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Challenges and Reconstruction of Human-Machine Collaboration in the Era of Embodied Intelligence

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Abstract. Embodied intelligence is driving the human-machine relationship from a "human-dominated" model toward "collaborative co-creation," which, while boosting productivity, also triggers deep-seated contradictions in production relations. Drawing on Marx's theory of reproduction, this paper analyzes the dilemmas of human-machine collaboration through the four stages of production, distribution, exchange, and consumption: In the production stage, workers lose decision-making power, are disciplined by algorithms, and are alienated into becoming data producers; in the distribution phase, behavioral data unconsciously generated by workers drives algorithmic iteration yet remains excluded from the distribution system, resulting in hidden data exploitation; in the exchange phase, high barriers to entry for technology and capital foster market monopolies; and in the consumption phase, high costs lead to service stratification, making it difficult for technological dividends to benefit the general public. The root causes lie in the disruption of labor relations boundaries by the transformation of the means of production, the exclusion of implicit data labor from distribution rules, the concentration of capital driven by high industry barriers, and social structural constraints on technological dissemination. Therefore, this paper advocates for the coordinated reconstruction of production relations across three levels: macro-level institutional constraints, meso-level organizational transformation, and micro-level rights protection. Through pathways such as the recognition of data labor rights, anti-monopoly regulation, and algorithmic transparency, we aim to build an equal, just, and sustainable future of human-machine collaboration.

Keywords: Era of Embodied Intelligence, Human-Machine Collaboration, Relations of Production, Challenges, Reconstruction

1. Introduction

With the rapid iteration of artificial intelligence technology, embodied intelligence, characterized by the integration of an "AI brain + physical body + environmental interaction," is gradually achieving deep integration with industrial reality and is setting off a wave of productivity transformation. While embodied intelligence brings about a tremendous leap in productivity, people also place high expectations on it, believing that it can liberate human beings from repetitive and dangerous labor and move toward a higher level of human emancipation. However, technology itself does not automatically guarantee the realization of emancipation; beneath the halo of technological

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empowerment, new contradictions in production relations and dilemmas of labor alienation are quietly emerging. Under the appearance of "collaboration," there are in fact predicaments such as the widespread anxiety over the structural replacement of labor and the disciplining of the body by algorithms. Consequently, the resulting human-machine relationship may not necessarily move toward harmonious coexistence; instead, driven by the logic of capital, it may evolve into a deeper level of domination, causing "collaboration" to become alienated into "dependence," thereby posing severe challenges to labor subjectivity. To truly understand and resolve the dilemmas of human-machine collaboration in the era of embodied intelligence, it is necessary to return to the analytical level of production relations and examine the dynamic game among capital, technology, and labor. Marx's critical analysis of machine-based large-scale industry in Capital and the fundamental method of his critique of political economy provide us with theoretical tools for gaining insight into the logic of capital. Following this approach, embodied intelligence can be situated within this analytical framework to reveal how capital reshapes the labor process and extracts surplus value beneath the glamorous appearance of the optimized reorganization of production factors catalyzed by embodied intelligence.

In view of this, this paper will first analyze how embodied intelligence reshapes the traditional labor process and the combination of production factors, then further explore the latent conflicts hidden within human-machine collaborative practices after embodied intelligence becomes embedded in the labor process, and finally attempt to propose governance strategies aimed at transcending the superficial appearance of collaboration and constructing substantive symbiosis. The purpose is to provide a critical political economy perspective for understanding the transformation of production relations brought about by embodied intelligence and to explore institutionalized implementation paths for building an equal, just, and sustainable future of human-machine collaboration.

2. Challenges posed by embodied intelligence to existing production relations

The rapid development of embodied intelligence is driving the transformation of human-machine relations from a model dominated by humans with machines serving as assistants to one characterized by collaborative human-machine co-creation. This transformation not only promotes a leap in productivity but also poses challenges to production relations. In the Introduction to A Contribution to the Critique of Political Economy, Marx pointed out that "production, distribution, exchange and consumption form a totality, distinctions within a unity," and that "there is interaction between the different elements. This is the case with every organic whole." [1] Based on Marx's theory of reproduction, this paper examines the multidimensional impacts of embodied intelligence on social production.

