0.00323)
constant	11.71***	$\eta_2^{high} \times t$	-0.00646**
	(0.0272)		(0.00322)
Origin-Sector-Skill-Year FE (α_t^{js})	Yes	Year FE (ζ_t)	Yes
Destination-Sector-Skill-Year FE (λ_t^{ki})	Yes	Origin-Skill FE (η_1^s)	Yes
Sector-to-Sector FE	Yes		
No. of Observations	53496	No. of Observations	42540
R^2	0.817	R^2	0.288

Notes: Estimation results of equations (32) and (34). In Stage 1, the base category omitted is the non-employed-low-skill group, such that $\lambda_t^{ki} = 0$ for this category. In Stage 2, the time trend for the origin-low-skill group is omitted, as it is absorbed by the year FEs (ζ_t).

Table 4: Welfare effects of Taiwan's WTO entry on Taiwanese workers by skill type and sector

Aggregate	Low-skilled workers	Middle-skilled workers	High-skilled workers
2.396%	2.139%	2.591%	2.685%
	Agriculture	Manufacturing	Services
	1.764%	3.073%	2.217%

Notes: The table reports the welfare effect of Taiwan's WTO entry on Taiwanese workers over the period 1995–2020. The welfare effect is measured in terms of total discounted consumption equivalent variation over the period. The labor market in Taiwan is sector-skill specific. The first column reports the aggregate welfare effect across all sectors and skills, computed using sector-skill employment shares in 1995 as weights. The second to fourth columns in the first panel report the welfare effects on low/middle/high-skilled workers, using sector-skill employment shares (normalized by each skill type's employment share) in 1995 as weights. The second to fourth columns in the second panel report the welfare effects on workers in the agricultural/manufacturing/service sectors, using sector-skill employment shares (normalized by each sector's employment share) in 1995 as weights. Refer to Table A.3 for the sector-skill employment share in 1995.

Table 5: Effects on the employment shares in Taiwan under different scenarios of tariff concessions

	(1) WTO accession by Taiwan	(2) WTO accession by China	(3) WTO accession by both	(4) Bilateral tariff concessions only
	Panel A. Aggregate sector			
Agriculture	−0.37%	0.08%	−0.27%	−0.00%
Manufacturing	4.36%	3.68%	4.24%	3.82%
Services	1.29%	1.13%	1.25%	1.16%
	Panel B. Individual sector			
Textiles, Leather, Footwear	0.52%	0.39%	0.49%	0.42%
Basic & Fabricated Metals	0.67%	0.57%	0.66%	0.58%
Computer, Electronics	0.94%	0.58%	0.86%	0.67%
Construction	0.30%	0.27%	0.29%	0.29%
Wholesale, Retail	−0.24%	−0.29%	−0.23%	−0.30%
Hotels, Restaurants	0.25%	0.21%	0.22%	0.24%
Financial Intermediation	0.27%	0.27%	0.27%	0.27%
Other Business Services	0.47%	0.46%	0.47%	0.46%
	Panel C. Skill type			
Low-skilled workers	−4.36%	−4.05%	−4.30%	−4.10%
Middle-skilled workers	1.37%	1.25%	1.35%	1.27%
High-skilled workers	2.99%	2.80%	2.95%	2.83%

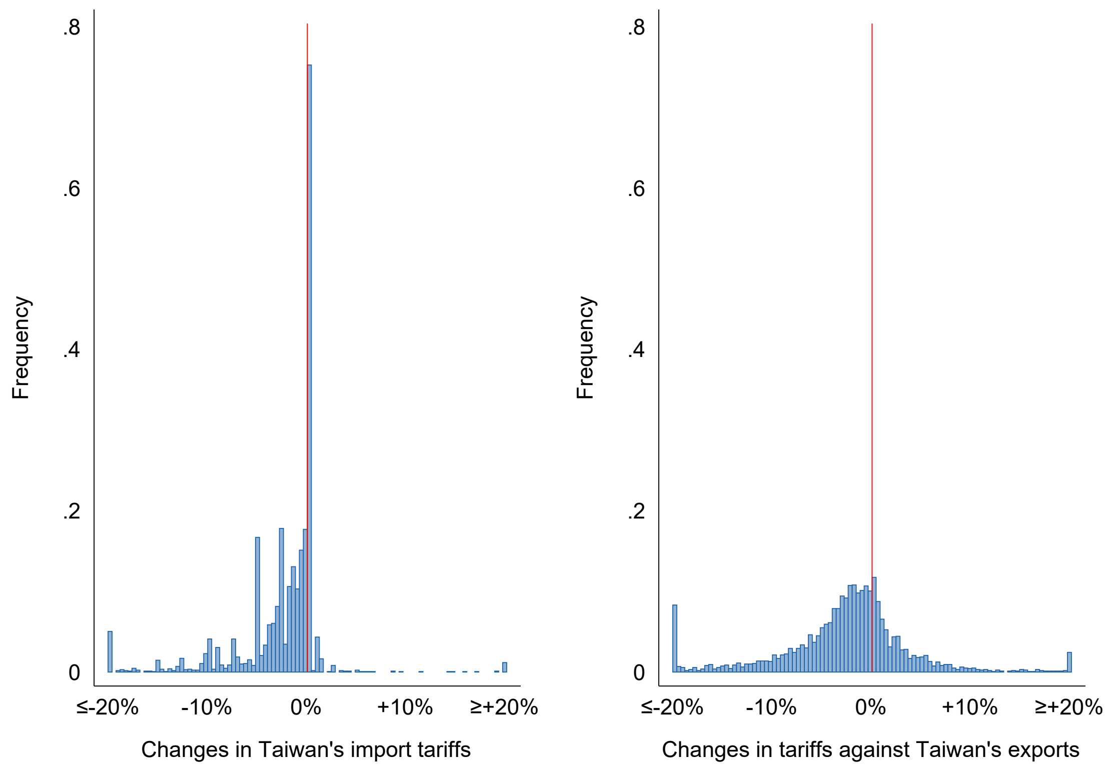
Notes: The table reports the effect on the employment share in the Taiwanese labor market under different scenarios of tariff concessions over the period 1995–2020. The effect is calculated as the difference between the baseline economy and the counterfactual economy. Panel A shows the employment effect across aggregate sectors. Panel B shows the employment effect for individual sectors that contribute significantly to the aggregate differences across scenarios. Panel C shows the employment effect across skill types. Column (1) reports the employment effect of Taiwan's WTO accession. Column (2) reports the employment effect of China's WTO accession. Column (3) reports the combined employment effect of WTO accession by both Taiwan and China. Column (4) reports the employment effect of bilateral tariff concessions between Taiwan and China only.

Table 6: Welfare effects on Taiwanese workers under different scenarios of tariff concessions

Scenario	Aggregate	Low-skilled workers	Middle-skilled workers	High-skilled workers
WTO accession by Taiwan	2.396%	2.139%	2.591%	2.685%
WTO accession by China	2.223%	2.072%	2.355%	2.367%
WTO accession by both	2.362%	2.127%	2.543%	2.621%
Bilateral tariff concessions only	2.266%	2.095%	2.409%	2.436%
		Agriculture	Manufacturing	Services
WTO accession by Taiwan		1.764%	3.073%	2.217%
WTO accession by China		1.694%	2.895%	2.026%
WTO accession by both		1.767%	3.039%	2.175%
Bilateral tariff concessions only		1.714%	2.938%	2.073%

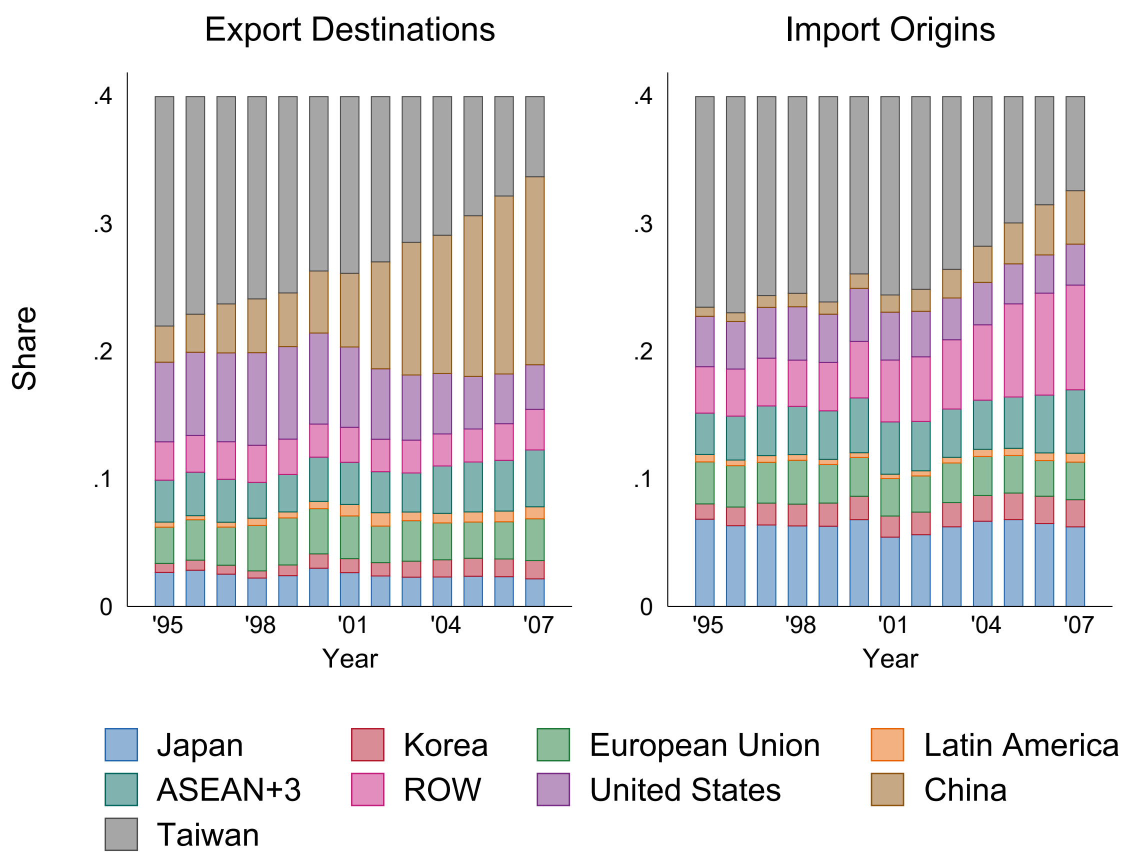
Notes: The table reports the welfare effect on Taiwanese workers under different scenarios of tariff concessions over the period 1995–2020. The welfare effect is measured in terms of total discounted consumption equivalent variation over the period. The labor market in Taiwan is sector-skill specific. The first column lists the scenarios studied. The second column reports the aggregate welfare effect across all sectors and skills, computed using sector-skill employment shares in 1995 as weights. The third to fifth columns in the first panel report the welfare effects on low/middle/high-skilled workers, using sector-skill employment shares (normalized by each skill type's employment share) in 1995 as weights. The third to fifth columns in the second panel report the welfare effects on workers in the agriculture/manufacturing/service sectors, using sector-skill employment shares (normalized by each sector's employment share) in 1995 as weights. Refer to Table A.3 for the sector-skill employment share in 1995.

