Simulation Modeling of the Transformation of Labor Market Institutions in the Covid-19 Era

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Abstract: This article delves into the transformative impact of digital technology on labor market institutions, particularly under the catalytic influence of the Covid-19 pandemic. It examines how the pandemic accelerated the formation of a comprehensive digital ecosystem, leading to a "disruption" or revolutionary transformation of the world economy's structure and socio-economic formation. Through detailed analysis, the study underscores the evolutionary trajectory of institutional changes, characterized by the development of mixed institutions and a global shift in job requirements towards increased mobility and flexibility. This shift is evident in the growing trend of temporary or part-time employment under short-term labor contracts, signaling a marginalization of the full-time permanent employment model. The article also explores the digital economy's role in fragmenting and modularizing work of various complexities, impacting labor relations through digital labor exchanges. It highlights the challenges in developing social protection for the self-employed and the inconsistency of institutions with the rapidly evolving business models and labor relations. The study concludes that in the face of cascading innovations and revolutionary changes, it is currently impractical to develop a universal institutional model. Instead, it advocates for accepting hybrid, fragmented, and imperfect regulatory policies as the new normal, underscoring the need for adaptive, flexible approaches in redesigning labor market institutions in this era of significant digital transformation.

1 INTRODUCTION

In the wake of the COVID-19 pandemic, the global labor market has undergone unprecedented transformations, necessitating a comprehensive analysis of its evolving landscape. This paper addresses the critical need to understand these shifts through the lens of simulation modeling, a tool that has become increasingly vital in analyzing complex, dynamic systems.

The onset of the pandemic has catalyzed significant changes across labor market institutions, disrupting traditional employment paradigms and accelerating the integration of digital technologies. The sudden shift to remote work, the rise of gig economy platforms, and the varying impacts across sectors have highlighted the fragility and adaptability of labor markets worldwide. This paper seeks to model these transformations, offering insights into the underlying mechanisms driving these changes and potential pathways for future development.

Drawing upon a rich tapestry of interdisciplinary research, this study employs a novel approach combining system dynamics with advanced simulation techniques. This methodology allows for a detailed examination of the interplay between various labor market agents, institutional frameworks, and the broader socio-economic context influenced by the pandemic. The objective is to not only chart the immediate impacts of COVID-19 on labor markets but also to project long-term trends and potential policy interventions.

The significance of this research lies in its ability to inform policymakers, industry leaders, and

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academics about the evolving nature of work, employment, and institutional structures in the post-pandemic era. By simulating various scenarios and examining their outcomes, the paper aims to contribute to the strategic planning and decision-making processes that will shape the future of labor markets globally.

2 MATERIALS AND METHODS

The object of this study was contemporary labor market institutions, as identified by Popov (2019). The research focused on the economic relations between labor market agents within the context of the digital transformation and the COVID-19 pandemic, which are overlapping and mutually reinforcing phenomena.

The research methodology comprised a comparative meta-analysis of qualitative scholarly literature, utilizing Critical and Extended Institutional Approaches. The Critical Institutional Approach (CIA), as per Cleaver and Koning (2015), focused on analyzing power dynamics and unequal access within institutions, advocating for adaptive behavior over rational behavior, leading to hybrid institutional structures. The Extended Institutional Approach (EIA), detailed by Frolov (2020), emphasized the complexities within institutional hybrids, including both overt and covert tensions. The study explored digitalization's impact on labor market institutions, examining the potential of digital technologies in various service sectors and their role in fostering economic growth. This included the development of digital platforms, blockchain technology, and machine learning in the context of big data and high-speed internet. Emphasizing evolutionary development principles, the research addressed the need for both formal and informal economic institutions to navigate the challenges of digitalization. Proactive institutional designs were proposed for enhancing digital work and providing social guarantees for digital workers. Additionally, a comparative institutional analysis based on new institutional economic theory (Frolov & Lavrentyeva, 2019) was conducted, focusing on transaction costs, market power distribution, and the exploitation of digital workers in the evolving creative economy.

The study was structured as follows: 1) analysis of labor market dynamics, identifying synchronous and asynchronous trends in digital transformations across countries, sectors, and employee categories; 2) scenario modeling of labor market institution development under pandemic conditions, including the comparison of evolutionary and revolutionary scenarios; 3) examination of the marginalization of full-time permanent employment, precarity, platform employment, and associated risks; 4) analysis of youth labor market support and the institution of youth guarantee; 5) exploration of the transformation in the state's role in the labor market towards active intervention and demand for non-standard regulatory methods.