2.1. The production process: Physical agency weakens the subject status of labor

Marx believed that the simple elements of the labor process are purposeful activity or labor itself, the object of labor, and the instruments of labor [2]. Accordingly, the labor process is a purposeful activity in which laborers use instruments of labor to act upon objects of labor in order to create use value. The core feature distinguishing embodied intelligence from disembodied intelligence lies in its "physical agency." It is not merely a tool that executes preset instructions; rather, through the dynamic coupling of "body–environment–cognition," it can autonomously complete the closed loop of "perception–decision-making–execution" in the physical world [3]. Embodied intelligence equipped with autonomous action capabilities is transforming from a passively used instrument of

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labor into an agent laborer operating alongside human laborers. This transformation means that instruments of labor are beginning to possess a form of "quasi-subjectivity," while the dominant position of laborers in the production process is being challenged, thereby weakening their subject status.

The marginalization of laborers at the level of physical operation is manifested in four dimensions. First, decision-making is to a certain extent taken over by algorithms. In traditional machine-based large-scale industry, although machines replaced part of the laborers' physical labor, they still operated according to fixed modes under the setting, supervision, and control of laborers. However, in production processes involving embodied intelligence, embodied intelligence itself possesses independent capabilities of perception, decision-making, and execution, and laborers may be excluded from the closed loop of "decision-execution." Second, the labor rhythm of workers is controlled by machines. The refined control exerted by embodied intelligence over production processes compels workers' action rhythms to obey algorithmic scheduling. Due to the rhythm calculated in real time by algorithms, workers may gradually lose the space for autonomous adjustment and shift from being leaders of operations to being subjects of dispatch. Third, a deeper level of alienation is reflected in the tendency toward deskilling of laborers. In traditional production, workers often accumulated experiential knowledge through long-term practice, whereas in production driven by embodied intelligence, such experiential accumulation rapidly depreciates in the face of standardized and large-scale databases. Fourth, and more covertly, the value creation of laborers becomes instrumentalized. Although laborers are marginalized in terms of physical operations, they have not truly left the production process. On the contrary, every action, every collaboration, and even every correction of machine errors continuously provides free data resources for the iterative optimization of algorithms. Unconsciously, laborers are alienated from material producers creating use value into data producers whose labor data are appropriated without compensation and then used in turn to strengthen control over themselves. The role of laborers has already been alienated into "data collectors" for robot learning.

It can thus be seen that even before embodied intelligence reaches full autonomy, its physical agency has already substantially weakened the subject status of laborers in the production process through the refined control of workers' bodies.

2.2. The distribution process: Data feedback impacts existing distribution principles

Distribution relations are essentially determined by ownership of the means of production. In the industrial era, the means of production were owned by capitalists, while laborers could only obtain wages by selling their labor power. The share of distribution received by laborers was mainly measured according to the quantity and quality of physical and mental labor they contributed during the production process. The introduction of embodied intelligence has transformed the process of value creation. During production, embodied intelligence continuously generates, collects, and feeds back massive amounts of perceptual data, behavioral data, and feedback data. The data generated by embodied intelligence not only drive current production operations but also further feed back into the iterative optimization of algorithms, continuously improving the productive efficiency of the system. The value of the data labor unconsciously produced by workers remains ambiguously defined under existing distribution rules. Ownership of data is often implicitly assumed to belong to the owners of embodied intelligence hardware or platforms, while the contributions of laborers to data production are not clearly defined. After deducting the wages obtained by laborers on the basis of traditional physical or mental labor, the remaining value generated through data feedback forms a more concealed type of data surplus value.

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Therefore, the crux of the issue lies in the following questions: To whom do the data generated in real time by embodied intelligence during production activities belong? Do the behavioral data unconsciously produced by laborers during operation, collaboration, and maintenance constitute part of their labor contribution? When such data are used to train algorithms, improve production efficiency, and generate profits for enterprises, can laborers share in the value-added gains thus created? Existing distribution principles lack clear definitions regarding these issues and still take traditional physical and mental labor as the core standards of measurement, failing to incorporate contributions from "data labor" into the scope of distribution. In March 2026, JD.com announced that it would establish the world's largest embodied intelligence data collection center, planning to organize more than 100,000 internal employees and up to 500,000 external participants from various industries to engage in data collection, with more than 100,000 citizens to be mobilized in Suqian alone. The collection scenarios cover logistics warehousing, industrial manufacturing, household services, and other fields, with the goal of accumulating more than 10 million hours of real-world scenario data within two years for training embodied intelligent robots [4]. How laborers' data contributions should be recognized and compensated has thus become an unresolved issue. Reports indicate that frontline couriers and warehouse sorters will wear sensors during daily operations and become "data teachers" for robots, while the future objective of these robots is precisely to replace such labor-intensive positions.