Figure 1: Changes in tariff rates at HS 6-digit level, 1995–2007



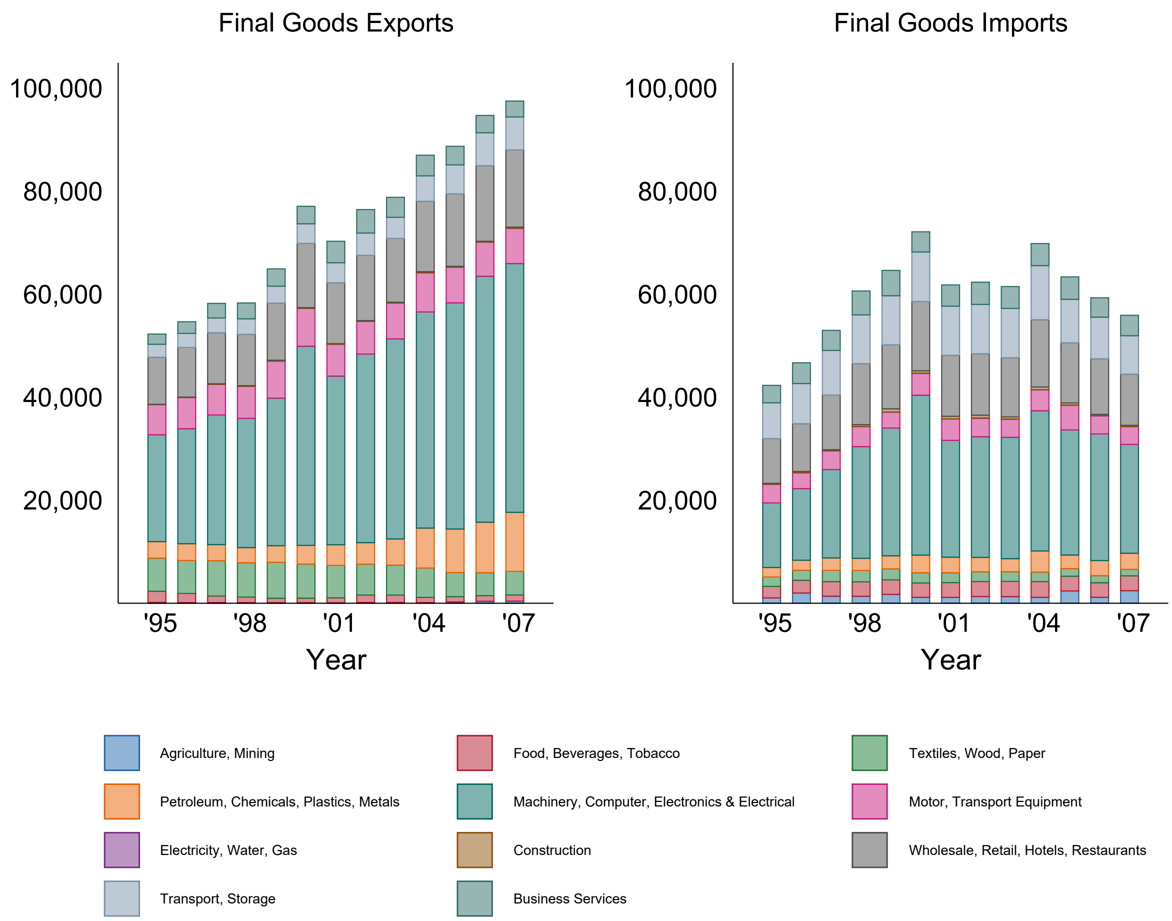
Notes: Each bar measures the frequency of the percentage point change in the tariff rates at HS 6-digit product code level from 1995 to 2007. Data were downloaded from WITS database. Trading partners include all economies available in the WITS database. The numbers reported are average change for each HS 6-digit product across all trading partners weighted by the WITS trade value. The left panel reports the percentage point change in Taiwan's import tariffs. The right panel reports the percentage point change in tariffs that Taiwan's trading partners imposed on Taiwanese exports.

Figure 2: Distribution of Taiwan's trade with its trading partners, 1995–2007



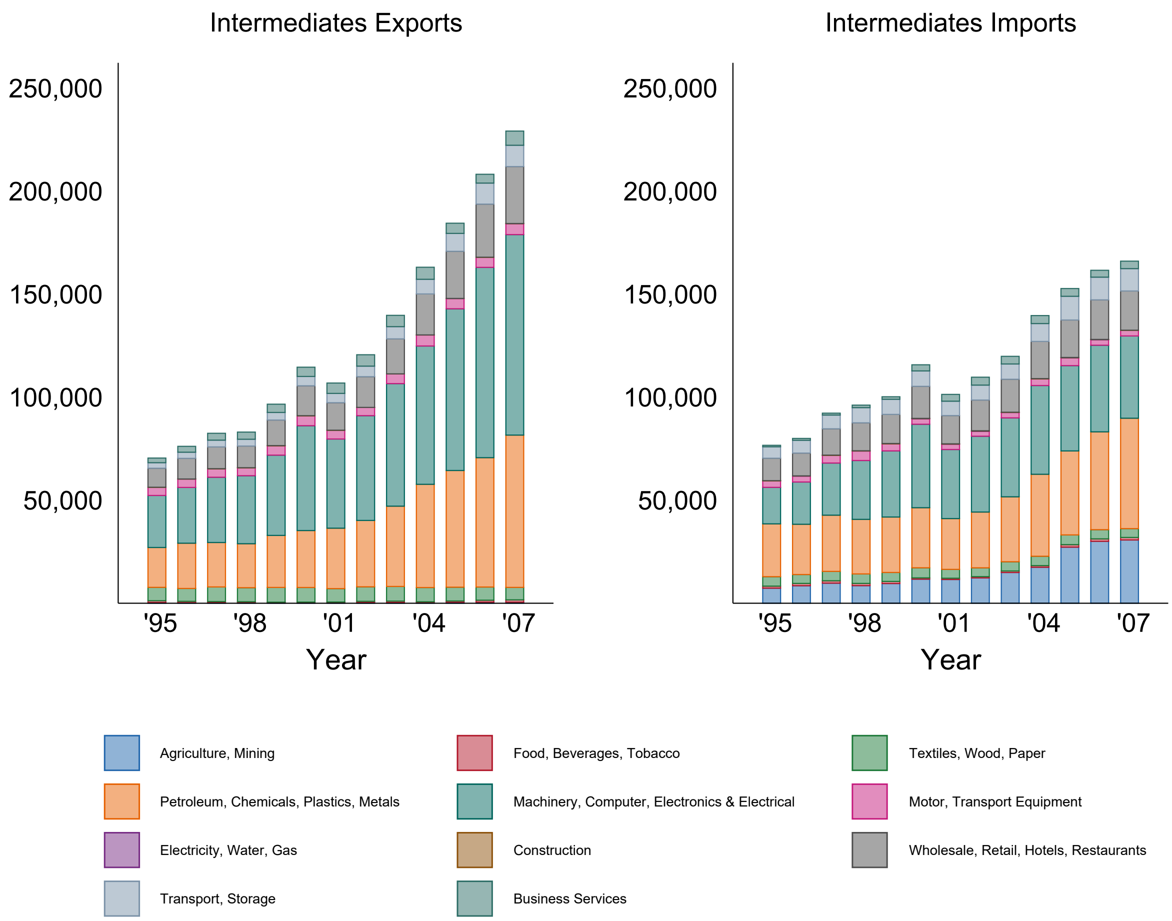
Notes: The length of each colored bar measures the share of Taiwan's trade with each of its trading partners in a year. The gray-colored bar with legend "Taiwan" measures the Taiwanese domestic trade share (truncated at 0.4). Trade data are from the OECD TiVA ICIO Tables (2016 edition). Trading partners include all economy entities in TiVA. "ROW" here refers to the residual economies not covered by the other groups reported above. The left panel reports the shares of Taiwan's exports to each of its export destinations. The right panel reports the shares of Taiwan's imports from each of its import origins. European Union includes all TiVA economies that were members of the EU in 2007. ASEAN+3 includes (a) all TiVA economies that were members of the ASEAN in 2007; and (b) India, Australia, and New Zealand.

Figure 3: Final goods trade of Taiwan across sectors, 1995–2007



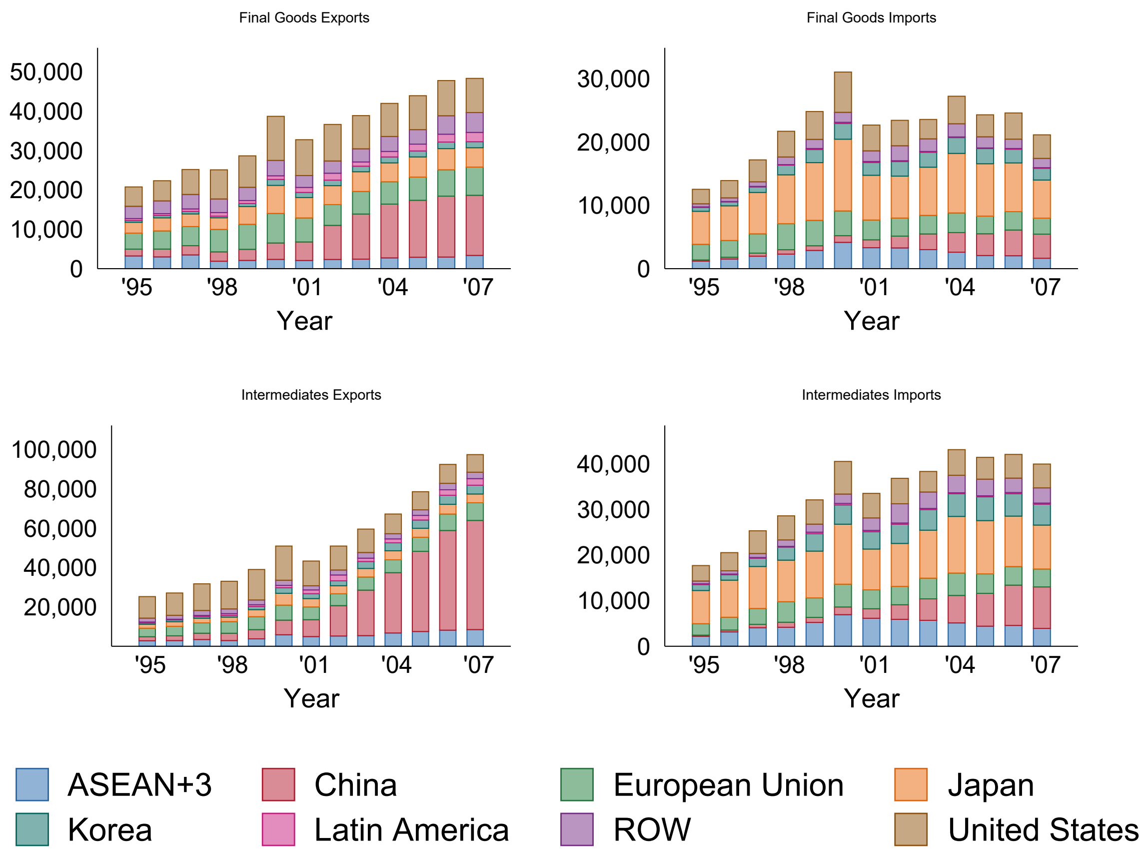
Notes: The length of each colored bar measures the final goods trade value of Taiwan in each sector in a particular year. Trade data are from the OECD TiVA ICIO Tables (2016 edition). The left panel reports the value of Taiwan's final goods exports in each sector. The right panel reports the value of Taiwan's final goods imports in each sector. Sector definitions follow Table 2.

Figure 4: Intermediates trade of Taiwan across sectors, 1995–2007



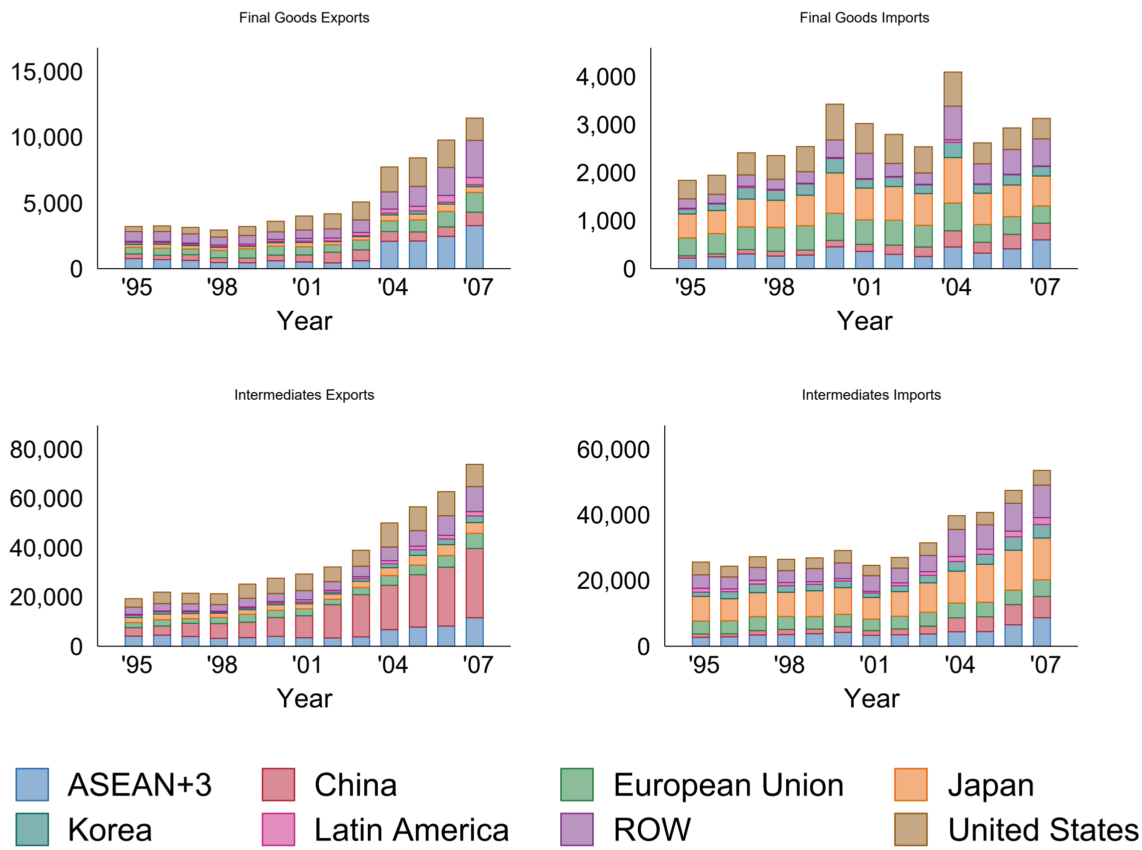
Notes: The length of each colored bar measures the intermediates trade value of Taiwan in each sector in a particular year. Trade data are from the OECD TiVA ICIO Tables (2016 edition). The left panel reports the value of Taiwan's intermediates exports in each sector. The right panel reports the value of Taiwan's intermediates imports in each sector. Sector definitions follow Table 2.