To create a model that accurately represents the necessary aspects of the problem area, the system dynamics method was utilized. This served as a tool for simulation modeling, enabling the development of a complex system model for analysis, effective management strategies, and forecasting changes in labor market processes (Bossel, 2018; Honti et al., 2019; Bazhina et al., 2020). The structural analysis method was used to gather the required data, facilitating the identification of the hierarchical structure of the problem area and detailing the key objects, processes, and parameters affecting. To create a model that reflects the necessary aspects of the problem area, the method of system dynamics was employed. This approach serves as a tool for simulation modeling, enabling the creation of an accurate model of a complex system for analysis, the development of effective management strategies, and the forecasting of changes in labor market processes. To acquire the data required for the modeling process, the method of structural analysis was utilized. The structural analysis method facilitated the identification of the hierarchical structure of the problem area, detailing the key objects, processes, and parameters that influence their qualitative and quantitative states (Isaeva et al., 2020); Yakimchenko et al., 2017; Laguna & Marklund, 2018).

3 RESULTS

The use of structural analysis methods and simulation modeling facilitated the development of a system dynamics model of the labor market (Fig. 1).

The model depicted in Fig. 1 can conventionally be divided into three areas, corresponding to the employment status of an individual: inexperienced, employed, and unemployed (highlighted in green). From the perspective of simulation modeling, these are accumulators, representing the quantitative composition of structured objects at a specific time. Various processes, indicated by arrows, influence their numbers.

In the labor market, any citizen can only be in one of two statuses: employed (regardless of the form of employment) or unemployed (regardless of the reasons). The increase in the number of workers occurs naturally due to citizens reaching working age or decreases (retirement, limitations in work ability due to physical characteristics, or death). In the model, citizens who have reached working age are denoted as 'inexperienced workers'. Table 1 presents a description of the processes and parameters that influence the number of such citizens.

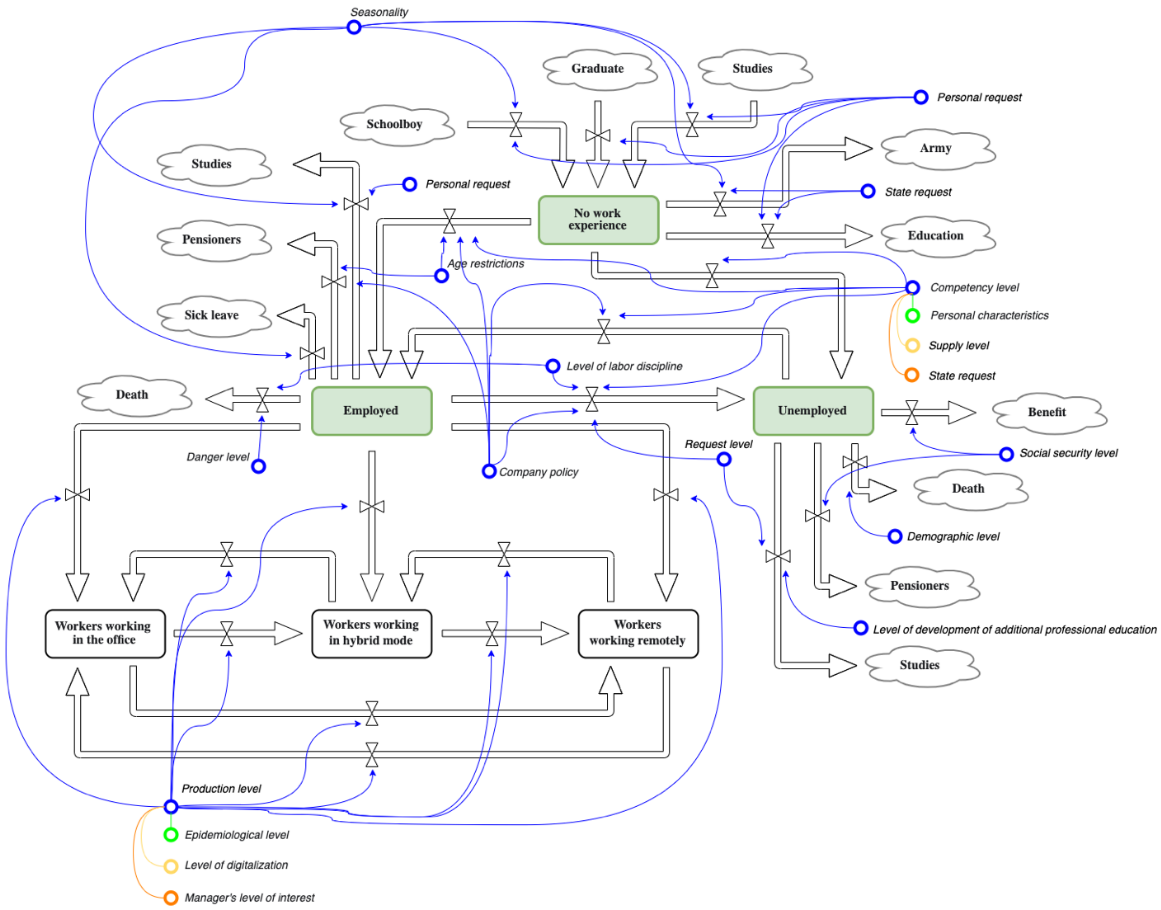

Figure 1: System dynamics model of the labor market.

