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Institutional Mediation of Technological Displacement: Port Automation and Dock Worker Outcomes in Hamburg, Rotterdam, and Qingdao

Muzi Su

The Second High School Attached to Beijing Normal University, Beijing, China
15120090281@163.com

Abstract. Automated container terminals opened at Hamburg in 2002, at Rotterdam in 2015, and at Qingdao in 2017. The three cases are compared here using published port-activity statistics together with case evidence on labor adjustment and institutional response. The comparison is descriptive; no causal effect is estimated. In all three cases, activity was higher in the post-adoption windows observed. Staffing is where the cases separate, and only Qingdao reports a terminal-level staffing figure: nine remote operators now perform work that previously required more than sixty people at a conventional terminal handling a comparable workload. Hamburg relied on firm-level employment protection and training. Rotterdam relied on social dialogue and an expected outflow of retirements. Qingdao relied on training organized by the enterprise itself. Automation does not simply reduce port activity or produce one uniform employment outcome; it reorganizes the labor a terminal requires. Employment protection, training, retirement, and social dialogue are governed by different institutions, and that is what decides who carries the cost. Comparable technologies can therefore have very different social consequences in different ports. That is what connects technological displacement to the practical content of a just transition in port work.

Keywords: port automation, dock workers, just transition, institutional variation, comparative case study

1. Introduction

For much of the twentieth century, dock work stood at the center of port operations. Dockworker unions held strong local bargaining power [1]. Containerization later cut the longshore employment share at many ports [2]. Terminal automation is the most recent phase of this shift.

Public debate on port automation tends to go to two extremes. One view stresses that a large share of jobs could be automated by computers [3]. Another points out that China now has more automated terminals than any other country, and its leading facilities set strong equipment-efficiency records [4]. Yet neither side looks at how the adjustment falls on the workers directly affected.

Three port-automation cases are examined below, and the labor-adjustment mechanisms each employed are compared. Port-activity indicators are used alongside case-based evidence on labor-

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task reorganization and institutional responses. Existing research has usually treated technological change and labor-market adjustment as separate questions. This study combines them. The argument is that institutional arrangements decide how the costs of automation are distributed. Technology alone cannot absorb those costs.

2. Literature review

Studies on automation draw a line between what technology takes away and what it brings. Acemoglu and Restrepo name two key effects: the displacement effect, where machines take over human tasks, and the reinstatement effect, where new-created tasks increase labor demand [5]. Frey and Osborne work at the level of occupations and estimate that a substantial share is susceptible to computerisation, though their concern is prospective rather than realized job loss [3]. Autor, Levy, and Murnane approach the same shift from the task side: routine tasks are more readily substituted, while non-routine cognitive tasks are complemented [6]. None of this is about ports. What carries over is the level of analysis. The typical pattern is task substitution, not wholesale job disappearance.

Evidence from port industries offers more concrete insights. Container shipping cut longshore workers' employment share in port cities, but local unemployment rates did not go up [2]. By tracking British dock workers over decades, El-Sahli and Upward find that employment security helps reduce costs brought by technological shifts. In the long run, former dock workers do not face obviously worse labor-market results than similar low-skill workers [1]. Remote operation, the International Transport Workers' Federation observes, tends to reduce and reconfigure dock labor, and unions have responded through collective bargaining and industrial action [7].

Assessing these adjustments requires a framework. McCauley and Heffron describe a just transition using distributional, procedural and restorative justice [8]. The International Labour Organization points out three practical tools for port-sector technological change: training, stable employment and social communication [9]. Both views stress that institutions handle social adjustments.

Why do similar technological pressures lead to different results? Comparative institutional theory explains this point. In coordinated economies, workers join decision-making through skill-building programs and group representation [10]. Different welfare systems provide different levels of protection against labor-market risks [11]. As Polanyi states, unregulated markets will trigger social responses for protection [12]. Therefore, institutions largely decide how automation-related costs are shared among groups. This framework does not predict one single final outcome. Instead, it shows how these costs get passed around.

3. Methodology

3.1. Case selection and design

Three cases structure the comparison. Hamburg's Container Terminal Altenwerder (CTA) began operations in 2002. Rotterdam's Maasvlakte II automated terminal cluster, comprising APM Terminals (APMT) and Rotterdam World Gateway (RWG), opened in 2015. Qingdao's fully automated container terminal entered commercial operation in 2017 [13-15], with a second phase following in 2019 [16]. The cases represent comparable forms of automated container-terminal operation, and each combines automated guided vehicles with automated yard or quay systems. They differ in institutional and organizational setting, and their firms, scales, and technologies are not identical either. The design follows a comparative institutional logic, in which similar pressures

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can produce different outcomes depending on the coordinating institutions in place [10, 11]. Comparing the channels through which each setting allocates adjustment costs is the aim. A single causal effect is not what this design estimates.