Figure 5: MCEE trade of Taiwan, 1995–2007



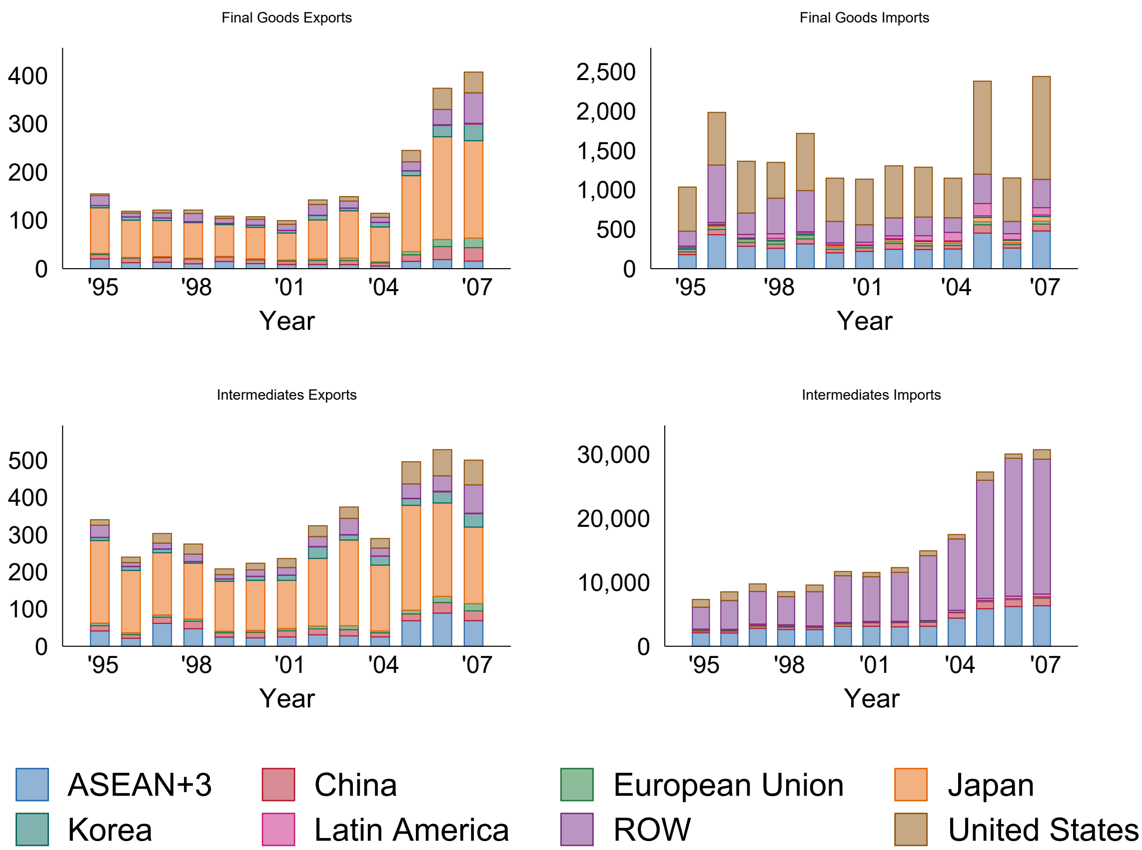
Notes: The length of each colored bar measures the corresponding trade value of Taiwan in MCEE. Trade data are from the OECD TiVA ICIO Tables (2016 edition). Trading partners include all economy entities in TiVA. "ROW" here refers to the residual economies not covered by the other groups reported above. The left panel reports the value of Taiwan's exports in final goods and intermediates to each of its export destinations. The right panel reports the value of Taiwan's imports of final goods and intermediates from each of its import origins. Sector definitions follow Table 2.

Figure 6: PCPM trade of Taiwan, 1995–2007



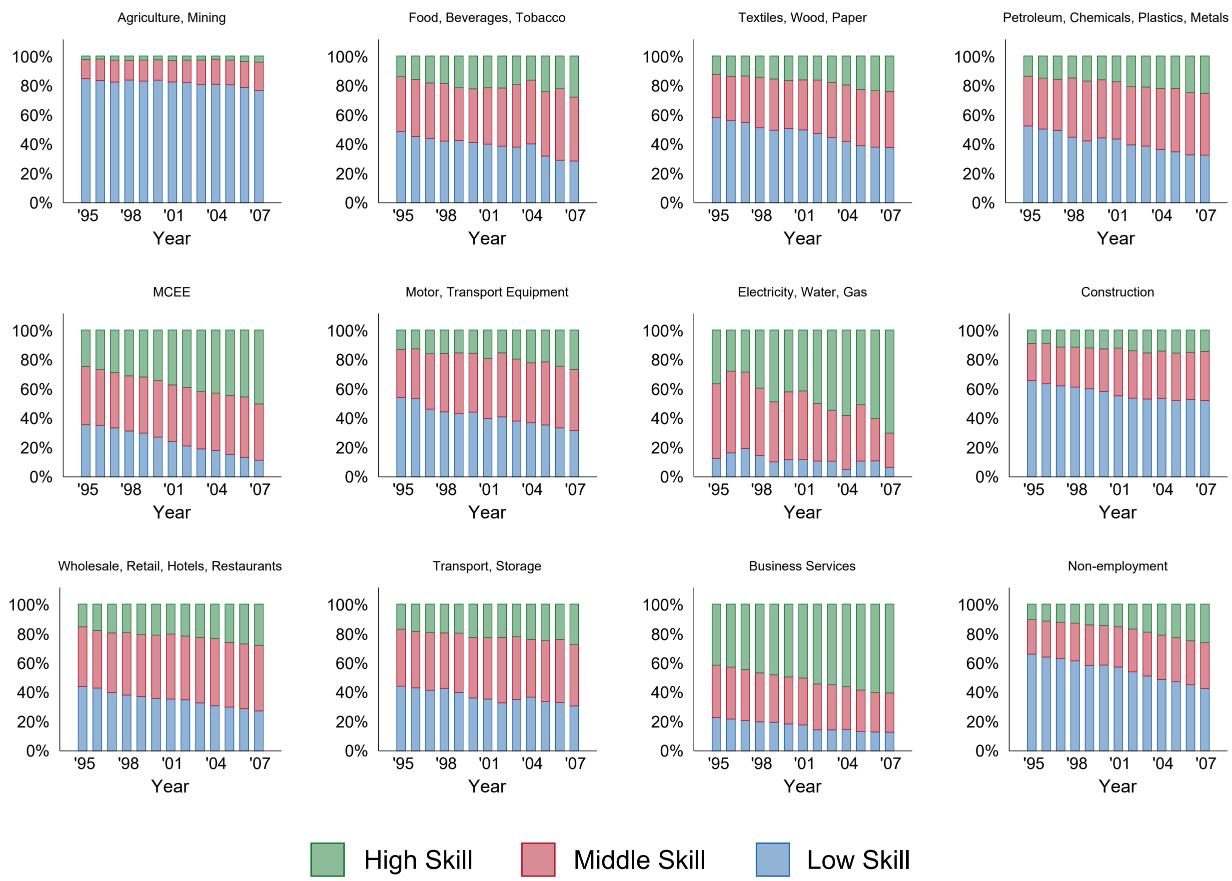
Notes: The length of each colored bar measures the corresponding trade value of Taiwan in PCPM. Trade data are from the OECD TiVA ICIO Tables (2016 edition). Trading partners include all economy entities in TiVA. "ROW" here refers to the residual economies not covered by the other groups reported above. The left panel reports the value of Taiwan's exports in final goods and intermediates to each of its export destinations. The right panel reports the value of Taiwan's imports of final goods and intermediates from each of its import origins. Sector definitions follow Table 2.

Figure 7: Agricultural trade of Taiwan, 1995–2007



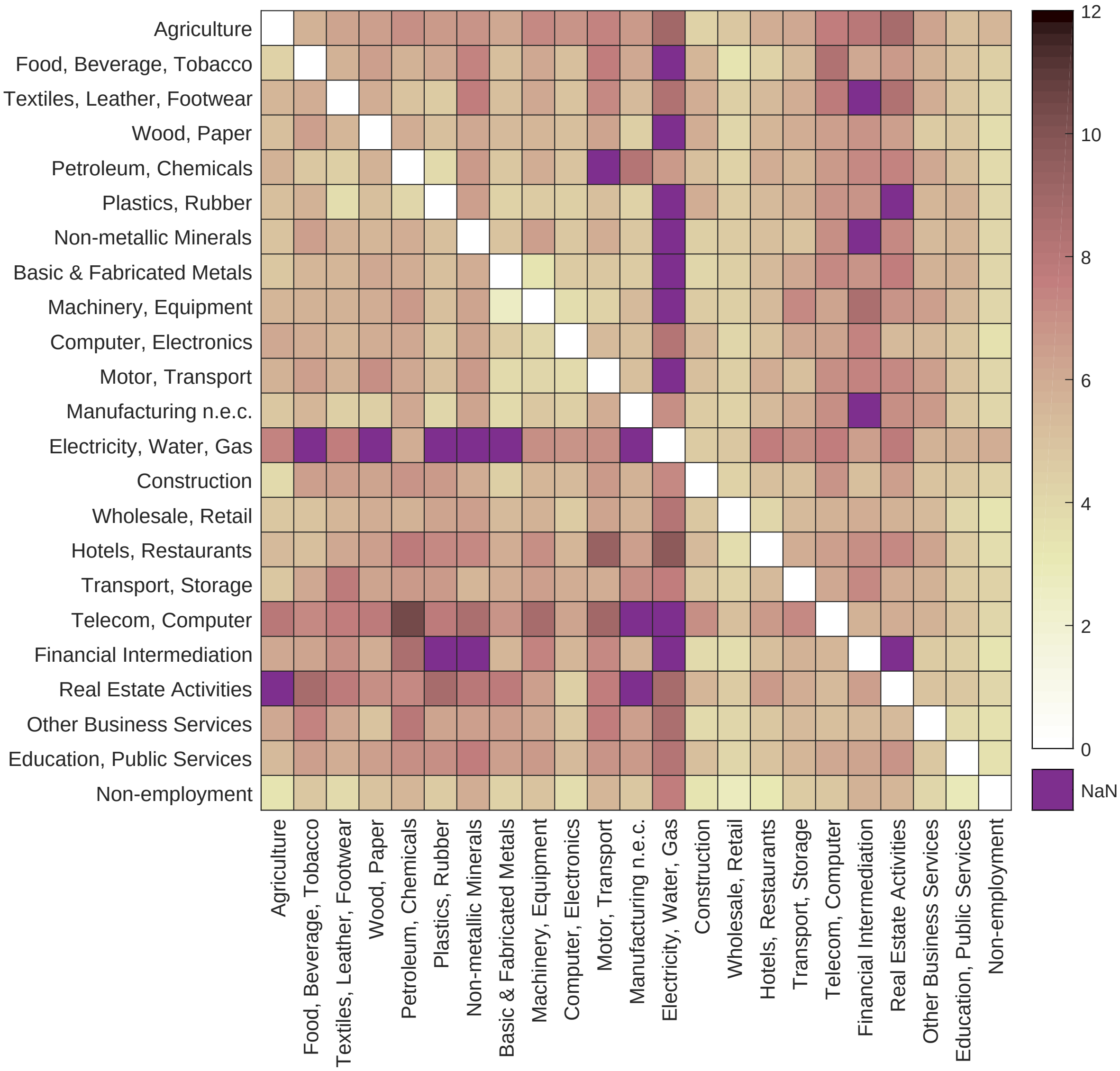
Notes: The length of each colored bar measures the corresponding trade value of Taiwan in agriculture. Trade data are from the OECD TiVA ICIO Tables (2016 edition). Trading partners include all economy entities in TiVA. "ROW" here refers to the residual economies not covered by the other groups reported above. The left panel reports the value of Taiwan's exports in final goods and intermediates to each of its export destinations. The right panel reports the value of Taiwan's imports of final goods and intermediates from each of its import origins. Sector definitions follow Table 2.