Table 1: Processes of forming labor resources without work experience.

Title	Characteristic	Designation
Schoolboy	Have time limitations for labor activities, not the main type of employment, and dependent on seasonality (e.g., work during holidays).	*Sch*
Graduate	College and University Graduates. Possess developed professional competencies, minimal work experience.	*Gra*
Studies	Students of educational institutions who combine study and work. Work schedule depends on seasonality (during holidays) and academic timetable.	*Stu*
Army	Graduates of educational institutions conscripted for mandatory military service, or students reaching the age limit and subject to conscription. They contribute to processes that cause an outflow of working citizens.	*Arm*
Education	Graduates of educational institutions enrolled in further education levels and without permanent	*Edu*

	employment. They contribute to processes that result in the outflow of the workforce.	
Seasonality	A parameter characterizing time intervals. These intervals include holidays, final assessments in educational institutions, military conscription, etc. During peak periods, there is an increase in the number of requests for employment.	*SeaSon*
Personal request	A parameter characterizing an individual's personal requests in job search (requirements for location, work schedule, monetary compensation, etc.). For instance, the job placement process slows down with exaggerated demands.	*PerReq*
State request	A parameter characterizing the level of government demand for labor (either federal or regional). It indicates the quantity and quality of job positions.	*StaReq*
Competency level	A parameter characterizing the competency level of a job applicant (such as level of education, computer literacy, work experience, etc.).	*ComLev*
Personal characteristics	A parameter related to the personal characteristics of an individual (for example, age, gender, physical and psychological traits).	*PerCha*
Supply level	A parameter related to the level of job offers, including the availability and number of positions, salary level, and employee incentives.	*SupLev*
Company policy	A parameter associated with the limitations or requirements set by an organization for employment (for example, age, wage level)	*ComPol*
Age restrictions	An age limitation parameter. It influences the work schedule and the feasibility of conducting labor activities.	*AgeRes*

Based on the data presented in Table 1, a parametric model has been created, which serves as the basis for the No Work Experience (NWE) labor resources area in the system dynamics model:

$$\frac{dNWE}{dt} = Sch \cdot i_{Sch} + Gra \cdot i_{Gra} + Stu \cdot i_{Stu} - Arm \cdot i_{Arm} - Edu \cdot i_{Edu} - EMP \cdot i_{EMP} - UNEMP \cdot i_{UNEMP},$$

where t – simulation time interval,

i_{Sch} – the *Sch* storage device change rate coefficient, equal to $SeaSon(t) \cdot PerReq(t)$;

i_{Gra} – the *Gra* storage device change rate coefficient, equal to $PerReq(t)$;

i_{Stu} – the *Stu* storage device change rate coefficient, equal to $SeaSon(t) \cdot PerReq(t)$;

i_{Arm} – the *Arm* storage device change rate coefficient, equal to $SeaSon(t) \cdot StaReq(t)$;

i_{Edu} – the *Edu* storage device change rate coefficient, equal to $PerReq(t) \cdot StaReq(t)$;

i_{EMP} – коэффициент темпа изменения накопителя *EMP* (трудоустроенные), equal to $AgeRes(t) \cdot ComPol(t) \cdot ComLev(t) \cdot PerCha(t) \cdot SupLev(t) \cdot StaReq(t)$;

i_{UNEMP} – коэффициент темпа изменения накопителя *UNEMP* (безработные), equal to $ComPol(t) \cdot ComLev(t) \cdot PerCha(t) \cdot SupLev(t) \cdot StaReq(t)$.

If we generalize all cases, a citizen can become unemployed either at the end of their employment with an employer (due to personal initiative, the employer's initiative, or the expiration of the employment contract) or at the beginning of their work life (for example, after graduating from an educational institution). Table 2 presents a description of the processes associated with unemployment and the parameters affecting their numbers.

Table 2: Processes forming the number of potential labor resources.