The behavioral data unconsciously produced by laborers are being systematically collected, processed, and used for algorithmic iteration, thereby becoming core assets for enterprises to improve production efficiency and reduce labor costs. However, the value of this "data labor" is not reflected in existing compensation systems: laborers still receive wages according to traditional working hours or piece-rate systems, while the value-added benefits created by the data they produce are entirely appropriated by platform owners.

2.3. The exchange process: Ecological monopoly intensifies unequal exchange

Exchange is the mediating element between production and distribution determined by production on the one hand and consumption on the other [1]; it is the indispensable link through which labor products realize their social attributes. Marx also regarded exchange relations as a direct reflection of the social connections among producers, with exchange activities directly representing the social relations among producers. Marx pointed out that commodity exchange based on exchange value establishes comprehensive equality among subjects [5]. In exchange activities, people not only treat one another as equal subjects, but also form objective social connections and interdependent relations through exchange. However, in the era of embodied intelligence, the market ecology may exhibit characteristics of ecological monopoly, thereby intensifying inequality in the exchange process.

"Ecological monopoly" refers to the phenomenon whereby, due to high technological barriers, massive capital investment, and long research and development cycles in the embodied intelligence industry, market resources increasingly concentrate in a small number of leading enterprises, thus forming an exchange structure dominated by such leading firms. The highly concentrated market structure is merely the superficial manifestation of ecological monopoly; its deeper mechanism lies in the fact that, unlike ordinary industries in which enterprises mainly rely on economies of scale to form market dominance, the leading position in the embodied intelligence industry is more heavily based on technological barriers, data accumulation, and ecosystem lock-in capabilities. The research and development of embodied intelligence products involves not only hardware manufacturing such as core components and control systems, but also the development of algorithms such as perception,

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decision-making, and control models, as well as the continuous accumulation of training data and scenario feedback data, thereby creating extremely high barriers to market entry. For small and medium-sized enterprises, even if they possess certain advantages in a specific technological link, it is often difficult for them to enter complete market competition on the basis of a single capability, because they neither have sufficient financial support nor can they bear the enormous costs of large-scale research and development, testing, and commercial implementation.

By virtue of their monopolistic positions, ecological dominators continuously extract data, lock in users, and expand ecosystems at extremely low cost, while small and medium-sized producers and laborers are placed at the end of the exchange chain and are compelled to surrender the value they create. More seriously, this unequal exchange possesses a self-reinforcing feedback mechanism: ecological monopolists continuously enhance product competitiveness through their control over the formulation of exchange rules, increasingly abundant data, and continuously optimized algorithms, thereby constantly widening the exchange gap between themselves and small and medium-sized producers.

2.4. The consumption process: Service stratification leads to imbalances in social reproduction

Consumption is the endpoint and purpose of the overall process of social production. It "makes the product into a real product," while at the same time "creating new needs for production." [5] In the consumption stage, embodied intelligence technology should in principle follow a developmental trajectory characterized by declining costs, expanding popularization, and the eventual realization of democratized consumption. However, actual development has instead tended toward service stratification, with the dividends of technological progress being confined to a small number of high-income groups and failing to extend to the broader population, thereby aggravating the solidification of the consumption structure.

The stratification of services is first manifested in extremely high consumption thresholds. At present, the costs of core components for embodied intelligent robots remain relatively high, making it difficult for the manufacturing costs of complete machines to decline and consequently causing product prices to remain at high levels for a long period. For example, imported harmonic reducers cost as much as tens of thousands of yuan per unit, resulting in persistently high costs for complete machines (the price of the Boston Dynamics Spot robot reaches 530,000 yuan) [6]. High costs determine high prices, and high prices in turn make high-value-added scenarios such as advanced manufacturing and commercial exhibitions the primary users of embodied intelligence, while inclusive demands such as elderly care and domestic services are excluded from the embodied intelligence application market. This distorted consumption structure in turn sends distorted signals back to the production side: driven by the pursuit of profit maximization, enterprises can only direct research and development resources toward embodied intelligence serving high-end industries while reducing investment in inclusive embodied intelligence, thereby forming a negative cycle in which embodied intelligence consumption increasingly departs from broad social needs and instead serves a small number of actors with stronger purchasing power.