Figure 8: Evolution of skill shares across sectors in Taiwan, 1995–2007



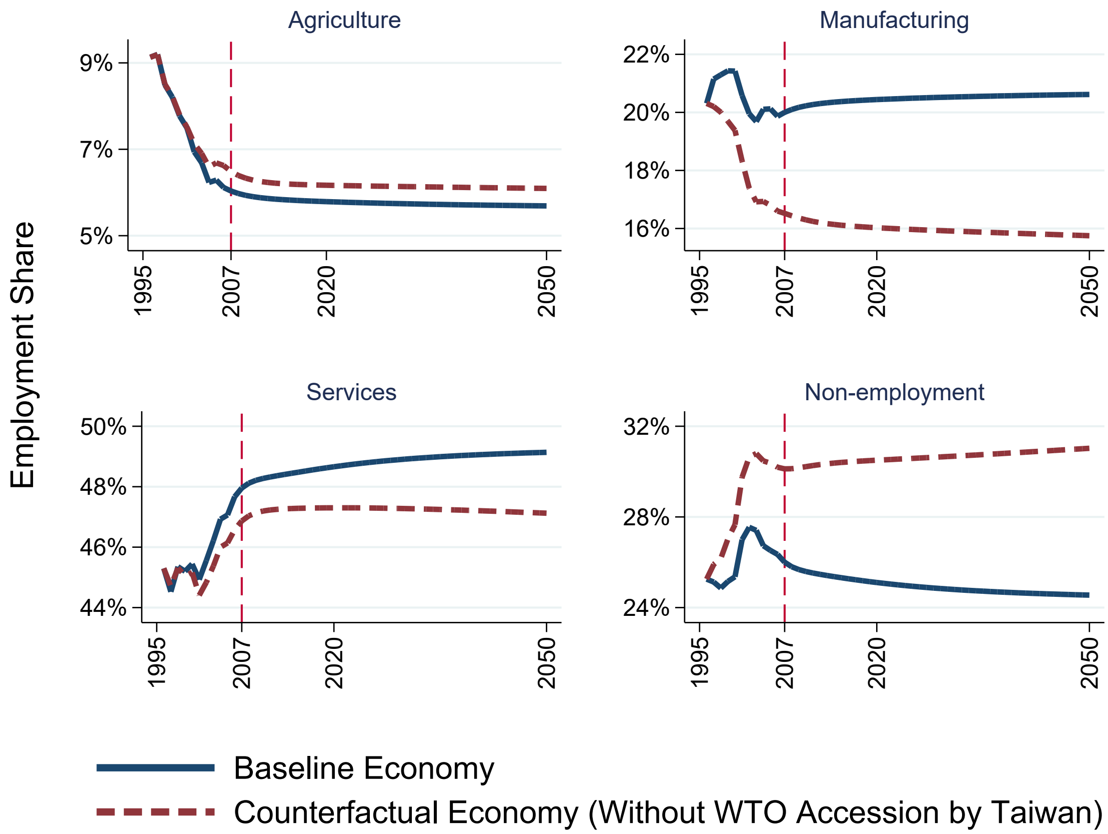
Notes: Statistics are computed based on the *Manpower Utilization Quasi-longitudinal Data* from 1995 to 2007. The numbers reported are the proportion of labor in a particular skill group in each year during 1995–2007. Sector definitions follow Table 2. The shares of high-, middle-, and low-skilled workers in the population changed from 17.4%, 30.3%, and 52.3% in 1995 to 34.7%, 34.5%, and 30.8% in 2007, respectively. The total population is measured as the sum of employed, unemployed, and not-in-labor-force, as elaborated in Appendix B.1. Non-employment equals the sum of unemployed and not-in-labor-force.

Figure 9: Sector-to-Sector Switching Cost



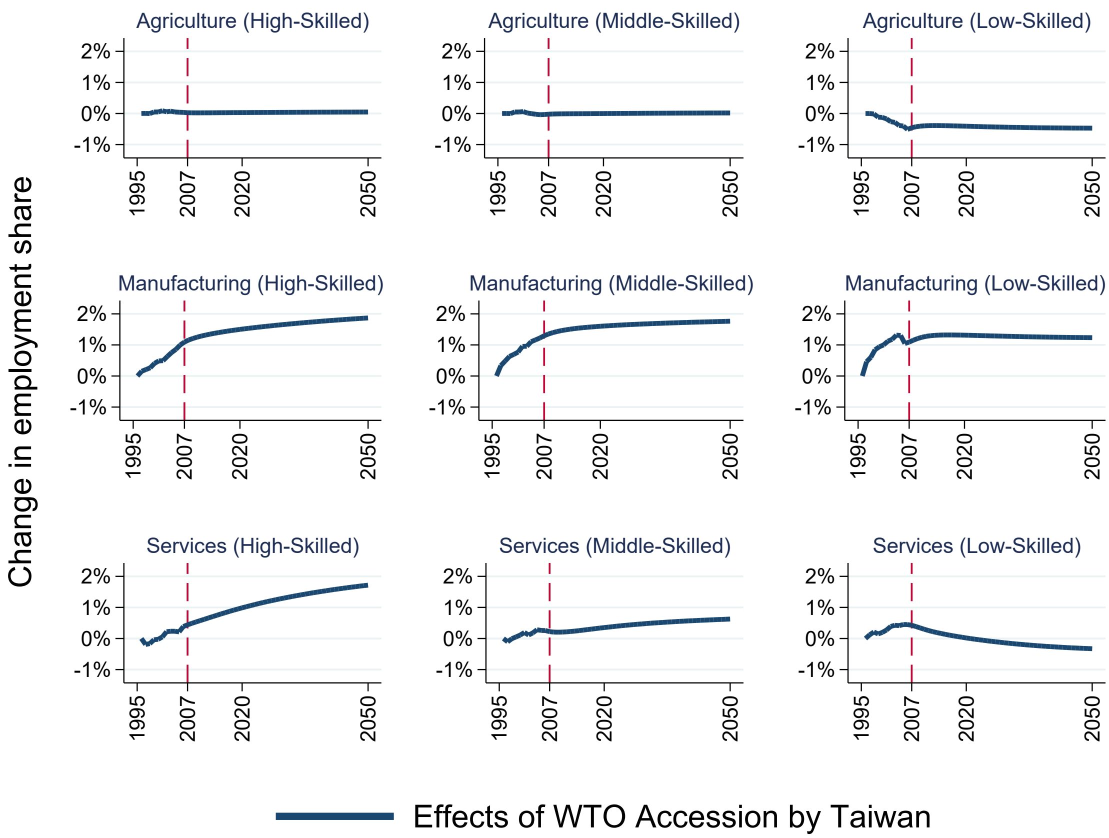
Notes: The figure shows the sector-to-sector switching costs based on estimations of Stage-1 equation (32) and the switching-cost specification in equation (33). The origin-sectors are in the rows and the destination-sectors in the columns. The magnitudes reported above reflect the average sector-switching costs with or without skill upgrading.

Figure 10: Transition dynamics of employment shares in Taiwan — effects of Taiwan's WTO entry



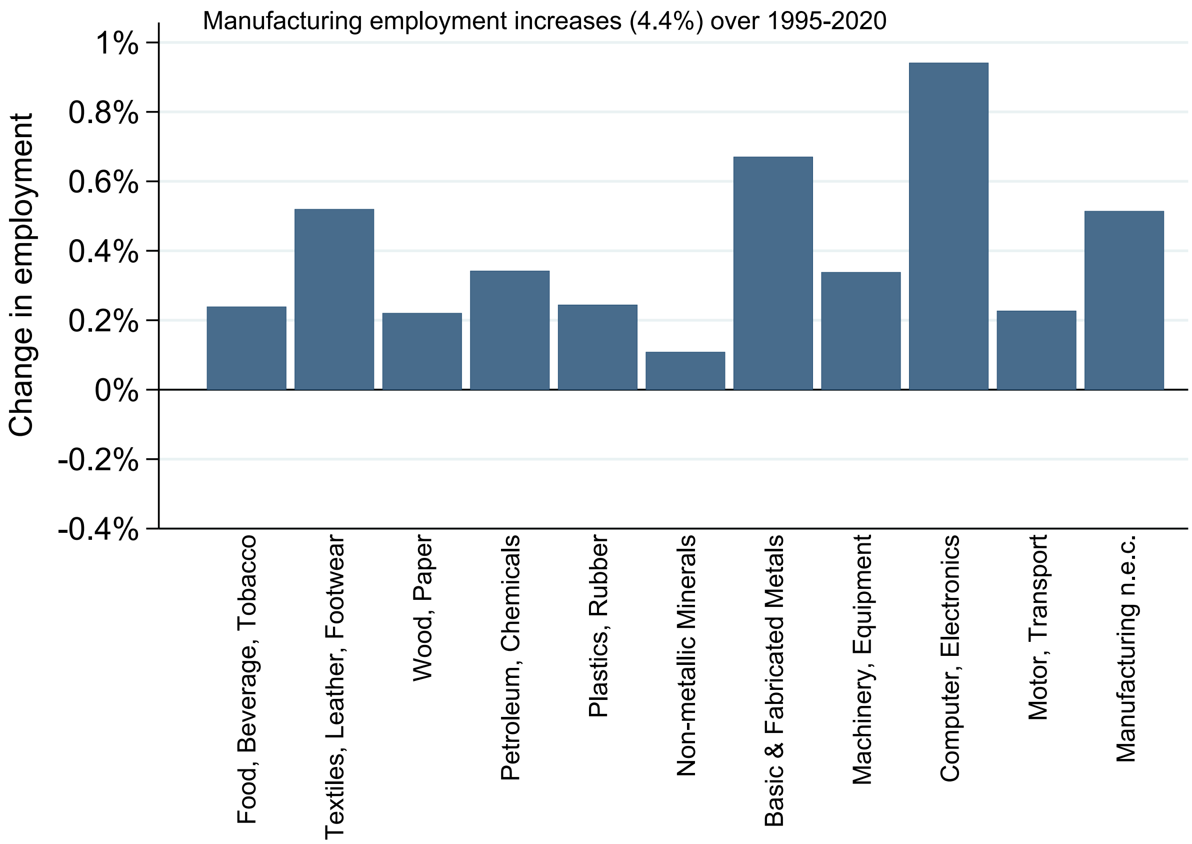
Notes: The figure shows the effect of Taiwan's WTO entry on employment shares in Taiwan by aggregate sectors. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The baseline economy shows the path of employment shares with all time-varying fundamentals evolving as in the data from 1995 to 2007 and constant fundamentals after 2007. The counterfactual economy is the same except that Taiwan's tariffs on imports and foreign tariffs on Taiwan's exports are set to their levels in 1995. We simulate the model until 3000.

Figure 11: Transition dynamics of employment shares in Taiwan by skill groups — effects of Taiwan's WTO entry



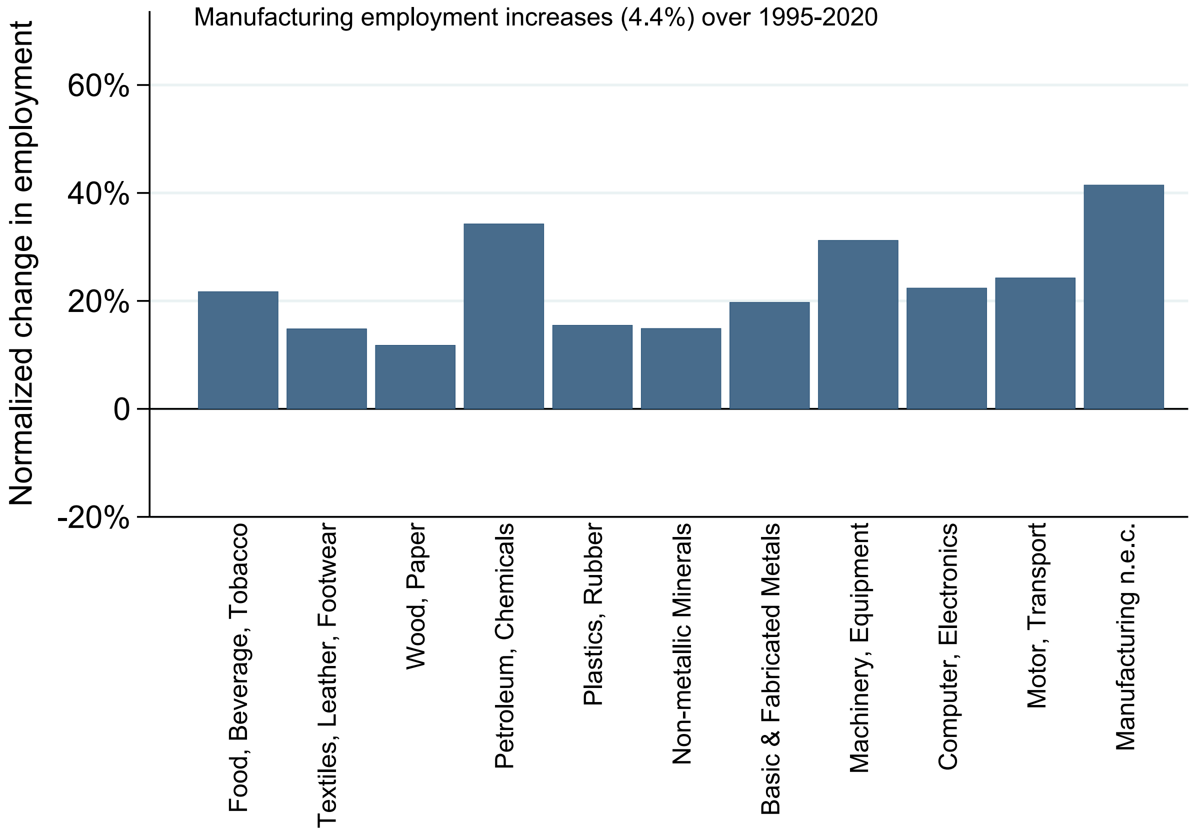
Notes: The figure shows the effect of Taiwan's WTO entry on employment shares in Taiwan by aggregate sectors and skill groups. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The effect is calculated to be the difference between the baseline economy and the counterfactual economy. The baseline economy shows the path of employment shares with all time-varying fundamentals evolving as in the data from 1995 to 2007 and constant fundamentals after 2007. The counterfactual economy is the same except that Taiwan's tariffs on imports and foreign tariffs on Taiwan's exports are set to their levels in 1995. We simulate the model until 3000.