3.2. Data sources

Port activity was measured using official container-throughput and cargo-volume statistics published by Port of Hamburg Marketing, the Port of Rotterdam Authority, and Qingdao Port International. The specific publications are cited alongside the corresponding results. Eurostat's database at level 2 of the Nomenclature of Territorial Units for Statistics (NUTS-2) supplies the regional employment, unemployment, and real GDP indicators [17]. Employment runs 2008 to 2025, unemployment 1999 to 2025, real GDP through 2024. Hamburg, Zuid-Holland, Antwerp, and Bremen are covered. These series describe the wider economic context; they are not measures of terminal-worker outcomes. Official company reports, port-authority publications, and Qingdao municipal documents provide the evidence on employment protection, training, social dialogue, and retirement.

3.3. Analytical approach and limitations

The analysis is descriptive and comparative. Port activity is shown in annual levels (Figure 1), and an event-time index that sets the year before automation to 100 is provided in the accompanying workbook for supplementary comparison. The descriptive windows are Hamburg 1997 to 2001 versus 2002 to 2006, Rotterdam 2011 to 2014 versus 2015 to 2019, and Qingdao 2016 versus 2017 to 2021. Percentage change is calculated as the difference between the post- and pre-adoption averages divided by the pre-adoption average. Because Qingdao's container-throughput series changes coverage in 2017, the formal comparison uses only the scope-consistent Group/JV/associate cargo series. The study does not claim causal identification. The regional employment series begins in 2008, whereas unemployment begins in 1999. Hamburg therefore has no comparable pre-automation employment series and only three pre-automation unemployment observations. Regional indicators are NUTS-2 aggregates rather than direct measures of terminal workers. Port-activity figures for Hamburg and Rotterdam are port-wide, so they describe the setting of automation rather than the isolated effect of a single terminal.

4. Results

4.1. Port activity around automation

Container throughput rose in the years following automation at the two ports with a continuous, same-scope series (Figure 1). At Hamburg, port-wide container throughput moved from 4.7 million twenty-foot equivalent units (TEU) in 2001, the year before CTA opened, to 8.3 million TEU in 2025 [18]. At Rotterdam, container throughput rose from 12.3 million TEU in 2014 to 14.2 million TEU in 2025 after the Maasvlakte II automated terminals opened in 2015 [19]. In the selected windows, Hamburg's pre/post container-throughput average rose by about 81.1 percent and Rotterdam's by about 13.6 percent. Qingdao's separate container-throughput series is shown in Figure 1 for context and draws on official annual reports and a national port comparison [15, 20-22]. It moves from 18.0 million TEU in 2016 to 32.2 million TEU in 2024, but its coverage changes in 2017 and it is not used for the formal pre/post comparison. Qingdao's scope-consistent Group/JV/associate cargo series rose by about 15.8 percent, although only one pre-treatment year is

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available and the comparison is therefore limited. Post-adoption window averages were higher in all three cases, although annual movements were not uniformly upward.