Take the Chinese market as an example. In 2024, China's per capita disposable income was 43,377 yuan, and urban residents reached 56,502 yuan [7]. Even calculated by urban residents' income, an industrial-grade embodied intelligent robot (300,000 to 800,000 yuan) equals 5 to 14 years of disposable income. Even lightweight products costing over 100,000 yuan need nearly two years of total income. At the same time, an industrial-grade embodied intelligent robot with basic autonomous functions usually costs 300,000 to 800,000 yuan. Even lightweight, general service products are mostly priced above 100,000 yuan. This means for most ordinary households and small

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service organizations, embodied intelligence is still an unaffordable capital good, not a daily consumer product.

Consumption power is highly concentrated. Under capital logic, market demand for embodied intelligence leans toward capital-intensive fields like high-end manufacturing and large research institutes. These high-value scenarios have low price sensitivity and high tech needs. They further push producers to focus on high-end markets. So demand from public procurement limits the space for inclusive consumption growth. To win orders from high-end firms and big research bodies, companies must meet specific project tech and performance rules. They do not simplify functions or cut costs for ordinary households. As a result, inclusive and livelihood-oriented consumption demand gets squeezed.

3. An analysis of the causes of the dilemmas in human-machine collaborative production relations in the era of embodied intelligence

The development of production relations often possesses characteristics of gradual change and lag. At present, the transformation of production relations lags behind the leap in productivity triggered by artificial intelligence. The dilemmas generated by embodied intelligence in the processes of production, distribution, exchange, and consumption are not the inevitable costs of technological progress, but rather the product of the asynchrony between the leap in productive forces and the transformation of production relations. At the technological level, the leap in the instrumental attributes of the means of labor brought about by embodied intelligence impacts the existing boundaries of labor relations; at the economic level, the value formation mechanism of the new type of "implicit data labor" breaks through the recognition framework of industrial-era distribution rules; at the institutional level, the high barriers of the industry promote the continuous concentration of capital and the strengthening of market dominance, thereby undermining the preconditions for fair exchange; and at the social level, existing structural inequalities constrain the inclusive dissemination of technology, leading to the solidification of consumption stratification.

3.1. The leap in the means of labor impacts the boundaries of labor relations

Embodied intelligence has reconstructed the system of production factors and promoted the development of new-quality productive forces, but it has also impacted the boundaries of labor relations. First, what embodied intelligence changes is not merely efficiency, but the instrumental attributes of the means of labor themselves. In the traditional industrial era, no matter how complex and sophisticated machines were, their essence remained an extension of the will of laborers; they were passive tools executing instructions. Marx once pointed out that the means of labor are "a thing or a complex of things which the laborer interposes between himself and the object of labor and which serves as the conductor of his activity." [2] However, the "perception–decision-making–execution" closed loop of embodied intelligence means that it no longer functions merely as a simple medium of transmission; rather, within a certain scope, it undertakes action functions that originally belonged to laborers, evolving from an "instrumental existence" into an "intelligent agent" possessing initiative [8]. When the means of labor begin to possess "quasi-subjectivity," the traditional boundary between them and laborers becomes blurred. Laborers are compelled to cede part of their decision-making power, and their subject status is thereby weakened.

Second, previous labor relations were established around the traditional logic of "humans dominating tools," and therefore often cannot promptly adapt to changes in the relationship between laborers and the means of labor. The labor regulations, job responsibilities, production processes,

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and even legal frameworks upon which current enterprise operations rely are all fundamentally based on the assumption that "humans are the subjects of labor, while tools are subordinate to humans." However, when embodied intelligence enters the production site in the form of a new type of tool, the old framework of labor relations becomes unable to reconcile the relationship between the two, specifically regarding how to effectively define the status and role of an autonomous "agent" in the production process. This indicates that the marginalization encountered by laborers in the production process is not an isolated technological issue, but rather the inevitable result of old labor relation boundaries being broken through by technological realities after the embedding of a new form of productive force, while corresponding adjustments have failed to be completed simultaneously. Against this background, when the nature of the means of labor changes while institutional frameworks fail to keep pace, the transfer of decision-making power and control becomes the direct cause of the dilemmas in the production process. In traditional production, laborers controlled the labor process through the use of tools. However, in labor processes involving embodied intelligence, because embodied intelligence possesses autonomous decision-making capabilities, key nodes in the labor process are increasingly determined independently by algorithms and machines. Laborers are downgraded from operators to supervisors or even assistants. Although laborers seemingly remain within the labor process, the mode of their existence within production has in fact been passively altered. It is precisely this transfer of control that suppresses the creativity of labor and causes subjectivity to gradually dissolve.