Figure 12: Effects of Taiwan's WTO entry on the employment shares of manufacturing sectors in Taiwan



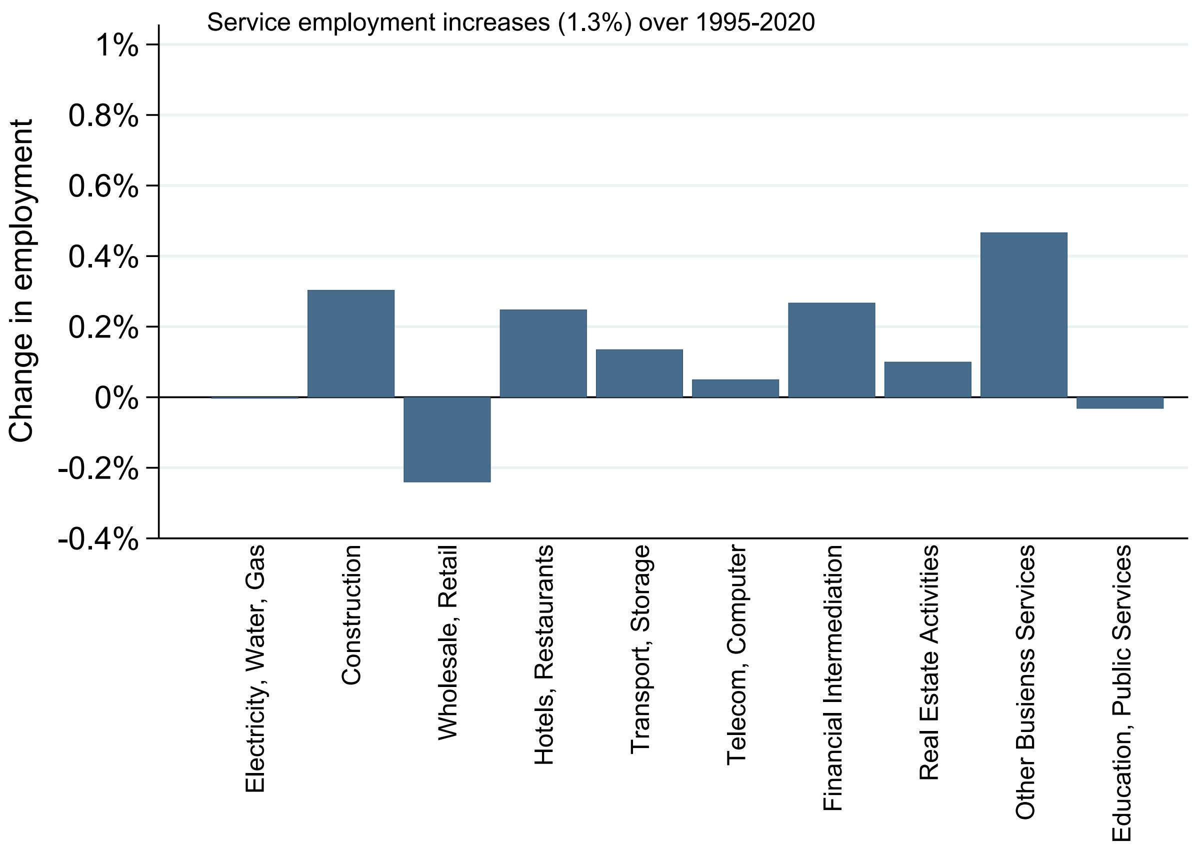
Notes: The figure shows the change in employment share for each manufacturing sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 13: Effects of Taiwan's WTO entry on the employment shares of manufacturing sectors in Taiwan — normalized by sector size



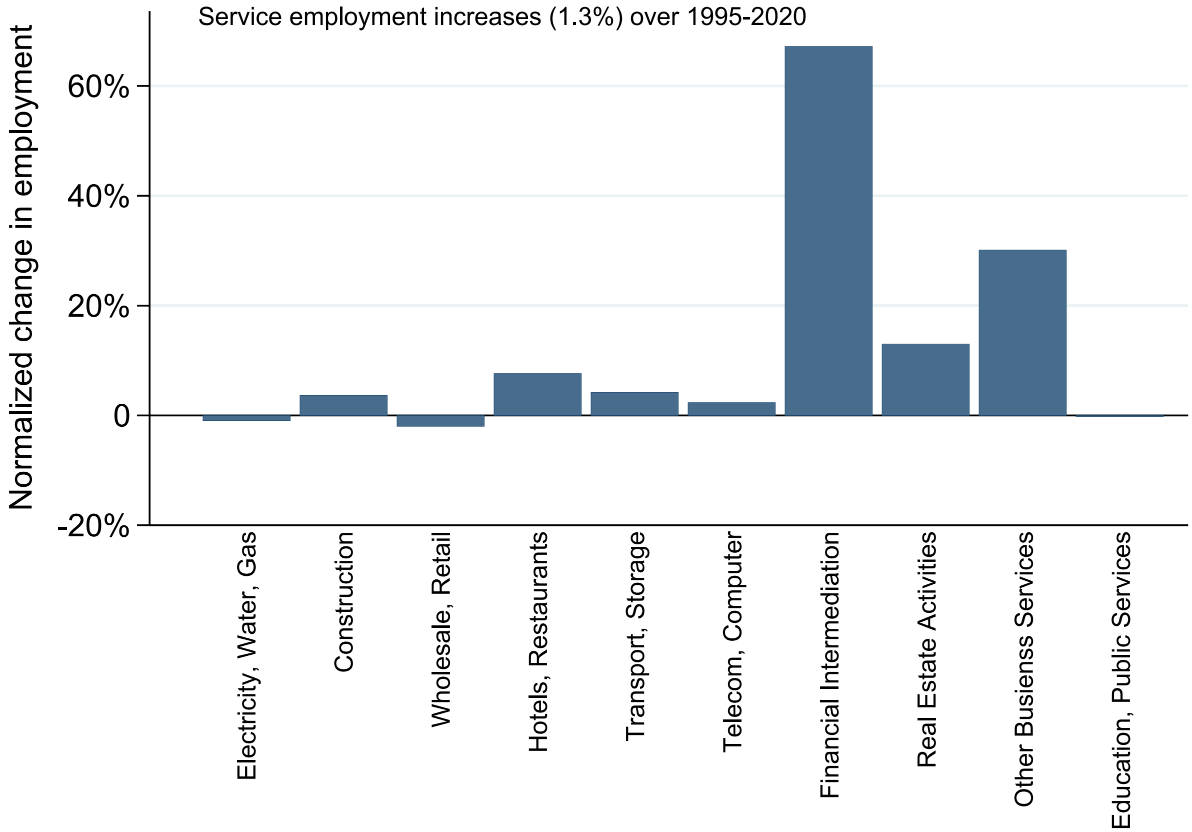
Notes: The figure shows the normalized change in employment share for each manufacturing sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force) and normalized by the sectoral employment share in year 1995. The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 14: Effects of Taiwan's WTO entry on the employment shares of service sectors in Taiwan



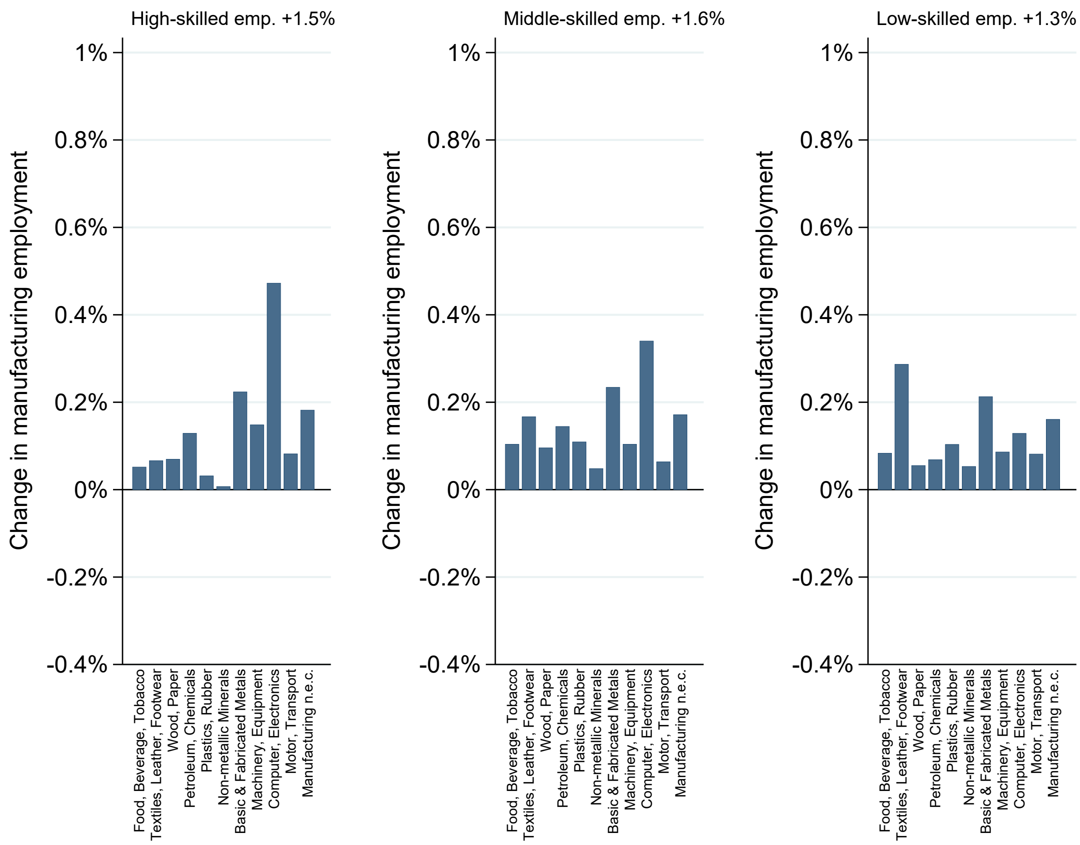
Notes: The figure shows the change in employment share for each service sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 15: Effects of Taiwan's WTO entry on the employment shares of service sectors in Taiwan — normalized by sector size