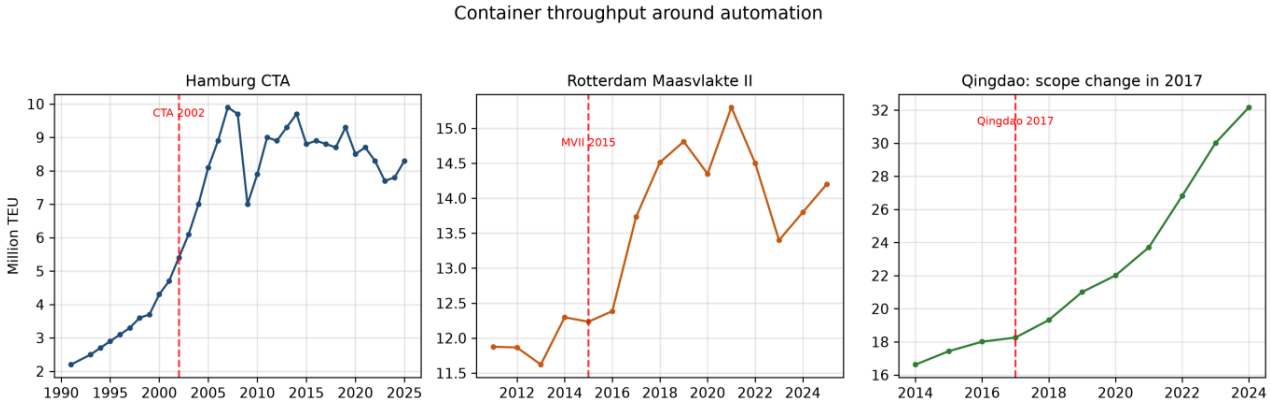

Figure 1. Container throughput around automation

4.2. Terminal-level labor intensity: Qingdao

Qingdao offers reported evidence of lower labor intensity in an automated terminal relative to a conventional-terminal comparison. Municipal sources report that nine remote operators at the automated terminal perform work that previously required more than 60 people at a conventional terminal, a reduction of about 85 percent in operating personnel at the terminal level (Figure 2, left panel) [23]. This is a cross-sectional comparison of staffing intensity, not a before-and-after headcount. The same case shows an enterprise-wide training capacity. Qingdao Port Group reports full training coverage across its workforce, with average annual training rising from more than 32 hours per employee in 2020 to at least 88 hours in 2023 [16, 24]. It also reported more than one million professional-skills training sessions in 2023 (Figure 2, right panel) [24]. An enterprise-wide training system therefore exists. Whether it produces automation-specific retraining or confirmed redeployment is not something these figures show. The International Transport Workers' Federation characterizes remote operation as tending to reduce and reconfigure dock labor [7]. That characterization matches the Qingdao pattern of fewer on-site operators combined with expanded training.

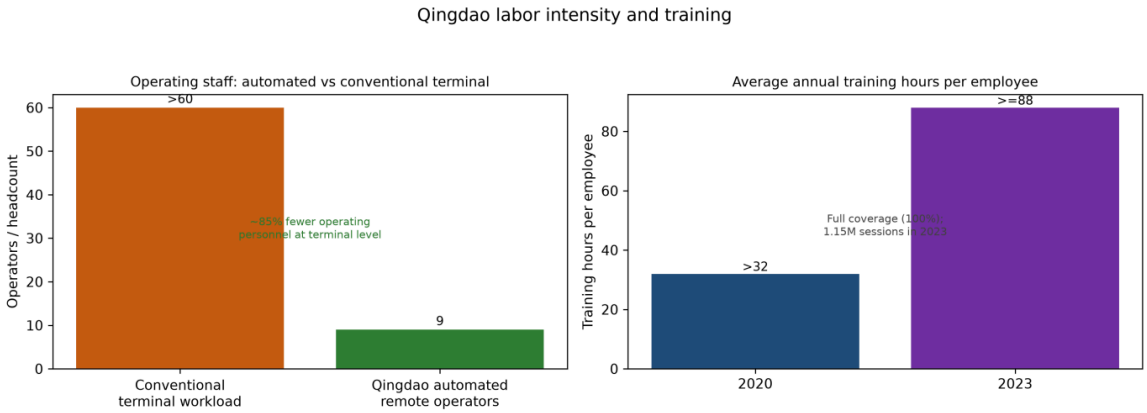

Figure 2. Qingdao labor intensity and training

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4.3. Institutional adjustment channels

The three cases allocate adjustment costs through different institutional channels. In Germany, HHLA reports employment-protection arrangements that include a ban on compulsory redundancies, grandfathering of existing staff, training commitments, and priority for affected employees in vacancies [25]. These are contemporary firm-level arrangements reported by HHLA, not a measured 2002 employment effect. The protection that frames adjustment at Hamburg is still visible in them. In the Netherlands, the Port of Rotterdam Authority reported about 500 APMT and RWG employees at the automated terminals in 2015 and an expected retirement outflow of roughly 200 workers through 2019, while describing the scale of redundancies as unclear. Social dialogue was used to prevent possible job losses as cargo shifted from Maasvlakte 1 to Maasvlakte 2 [14]. In China, the available evidence documents enterprise-led training, although it does not show whether training resulted in redeployment or employment retention. The cases place different weight on the training, employment-security, and social-dialogue mechanisms identified by the International Labour Organization [9].

4.4. Regional labor-market context

The regional indicators do not show a sustained region-wide deterioration after the automation years (Figure 3). Between 2008 and 2025, the NUTS-2 unemployment rate fell in Hamburg from 7.1 to 5.3 percent and in Bremen from 9.6 to 5.1 percent, rose slightly in Zuid-Holland from 3.8 to 4.8 percent, and fell in Antwerp from 4.6 to 4.3 percent. In the broad Statistical Classification of Economic Activities in the European Community (NACE) G-I aggregate, employment changed by about minus 4.9 percent in Hamburg, plus 23.0 percent in Zuid-Holland, plus 8.5 percent in Antwerp, and plus 7.8 percent in Bremen over the same period. These are regional aggregates, not dockworker employment. The patterns are consistent with Gomtsyan's finding that containerization reduced the longshore employment share in port cities without raising local unemployment [2]. Taken with the case evidence, the regional data point the same way as the paper's central argument: institutions mediate the costs of automation.