3.2. Implicit data labor exceeds the framework of distribution rules

In the embodied intelligence era, workers unconsciously create a new form of "implicit data labor" during work. This labor has become a key source of value. But today's distribution system still follows industrial-era production rules. It cannot correctly identify, measure or fairly share the value from this new labor, so unfair distribution keeps happening. In the industrial age, value creation mostly relied on workers' physical and mental work. This work had clear measurable features, so distribution systems could judge it well. But embodied intelligence has made value sources more complex. It keeps creating, gathering and sending back large amounts of data during production. These data drive algorithm updates and improve system performance. So "labor objects expand from physical things to information symbols", and data become "a new important labor object" [9]. A new value creation method appears here, one that does not depend on workers' active awareness. Value no longer only lies in physical products—what workers finish. It also exists in their work behaviors, stored as hidden data value. Thus, data labor under embodied intelligence differs greatly from past labor forms. First, it is binding. It always happens with traditional work, so it is hard to split from it. Second, it is unconscious. Workers focus on tasks and do not know they are "making" data. Third, it can be combined. One worker's behavior data has little value alone, but combining and analyzing huge amounts of such data creates great business value.

Under current laws and business rules, data ownership is usually thought to belong to equipment owners or platform operators. This ownership logic follows old industrial-era habits. Back then, products from production tools naturally belonged to capital owners. But data are the main output in the embodied intelligence era, so these old distribution rules no longer work well. Workers actually create data, but the system does not see them as data "makers" or "owners". This system flaw is not random. It comes from big changes in how labor value forms. Embodied intelligence has not removed labor's role in creating value. Instead, distribution rules have not changed at the same time—they still focus on paying for obvious labor, not sharing new value.

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3.3. High industrial entry barriers drive the continuous concentration of capital

The causes of the ecological monopoly dilemma in the exchange process mainly lie in the composite technological characteristics of the embodied intelligence industry itself, which disrupt the prerequisite of equality among subjects necessary for fair exchange. As a result, small and medium-sized enterprises are not eliminated through competition; rather, they are excluded from market entry in advance by multiple extremely high barriers involving hardware, algorithms, data, and capital. Moreover, this inequality is continuously self-reinforced under the drive of capital logic.

Equal exchange relations require equal market subject status as support, including equality among participating subjects in terms of opportunities for market entry, capabilities of information possession, and discourse power in rule-making. The embodied intelligence industry is a composite industry highly dependent on industrial coordination. The realization of the value of an embodied intelligent robot depends not only on hardware manufacturing such as core components and precision assembly, but also on the support of algorithm development involving perception, decision-making, and control models, as well as training data and scenario feedback data. Within this "hardware–algorithm–data" trinity of competitive ecology, enterprises can participate in market competition only on the premise that they possess the capability to integrate multiple industrial sectors. Therefore, inequality in the exchange process does not emerge only after market transactions occur; rather, it is preset and constrained by the industrial structure before market entry even takes place. Even if an enterprise possesses advantages in a certain technological link, if it cannot integrate resources from other links, it is still difficult for it to participate in the exchange of final products as an equal subject.

The characteristics of the embodied intelligence industry—high technology intensity, high investment requirements, and long development cycles—also determine that only a small number of effective market participants can enter the market. The high entry barriers first exclude a large number of potential competitors from the market, and once the number of market participants decreases, technological accumulation, platform resources, and data assets become more easily concentrated in the hands of a few leading enterprises. These enterprises not only possess pricing power over products, but also control the power to formulate exchange rules, such as technical standards, data interfaces, and ecosystem access conditions. Thus, relying on first-mover advantages, the earlier enterprises occupy technological accumulation and data resources, the more capable they become of forming a continuously optimized positive feedback loop: better products attract more users, more users generate more data, more data train better algorithms, and better algorithms further enhance product competitiveness. Exchange relations therefore evolve from "inequality within the market" into "structural inequality," while capital becomes increasingly concentrated in leading enterprises.