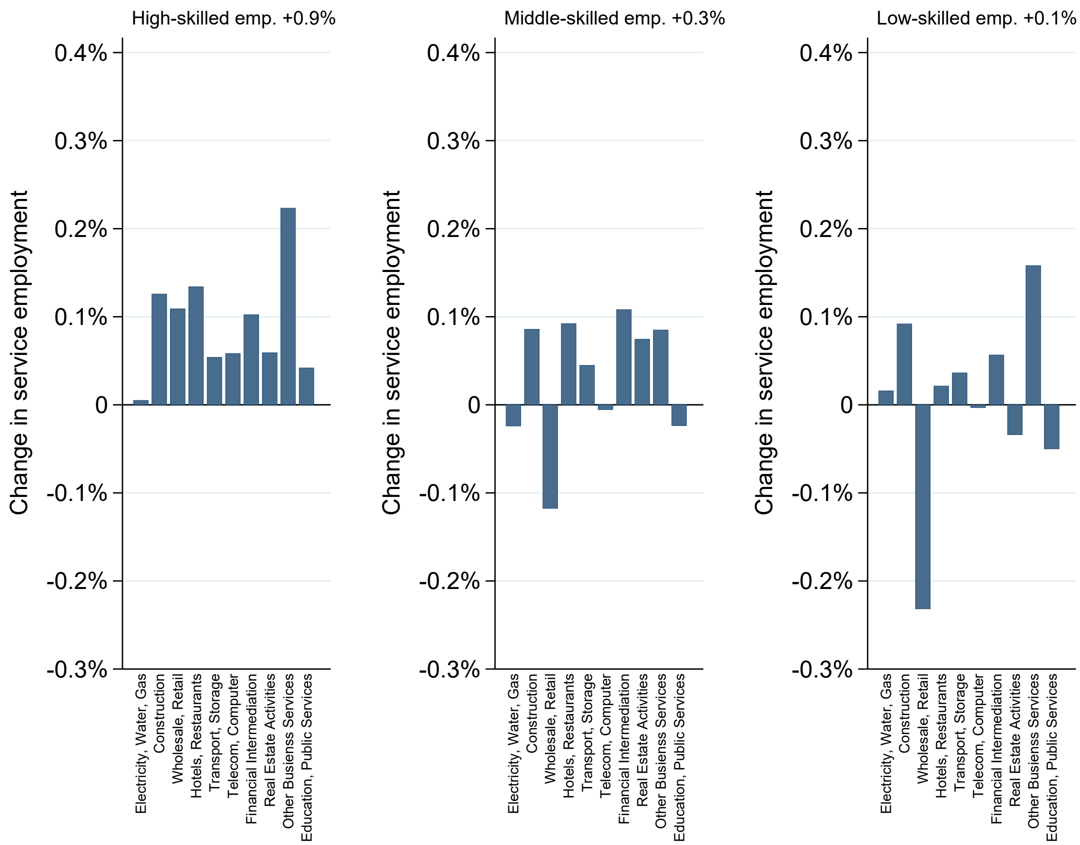
Notes: The figure shows the normalized change in employment share for each service sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force) and normalized by the sectoral employment share in year 1995. The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 16: Effects of Taiwan's WTO entry on the employment shares of manufacturing sectors in Taiwan by skill groups



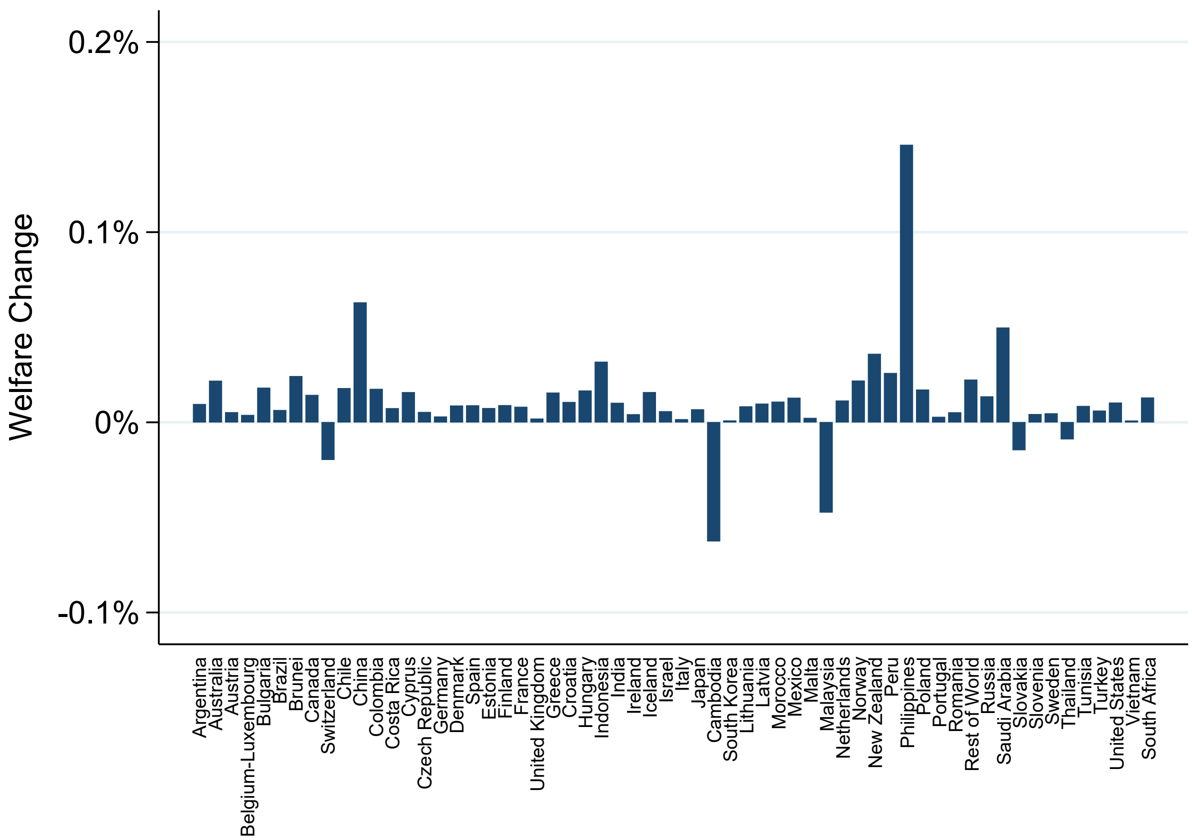
Notes: The figure shows the change in employment share by skill groups for each manufacturing sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 17: Effects of Taiwan's WTO entry on the employment shares of service sectors in Taiwan by skill groups



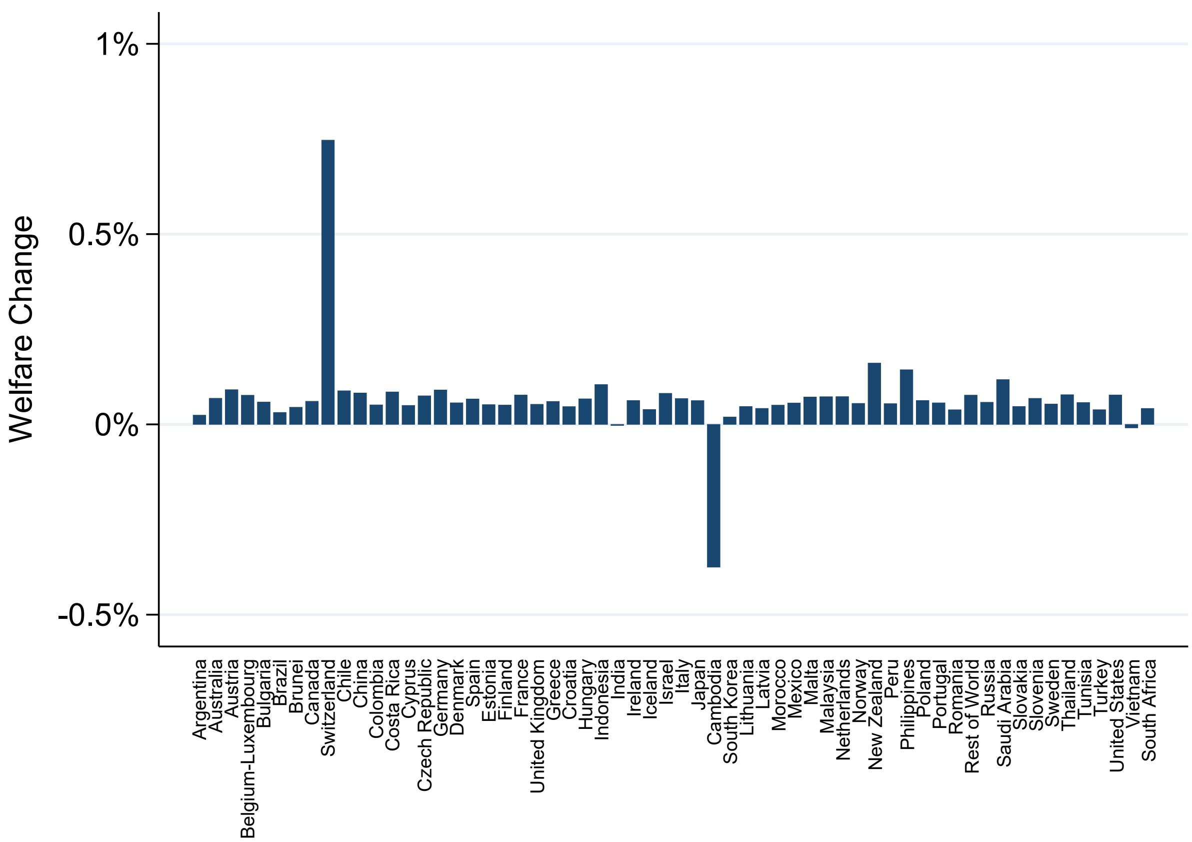
Notes: The figure shows the change in employment share by skill groups for each service sector in Taiwan over the period of 1995–2020, due to Taiwan's WTO entry. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). The effect is calculated to be the difference between the baseline economy and the counterfactual economy. See Figure 10 footnote for the definitions of the baseline and the counterfactual economy.

Figure 18: Welfare effects of Taiwan's WTO entry across economies — aggregate



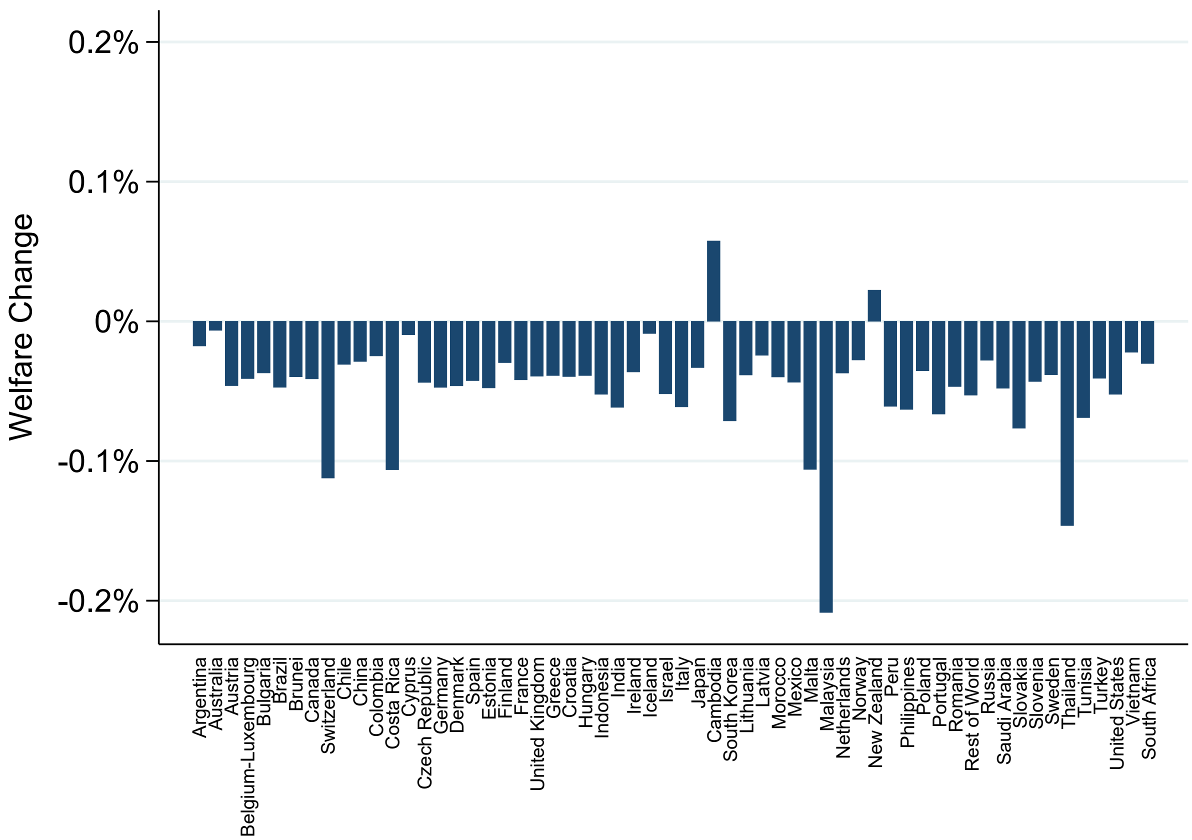
Notes: The figure shows the aggregate welfare effect of Taiwan's WTO entry on workers in economies other than Taiwan over the period of 1995–2020. The labor markets in economies other than Taiwan are country-sector specific. We aggregate the welfare effect across different sectors for each economy by using sectoral labor value added as weights. Data on value added are based on TiVA 2016, and data on labor share of value added are from Karabarbounis and Neiman (2014).