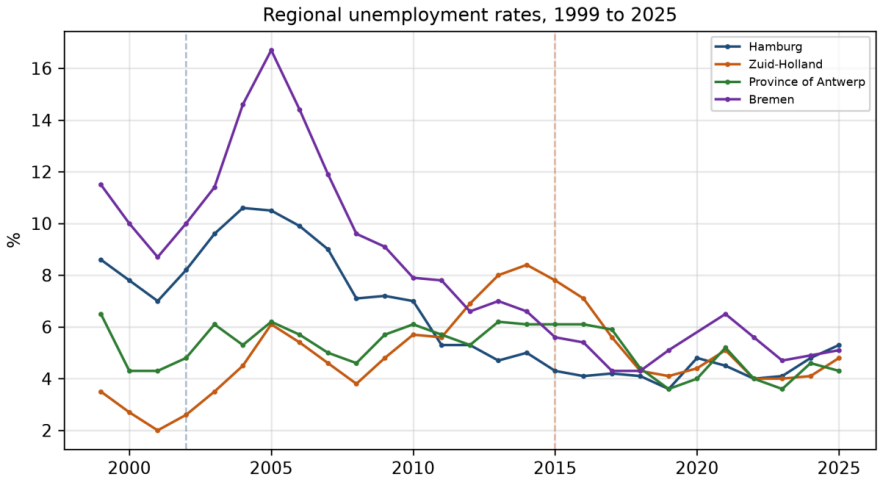

Figure 3. Regional unemployment rates, 1999 to 2025

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5. Discussion

Port activity rose after automation in all three cases. That is the least informative finding here. Hamburg's figures cover a whole port, as do Rotterdam's; neither isolates a terminal, and both ports were growing before the automated terminals opened. What these movements show is that the timing coincides with automation. Causation is a different claim, and this design cannot support it. The result that carries the argument is one only Qingdao publishes: nine operators where sixty worked. It is a substitution at the level of tasks. Nothing else in this paper measures changing labor requirements directly. The International Transport Workers' Federation characterizes remote operation the same way, as reducing and reconfiguring dock labor [7].

The three cases then handle the consequence differently. That difference is the paper's central point. Displacement and reinstatement, in Acemoglu and Restrepo's distinction, help interpret the evidence [5]; what the port cases mainly show is displacement at the level of tasks, cushioned by institutional response. In Germany, HHLA's contemporary arrangements, which include a ban on compulsory redundancies, grandfathering of existing staff, training commitments, and priority for affected employees in vacancies, give affected workers a claim on the adjustment [25]. Employment security softened the long-run cost of technological change for British dockworkers, and the German case is consistent with that evidence [1]. Social dialogue and an expected retirement outflow framed the adjustment at Rotterdam [14]. Enterprise-led training is the only channel the Chinese evidence documents. The three mechanisms identified by the International Labour Organization [9] therefore carry different weights across the cases, even though the underlying technologies are comparable.

Which question does each channel answer? McCauley and Heffron's dimensions of a just transition give the answer: who bears the cost, through what process, and what repair is available [8]. The broader comparative-institutional account accommodates them as well. Coordination through representation and skill formation is what Hall and Soskice emphasize [10]; Esping-Andersen's welfare states differ instead in how far they cushion labor-market risk [11].

This interpretation has two key limitations. The study compares adjustment channels among different cases, but it cannot calculate one clear causal effect of automation on employment. Besides, direct data about labor intensity mostly comes from Qingdao. Even there, researchers only compare different terminals at one time point instead of tracking worker numbers before and after changes. For Hamburg and Rotterdam, we can only get institutional evidence, with no measurable employment-change results. The regional labor-market background shows no sustained region-wide deterioration after the automation years, in line with evidence that containerization reduced the longshore employment share in port cities without raising local unemployment [2]. Those figures measure NUTS-2 populations, not terminal workers, and they offer no counterfactual. The contribution, therefore, is to show that comparable forms of automation produce different adjustment paths depending on the institutional setting. Quantifying net job loss is beyond what this design can do.

6. Conclusion

Port automation is usually argued about as a number: how many jobs, and how soon. The three cases suggest a better question: which institutions decide how that number falls. A firm-level ban on compulsory redundancies covers Hamburg's workers. An expected outflow of retirements shaped Rotterdam's adjustment. Enterprise-led training is how Qingdao's adjustment is handled. The technologies involved are close enough that they cannot explain the difference. What differs is who

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negotiates the adjustment, and therefore what automation turns out to mean for the people on the quay.

A practical implication follows. Training, employment security, and social dialogue can all reduce adjustment costs. Their effects, however, depend on whether workers gain real access to new roles. Qingdao's rise from more than 32 hours of training per employee in 2020 to at least 88 hours in 2023 [16, 24] shows that a training system exists; it does not show that anyone moved into a new job because of it. Firm-level worker panels and wage data would separate task substitution from net employment change. Terminal-level employment records are not available, and without them claims about the employment effects of automation, including the ones made here, remain harder to check than they should be.

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