3.4. Social structure constrains the popularization of technology

The dilemmas manifested in the consumption process, such as service stratification and the marginalization of inclusive demand, are the result of a profound social process. The popularization of technology has never been a neutral diffusion process; rather, it is a process of power shaped and filtered by social structure. The application effects of digital technology in society are exhibiting an inevitable trend from "digital suspension," characterized by the mutual disconnection between technology and society, toward "digital embeddedness," characterized by the deep integration of technology and society [10]. As a high-cost and high-technology-threshold consumer product, the path of technological popularization for embodied intelligence is, to a large extent, filtered by social

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structure. Factors such as income disparity and differentiated purchasing power transform broad social needs into stratified market demands, causing the technological dividends brought by embodied intelligence, at the initial stage of popularization, to tilt toward resource-concentrated subjects and fields under the drive of capital logic.

Whether a technology benefits the public depends on both its tech maturity and whether it enters real social consumption. Tech spread is not a simple automatic process. Instead, it is a social process about how people accept, use and share the technology. People's consumption ability, ideas and willingness to try new tech all shape how the technology spreads. Besides, real society has clear differences from income, education, location and job. When a new technology enters the market, it does not reach everyone equally. It first goes to people with more money, better education and easier access to information. This unequal start in tech use is not random. It comes from the existing social structure. Gaps in buying power create unequal starting points for different groups. This leads to natural differences in their ability to get new technology.

This social filtering effect grows stronger because the market aims for profit. The market always favors demands that bring higher profits and faster returns, rather than meeting broad social needs. In this process, groups with more money have their demands seen as valid. The market meets these demands first. But the wide needs of poorer groups may be ignored, as they bring less profit. Embodied intelligence makes social inequality worse, showing a "rich-get-richer effect" [11]. Tech benefits keep gathering in certain groups. Meanwhile, income and wealth gaps grow wider in many ways. Social resource gaps mean high-cost new tech first reaches resource-rich areas. So tech benefits become clearly divided during consumption.

4. Reconstruction of human-machine collaborative production relations in the era of embodied intelligence

From the weakening of the subject status of laborers to the failure of distribution principles, from the monopolization of exchange structures to the imbalance of consumption dividends, in response to the various dilemmas of human-machine collaboration in the era of embodied intelligence, this paper advocates proactively promoting institutional adjustment and power restructuring. Through legal updates and industrial policies, ethical boundaries and competitive rules should be established for technological development; through organizational transformation and distributional innovation, ecological monopolies should be broken; and through rights protection and capability empowerment, the subject status and personal dignity of laborers should be safeguarded. In this way, the systematic reconstruction of production relations can empower the positive development of embodied intelligence.

4.1. The macro level: Strengthening top-level design and ensuring technology for good through institutional constraints

At the macro level, the state should establish ethical boundaries for embodied intelligence and provide directional guidance and security guarantees for its development through the supplementation and improvement of laws, policies, and institutions. The dilemmas in the distribution and exchange processes in the era of embodied intelligence lie in the fact that existing legal frameworks can neither accurately identify the value of "data labor" nor provide corresponding legal provisions to restrict the new forms of "data-driven" monopolies.

To this end, efforts should be advanced simultaneously in two respects. First, legislative confirmation of data labor rights should be explored. For the behavioral data unconsciously

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produced by laborers during the embodied intelligence production process, systematically collected and used for algorithmic iteration, yet excluded from the distribution system, a secondary distribution mechanism for data-generated benefits should be established at the legal level. When the data contributed by laborers are used for algorithm training, product iteration, and the creation of value-added profits for enterprises, laborers should have the right to share part of the resulting gains. In terms of legislative pathways, relevant concepts from the European Union's *General Data Protection Regulation* may serve as a reference. The regulation requires automated decision-making systems to provide data subjects with "meaningful information about the logic involved." [12] China may add special provisions within the framework of the *Personal Information Protection Law* and the *Labor Law*, or establish a dedicated chapter on "data labor rights and interests" in a future Artificial Intelligence Law, in order to systematically regulate laborers' data rights in the era of embodied intelligence. Second, the anti-monopoly legal framework should be updated to respond to the ecological monopoly characteristics of the embodied intelligence industry. The exclusionary behaviors of enterprises have become more covert, extending beyond direct exclusionary acts to the natural formation of structural advantages through algorithm optimization and ecological expansion. Accordingly, the *Anti-Monopoly Law* should undergo adaptive revision. The focus of anti-monopoly policy should shift from ex post punishment to ex ante prevention, establishing preventive regulatory mechanisms specifically for the embodied intelligence industry, including obligations of algorithmic transparency, mandatory standards for open data interfaces, and interoperability requirements. Specific measures may include introducing a "data asset" evaluation dimension into merger review procedures and conducting key scrutiny over mergers and acquisitions involving core data resources.