Figure 19: Welfare effects of Taiwan's WTO entry across economies — agriculture



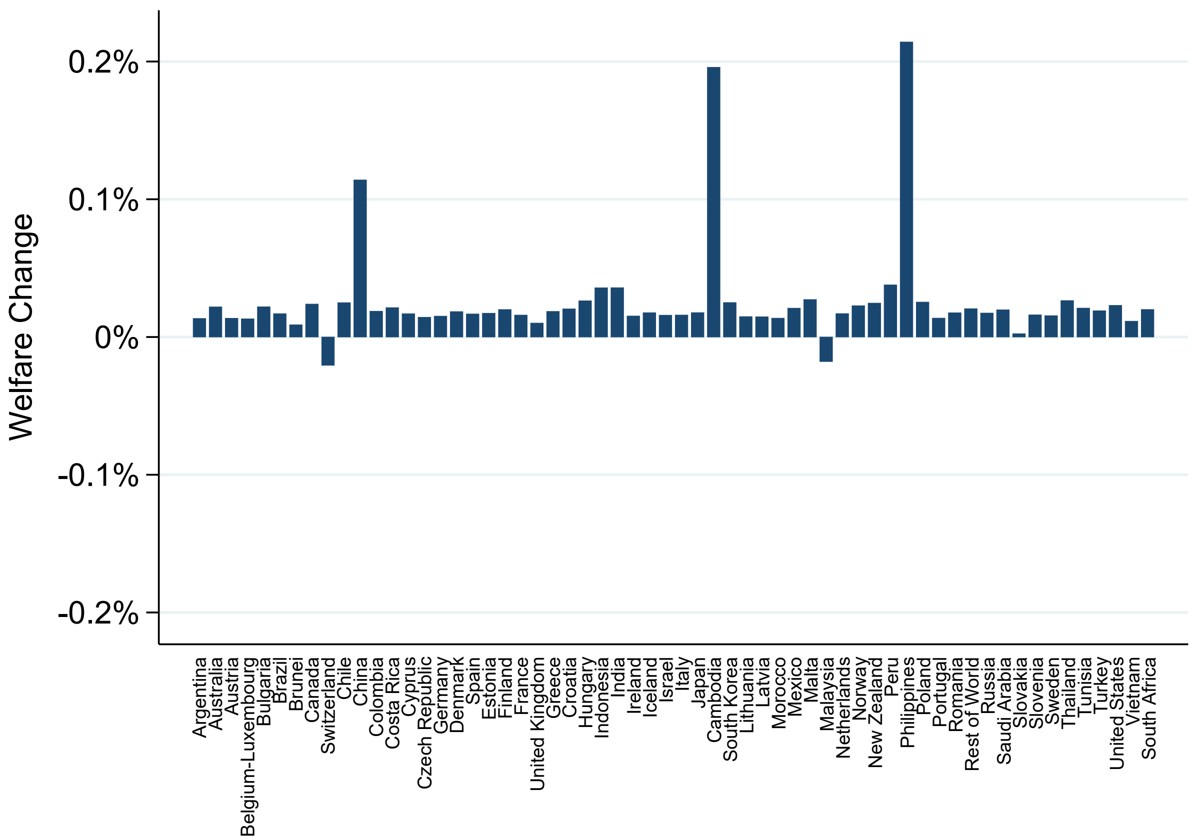
Notes: The figure shows the welfare effect of Taiwan's WTO entry on workers in the agriculture sector in economies other than Taiwan over the period of 1995–2020. The labor markets in economies other than Taiwan are country-sector specific.

Figure 20: Welfare effects of Taiwan's WTO entry across economies — manufacturing



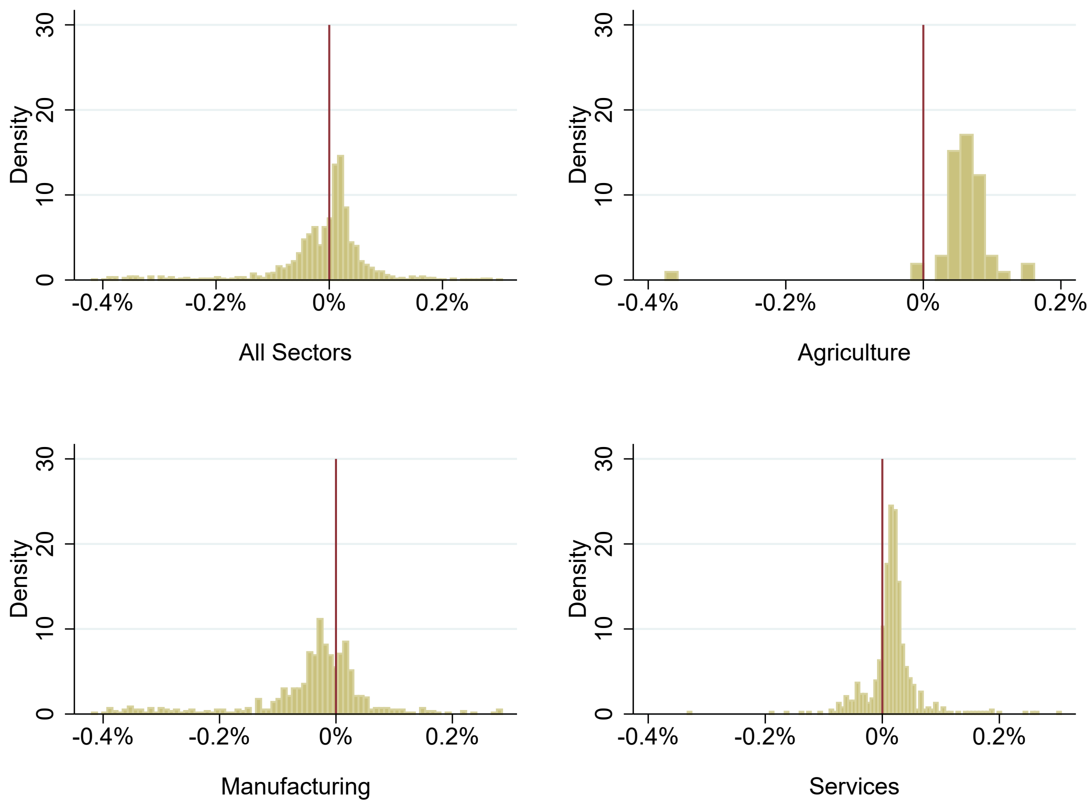
Notes: The figure shows the aggregate welfare effect of Taiwan's WTO entry on workers in the manufacturing sectors in economies other than Taiwan over the period of 1995–2020. The labor markets in economies other than Taiwan are country-sector specific. We aggregate the welfare effect across different sectors for each economy by using sectoral labor value added as weights. Data on value added are based on TiVA 2016, and data on labor share of value added are from Karabarbounis and Neiman (2014).

Figure 21: Welfare effects of Taiwan's WTO entry across economies — services



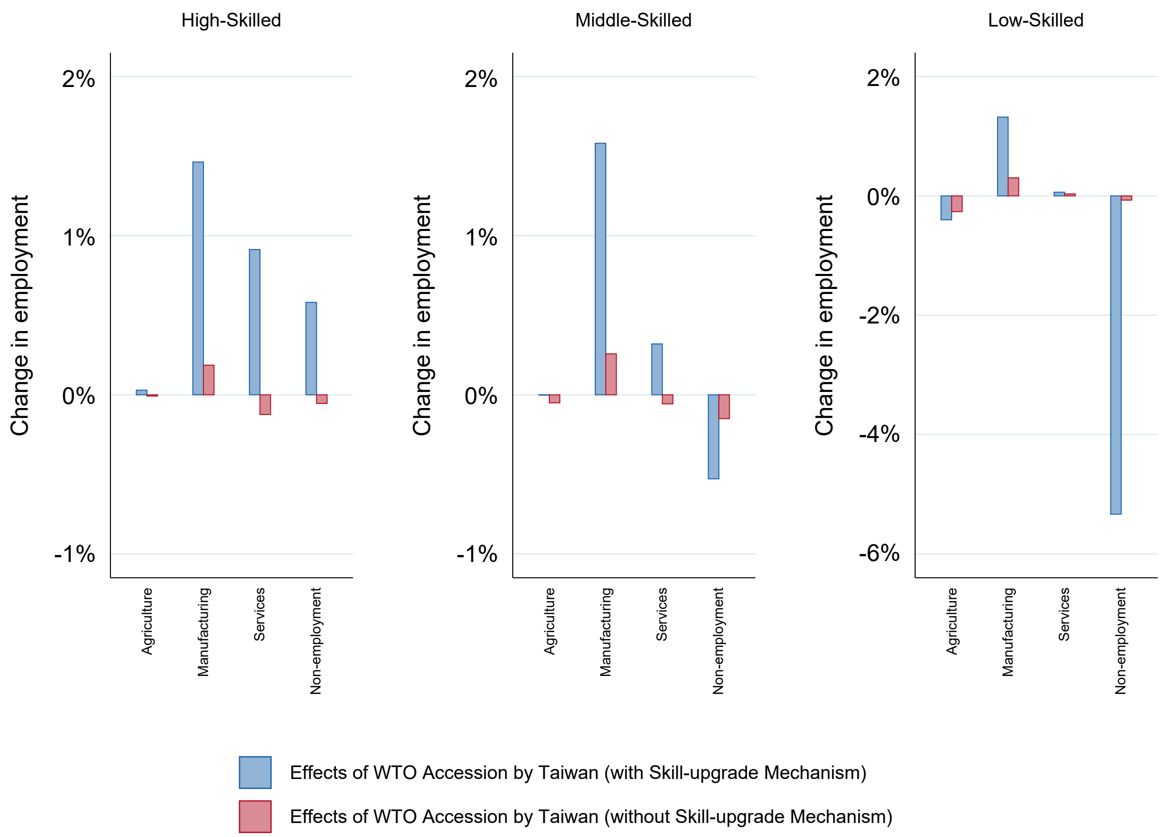
Notes: The figure shows the aggregate welfare effect of Taiwan's WTO entry on workers in the service sectors in economies other than Taiwan over the period of 1995–2020. The labor markets in economies other than Taiwan are country-sector specific. We aggregate the welfare effect across different sectors for each economy by using sectoral labor value added as weights. Data on value added are based on TiVA 2016, and data on labor share of value added are from Karabarbounis and Neiman (2014).

Figure 22: Distribution of the welfare effects of Taiwan's WTO entry across economies and sectors



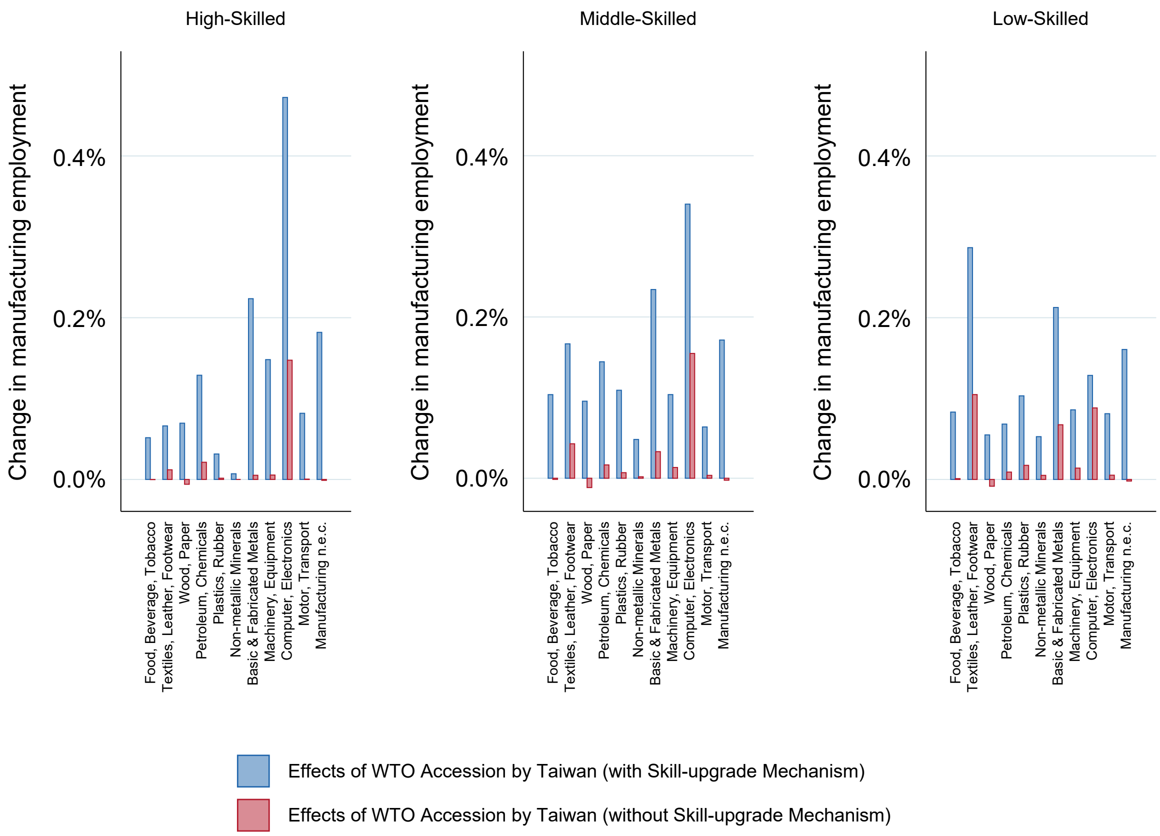
Notes: The figure shows the distribution of the welfare effects of Taiwan's WTO entry on workers across sectors and economies (other than Taiwan) over the period of 1995–2020. The labor markets in economies other than Taiwan are country-sector specific. In total, there are 1,320 such labor markets across economies (other than Taiwan). Labor markets with the largest and smallest changes in welfare due to Taiwan's WTO entry (above the 99th percentile and below the 1st percentile cutoffs) are dropped in each sub-figure.