In sum, macro-level institutional reconstruction responds to the two major dilemmas of distributive injustice and ecological monopoly by establishing legal and policy boundaries for production relations in the era of embodied intelligence. Although macro-level institutional design does not directly intervene in specific production sites, it provides the foundation of legitimacy and rigid constraints for subsequent meso-level organizational transformation and micro-level rights protection, thereby constituting the primary prerequisite for reconstructing harmonious human-machine collaborative relations.

4.2. The meso level: Breaking ecological monopolies and constructing a collaborative development pattern

If macro-level institutional design provides legal guarantees and policy orientation for the reconstruction of production relations, then the meso level serves as the key hub for transforming macro visions into concrete practices. As intermediary organizations situated between macro policies and micro individuals, enterprises, trade unions, and industry associations are not only executors of macro institutions but also concrete implementers of labor rights. It is therefore necessary to promote the transformation of the relationship between these organizations and laborers from one characterized by unilateral discourse power to one characterized by collaborative symbiosis.

First, organizational management models should be transformed to address the loss of laborers' subjectivity in the production process. The introduction of embodied intelligence has transformed laborers from leaders of operations into subjects of algorithmic dispatch, with their labor rhythms finely controlled by algorithms and their labor creativity greatly compressed. Enterprises should establish and expand institutionalized channels for laborer participation in decision-making,

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enabling frontline workers to participate in the design of embodied intelligence workflows and the formulation of performance evaluation rules.

Second, collective bargaining mechanisms within distribution models should be improved in order to promote the sharing of data-generated benefits with laborers. The implicit data labor of workers creates enormous commercial value during the embodied intelligence production process, yet this value has not been incorporated into the existing distribution system. Therefore, the key to improving the mechanism lies in formally incorporating "data benefit sharing" into labor-capital negotiation agendas through collective bargaining mechanisms organized by trade unions. In 2025, the "centralized consultation initiative" promoted by the All-China Federation of Trade Unions provided a highly enlightening practical example: to date, 15 leading platform enterprises have been included within the scope of algorithmic consultation, focusing negotiations on core labor rights such as labor remuneration, the right to rest, labor safety, and workers' rights to be informed about and participate in algorithmic governance [13]. This demonstrates that collective bargaining can effectively transform algorithmic rules from unilateral corporate decisions into mechanisms of pluralistic co-governance.

Finally, an open industrial ecosystem should be constructed in order to break platform technological barriers. The ecological monopoly dilemma of the embodied intelligence industry originates from the "hardware–algorithm–data" trinity of composite competitive structures. Artificial intelligence driven by "algorithms + data" may trigger multiple monopoly risks such as model collusion, data exploitation, discriminatory licensing, and ecological enclosure [14]. To break this structure, industry associations and leading enterprises should jointly promote the unification of embodied intelligence data interfaces, communication protocols, and safety standards, enabling embodied intelligence systems from different manufacturers to operate collaboratively within the same ecosystem. At the same time, leading enterprises should be encouraged to open portions of their technological platforms and data resources, while industry-level data-sharing mechanisms, open-source algorithm libraries, and public training platforms should be established to lower the technological barriers for small and medium-sized enterprises to participate in market competition, thereby returning market competition to a healthy trajectory driven by innovation and efficiency.

Meso-level organizational transformation and industrial openness transform macro-level institutional design into operable practical pathways while also providing organizational carriers for micro-level rights protection. The three dimensions of production, distribution, and industry are closely interconnected: laborers' participation reshapes power structures, collective bargaining reconstructs distribution patterns, and industrial openness safeguards market vitality. The coordinated efforts of these three dimensions provide an organizational pathway for human-machine collaboration to move from "dependence" toward genuine "symbiosis."