Figure 23: Effects of Taiwan's WTO entry on the employment shares in Taiwan by aggregate sectors and skill groups



Note: The figure shows the effect of Taiwan's WTO entry on employment shares in Taiwan by aggregate sectors and skill groups over the period of 1995–2020. The change in employment shares is measured in terms of shares of total population (employed, unemployed, plus not-in-labor-force). In the scenario "Effects of WTO Accession by Taiwan (with Skill-upgrade Mechanism)," the effect is calculated to be the difference between the baseline economy (with WTO accession) and the counterfactual economy (without WTO accession), allowing for the skill-upgrade mechanism as modeled in the paper. See Figure 10 for the definitions of the baseline and the counterfactual economy. In the second scenario "Effects of WTO Accession by Taiwan (without Skill-upgrade Mechanism)," the effect is calculated as the difference between the baseline economy (with WTO accession) and the counterfactual economy (without WTO accession), in a setup without the skill-upgrade mechanism. In particular, the baseline economy is an economy where all time-varying fundamentals evolve as in the data from 1995 to 2007 (and remain constant after 2007), but the sector-skill transition costs if involving skill upgrade are set to be 10-fold in 1996 onwards relative to the level in 1995, which effectively shuts down the skill-upgrade mechanism. The counterfactual economy is the same as the baseline economy without skill-upgrade mechanism, except that Taiwan's tariffs on imports and foreign tariffs on Taiwan's exports are set to their levels in 1995. We simulate the model until 3000.

Figure 24: Effects of Taiwan's WTO entry on the employment shares in Taiwan by manufacturing sectors and skill groups



Note: The figure shows the effect of Taiwan's WTO entry on employment shares in Taiwan by manufacturing sectors and skill groups over the period of 1995–2020. See Figure 23 for the setup of the two scenarios, "Effects of WTO Accession by Taiwan (with Skill-upgrade Mechanism)" and "Effects of WTO Accession by Taiwan (without Skill-upgrade Mechanism)."

Table A.1: Sector concordance between ISIC Rev 3 and Taiwanese SIC

ISIC Rev 3	ISIC Rev 3 Descriptions	ROC SIC 5 (1995–1996)	ROC SIC 6 (1997–2001)	ROC SIC 7 (2002–2006)	ROC SIC 8 (2007)
c01t05	Agriculture, hunting, forestry and fishing	01–03	01–03	01–03	01–03
c10t14	Mining and quarrying	05–09	05–09	04–06	05–07
c15t16	Food products, beverages and tobacco	11–12	11–12	08–09	08–10
c17t19	Textiles, textile products, leather and footwear	13–15	13–15	10–12	11–13
c20	Wood and products of wood and cork	16	16	13	14
c21t22	Pulp, paper, paper products, printing and publishing	18–19, 83	18–19, 83	15–16, 84	15– 16, 58
c23	Coke, refined petroleum products and nuclear fuel	23	23	19	17
c24	Chemicals and chemical products	21–22	21–22	17–18	18–20
c25	Rubber and plastics products	24–25	24–25	20–21	21–22
c26	Other non-metallic mineral products	26	26	22	23
c27t28	Basic metals and fabricated metal products	27–28	27–28	23–24	24–25
c29	Machinery and equipment, nec	29	29	25	29, 34
c30t33	Computing, electrical and optical equipment	31, 33	31, 33	26–28, 30	26–28
c34t35	Transport equipment	32	32	29	30–31
c36t37	Manufacturing nec; recycling	17, 39	17, 39	14, 31	32–33
c40t41	Electricity, gas and water supply	41–44	41–44	33–36	35–36
c45	Construction	45–49	45–49	38–42	41–43, 81
c50t52	Wholesale and retail trade; repairs	51–57	51–56	44–48, 95	45–48
c55	Hotels and restaurants	58, 88	57, 88	50–51	55–56
c60t63	Transport and storage	61–62	61–62	53–58	49–53, 79
c64 and c72	Post and telecommunications; Computer and related activities	63, 75	63, 75	59–60, 72– 73	54, 61–63
c65t67	Financial intermediation	65–67	65–67	62–64	64–66
c70	Real estate activities	68	68	66	67–68
c71	Renting of machinery and equipment	78	78	67	77
c73t74	R&D and other business activities	71–74, 76, 77, 79	71–74, 76, 77, 79	69–71, 74–77, 92	69–76, 78, 80, 82
c75t95	Community, social and personal services	Else	Else	Else	Else

Notes: In the quantitative simulation analysis, we combine: c01t05 and c10t14; c20 and c21t22; c23 and c24; and c71 and c73t74. In presenting the stylized facts, we group sectors further to reduce the dimensionality. The 12 aggregate sectors in the stylized facts are as follows: "Agriculture, Mining" includes c01t05 and c10t14. "Food, Beverages, Tobacco" includes c15t16. "Textiles, Wood, Paper" includes c17t19, c20 and c21t22. "Petroleum, Chemicals, Plastics, Metals" includes c23, c24, c25, c26, and c27t28. "Machinery, Computer, Electronics & Electrical" includes c29 and c30t33. "Motor, Transport Equipment" includes c34t35 and c36t37. "Electricity, Water, Gas" includes c40t41. Construction includes c45. "Wholesale, Retail, Hotels, Restaurants" includes c50t52 and c55. "Transport, Storage" includes c60t63. "Business Services" includes c64, c65t67, c70, c71, c72, c73t74, and c75t95. "Non-employment" includes unemployment and not-in-labor-force. See Appendix B.1 for the definition of not-in-labor-force observations.

Table A.2: Summary statistics for selective parameters/variables

	Measurement	Source	Mean
			World/Taiwan/China
ζ^{nj3}	Wage-bill share of high-skilled workers in 1995	WIOD 2013	0.22/0.25/0.05
ζ^{nj2}	Wage-bill share of middle-skilled workers in 1995	WIOD 2013	0.46/0.30/0.45
ζ^{nj1}	Wage-bill share of low-skilled workers in 1995	WIOD 2013	0.32/0.44/0.49
γ^{nj}	Value-added share of gross output in 1995	TiVA 2016	0.52/0.44/0.39
$(1-\xi_n)$	Labor share in value added in 1995	KN 2014	0.44/0.51/0.55
			Agriculture/Manufacture/Services
α_j	Final consumption expenditure share in 1995	TiVA 2016	0.03/0.25/0.72
θ_j	Dispersion of productivity	CP 2015	8.59/4.58/10
			USA-TWN/USA-CHN/TWN-CHN/CHN-TWN
$\pi_{1995}^{nj,oj}$	Trade Share in 1995	TiVA 2016	1.7%/1.6%/1.7%/1.5%
$\pi_{2007}^{nj,oj}$	Trade Share in 2007	TiVA 2016	0.9%/10.1%/6.7%/4.3%
$\tau_{1995}^{nj,oj}$	Import Tariff in 1995	WITS	4.1%/6.5%/4.6%/20.4%
$\tau_{2007}^{nj,oj}$	Import Tariff in 2007	WITS	1.6%/2.8%/1.9%/4.6%

Notes: Measurements and sources of the data are documented in Appendix B. (i) The wage-bill share used in the analysis is that for each economy-sector-skill in 1995. The mean statistic for each economy reported in the table is the average across sectors of the economy. The "World" mean statistic is the average across all economy-sector observations, based on 60 individual economies in our sample. (ii) The value-added share of gross output for each economy-sector used in the analysis is constructed by: first aggregating value-added (and respectively, gross output) to our sector definitions, and then computing the share of value-added in gross output for each sector. The mean statistic for each economy reported in the table is computed using gross output of each sector as weights. The "World" mean statistic is computed using gross output of each economy and sector as weights. (iii) The labor share in value-added used in the analysis is that for each economy in 1995. The "World" mean statistic is the average across all economies, based on 60 individual economies in our sample. (iv) The final consumption expenditure share of each sector is computed using the ratio of the total expenditure on a sector's final goods and the total world income in 1995, similar to Caliendo, Dvorkin and Parro (2019). The shares for agriculture/manufacturing/services are the sum of the shares across individual sectors under each broad category. (v) The mean productivity dispersion parameter for the manufacturing sectors is the unweighted average across 11 manufacturing sectors in our study. Note we dropped the extreme elasticity estimates of Caliendo and Parro (2015) for mining and quarrying, wood, and petroleum, before calculating the elasticity for each of the 11 aggregate manufacturing sectors. We adopt a value of 10 for the service sector's productivity dispersion parameter, assuming that trade in services is more sensitive to trade costs than agriculture and manufacturing. (vi) The trade share $\pi^{nj,oj}$ measures economy n's share of expenditures in sector j that is allocated to source o. The mean trade share for a country-pair reported in the table is averaged across sectors weighted by sectoral expenditures. (vii) The import tariff $\tau^{nj,oj}$ indicates the tariff rate imposed by economy n against source o in sector j. The mean tariff rate for a country-pair reported in the table is the average across sectors weighted by sectoral import values. The label USA-TWN indicates the importing-exporting economies and similarly for the other pairs. KN 2014: Karabarbounis and Neiman (2014); CP 2015: Caliendo and Parro (2015).

Table A.3: Employment shares of the Taiwanese labor market by sector and skill type in 1995

Sector	Low-skilled workers	Middle-skilled workers	High-skilled workers	Sector total
Agriculture	7.81%	1.24%	0.23%	9.28%
Food Beverage, Tobacco	0.52%	0.42%	0.16%	1.10%
Textiles, Leather, Footwear	2.35%	0.86%	0.28%	3.50%
Wood, Paper	0.78%	0.70%	0.39%	1.87%
Petroleum, Chemicals	0.20%	0.41%	0.38%	1.00%
Plastics, Rubber	0.84%	0.53%	0.20%	1.57%
Non-metallic Minerals	0.40%	0.23%	0.10%	0.73%
Basic & Fabricated Metals	2.03%	1.10%	0.27%	3.40%
Machinery, Equipment	0.43%	0.43%	0.22%	1.08%
Computer, Electronics	1.45%	1.65%	1.11%	4.20%
Motor, Transport	0.40%	0.36%	0.17%	0.93%
Manufacturing n.e.c.	0.76%	0.36%	0.12%	1.24%
Electricity, Water, Gas	0.04%	0.18%	0.13%	0.35%
Construction	5.45%	2.07%	0.78%	8.30%
Wholesale, Retail	4.64%	5.21%	2.27%	12.13%
Hotels, Restaurants	2.01%	1.08%	0.16%	3.25%
Transport, Storage	1.39%	1.26%	0.57%	3.22%
Telecom, Computer	0.15%	0.90%	1.08%	2.13%
Financial Intermediation	0.07%	0.18%	0.14%	0.40%
Real Estate Activities	0.07%	0.29%	0.41%	0.77%
Other Business Services	0.22%	0.74%	0.58%	1.55%
Education, Public Services	3.48%	4.28%	5.33%	13.09%
Total: Manufacturing	10.18%	7.06%	3.38%	20.62%
Total: Services	17.53%	16.19%	11.46%	45.18%
Total: MCEE	1.88%	2.08%	1.32%	5.29%
Total: Business Services	0.51%	2.11%	2.22%	4.84%
Total: Exclud. non-employ.	35.53%	24.49%	15.07%	75.08%
Non-employment	16.50%	5.88%	2.53%	24.92%
Total	52.03%	30.37%	17.60%	100.00%

Notes: The table reports the employment shares of the Taiwanese labor market across sectors and skill types in 1995.