4.3. The micro level: Empowering laborers and safeguarding their dignity

Macro-level institutional design and meso-level organizational transformation ultimately materialize in the concrete conditions faced by individual laborers within embodied intelligence production sites. In the face of dilemmas in which laborers are compelled to cede decision-making power, their bodily rhythms are finely disciplined by algorithms, and their behavioral data are collected without compensation, only through the effective protection of laborers' concrete rights can the unilateral domination of algorithms be restrained and the subjectivity and personal dignity of laborers be safeguarded.

The starting point for resolving this dilemma lies in granting laborers the rights to information and explanation. In embodied intelligence production scenarios, laborers are often entirely unaware

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of what behavioral data are being collected from them and how such data are used in algorithmic decision-making, leaving them excluded from the scope of knowledge concerning algorithmic decisions. Therefore, the law should explicitly require enterprises to inform laborers, in a concise and transparent manner, of the scope, methods, purposes, and storage periods of data collection. At the same time, when automated decisions made by algorithms exert significant impacts on laborers' work arrangements, remuneration assessments, and other matters, laborers should have the right to require enterprises to provide clear explanations regarding the logic, basis, and key parameters of such decisions. Only by achieving meaningful algorithmic transparency can laborers hope to free themselves from the disadvantaged position created by information asymmetry. In February 2025, the Court of Justice of the European Union, in the Dun & Bradstreet Austria case (C-203/22), confirmed that data subjects have the right to obtain a "meaningful explanation" regarding the logic of automated decision-making, and that such an explanation must enable them to "meaningfully exercise the procedural rights to obtain human intervention, express their point of view, and challenge the decision." The judicial practices of the European Union provide useful reference points for China [15]. In China, the Measures for the Ethical Review and Services of Artificial Intelligence Science and Technology (Trial Implementation), issued in April 2026 by the Ministry of Industry and Information Technology together with nine other departments, has already explicitly required that artificial intelligence products and services should "reasonably disclose information such as the purposes, operational logic, interaction methods, and potential risks of algorithms, models, and systems, and adopt effective technical measures to enhance their explainability." [16] This provides a policy basis for the institutional implementation of the rights to information and explanation in embodied intelligence scenarios. Accordingly, laborer feedback mechanisms should also be established and improved, so that workers' feedback regarding labor rhythms, safety risks, process defects, and related issues can be incorporated into the optimization and iteration procedures of the system.

In summary, the rights to information and explanation enable laborers to penetrate the "black box" of algorithms, while laborer feedback mechanisms elevate workers from passive objects of discipline into active participants in technological governance. Together, these three dimensions consolidate, at the micro level, the power foundation for symbiotic human-machine collaboration, allowing the alienated relationship of dependence between humans and machines to return to collaborative development, thereby genuinely safeguarding the subjectivity and personal dignity of laborers.

5. Conclusion

The deep embedding of embodied intelligence is reshaping the fundamental form of human-machine collaboration, and the contradictions in production relations thus generated have become unavoidable practical issues. Unlike existing studies that primarily discuss embodied intelligence from the perspectives of technological feasibility or ethical principles, this paper, proceeding from Marx's political economy theory of reproduction, examines the structural dilemmas faced by human-machine collaboration in the era of embodied intelligence along the four dimensions of production, distribution, exchange, and consumption, thereby revealing the deeper causes of these dilemmas. These dilemmas are not the inevitable costs of technological progress; rather, they are the inevitable consequence of capital logic reshaping the labor process through data and algorithms while existing production relations fail to undergo corresponding adjustments.

This paper has mainly focused on theoretical analysis and institutional critique. Due to research limitations, empirical investigations into differences in the application of embodied intelligence

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across industries and enterprises of different scales remain insufficient, and the quantitative accounting of the value of data labor also requires further in-depth study. The trajectory of human-machine collaboration is not a deterministic destiny dictated by technology. From the rigid protection of laborers' rights to institutional constraints on capital logic, from the proactive construction of distributive justice to the inclusive sharing of technological dividends, the systematic reconstruction of production relations requires coordinated efforts at the macro, meso, and micro levels, so that embodied intelligence may truly become a real force for promoting human emancipation rather than alienation.

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