Title	Characteristic	Designation
No work experience	Citizens who have reached working age, in search of their primary job (not combined with education).	*NWE*
Employed	Stream of workers who, for various reasons, lack a primary place of employment (contributing to the increase in unemployment numbers), or have become employed irrespective of the type of employment	*EMP*

	(contributing to the decrease in unemployment numbers).	
Benefit	Unemployed individuals receiving state unemployment benefits.	*Ben*
Death	Citizen's death, irrespective of the cause.	*Dea*
Pensioners	Citizens who have ended their work career upon reaching the maximum age, varying by their field of activity.	*Pen*
Studies	Citizens engaged in retraining to switch their professional field of work.	Stu_{UNEMP}
Request level	A parameter indicating the level of demand for labor resources by an organization.	*ReqLev*
Level of development of additional professional education	A parameter defining the required educational level for qualification enhancement or retraining. This facilitates the professional advancement of an individual and the improvement of work conditions (related to moving to a new role within an organization).	*DevLev*
Demographic level	A parameter reflecting the demographic situation in a region or country (such as life expectancy, mandatory period of labor activity).	*DemLev*
Social security level	A parameter indicating the level of social development in a region or state. This determines the extent of support provided to unemployed citizens, including the establishment of employment centers, financial aid, career centers, etc., and the quality of medical services available for maintaining citizens' life and health.	*SocLev*
Level of labor discipline	A parameter reflecting an employee's compliance with labor discipline. An increase in disciplinary breaches speeds up the transition of an employee from 'employed' to 'unemployed' status.	*DisLev*

It should be noted that the accumulators and flows whose characteristics were presented in Table 1 are not included in Table 2. This is due to the fact that their descriptions are identical.

Based on the data presented in Table 2, a parametric model has been developed, which serves as the basis for the unemployment area in the system dynamics model:

$$\frac{dUNEMP}{dt} = NWE \cdot i_{NWE} + EMP_1 \cdot i_{EMP_1} - EMP_2 \cdot i_{EMP_2} - Ben \cdot i_{Ben} - Dea \cdot i_{Dea} - Pens \cdot i_{Pen} - Stu_{UNEMP} \cdot i_{Stu_{UNEMP}},$$

where t – simulation time interval,

i_{NWE} – the *NWE* storage device change rate coefficient, equal to $ComLev(t) \cdot PerCha(t) \cdot SupLev(t) \cdot StaReq(t)$;

i_{EMP_1} – the EMP_1 (increases the number of unemployed) storage device change rate coefficient, equal to $ComLev(t) \cdot PerCha(t) \cdot SupLev(t) \cdot StaReq(t) \cdot ComPol(t) \cdot RecLev(t) \cdot DisLev(t)$;

i_{EMP_2} – the EMP_2 (reduces the number of unemployed) storage device change rate coefficient, equal to $ComLev(t) \cdot PerCha(t) \cdot SupLev(t) \cdot StaReq(t) \cdot ComPol(t)$;

i_{Ben} – the *Ben* storage device change rate coefficient, equal to $SocLev(t)$;

i_{Dea} – the *Dea* storage device change rate coefficient, equal to $DemLev(t) \cdot SocLev(t)$;

i_{Pen} – the *Pen* storage device change rate coefficient, equal to $SocLev(t)$;

$i_{Stu_{UNEMP}}$ – the Stu_{UNEMP} storage device change rate coefficient, equal to $EduLev(t) \cdot ReqLew(t)$.

The characteristics of processes and parameters influencing the number of employed (EMP) citizens are presented in Table 3. It does not include processes and parameters whose descriptions are identical to those in Tables 1 and 2.

Table 3: Processes of forming the quantity of labor resources.

Title	Characteristic	Designation
Studies	Workers who have terminated their employment due to the commencement of an educational period, where work	Stu_{EMP}

	was not their primary form of activity.	
Pensioners	Workers who have concluded their employment upon reaching the age limit.	Pen_{EMP}
Sick leave	Temporarily incapacitated workers (including employees on parental leave).	*Sic*
Death	Death of an employee occurring directly at the workplace or during non-working hours.	Dea_{EMP}
Workers working in the office	Employees engaged in work activities on the premises of the employer. This value does not impact the overall count of employed individuals but provides detail about the nature of the work location.	*WWO*
Workers working in hybrid mode	Employees engaged in work activities both on-site at the employer's premises and remotely. This value does not impact the total number of employed individuals but provides specifics about the nature of the work location.	*WWG*
Workers working remotely	Employees engaged in work entirely outside of the employer’s premises (fully remote work). This value does not influence the total number of employed individuals but elaborates on the nature of the work location.	*WWR*
Danger level	A parameter defining the level of risk associated with the work performed. It necessitates compliance with safety procedures and job instructions. This parameter influences the rate of worker mortality in the organization.	*DanLev*
Production level	A parameter defining work activity. It influences the ability to organize work remotely or in a hybrid format (for instance, office work may be allocated to employees engaged in continuous production, or those requiring access to restricted resources or confidential information).	*ProLev*
Epidemiological level	A parameter reflecting the level of the epidemiological situation at the employer's location, regionally, nationally, or globally (such as quarantine measures implemented after detecting a pathogen dangerous to human life and health). This parameter is directly proportional to the acceleration of shifting employees to remote or hybrid work arrangements.	*EpiLev*
Level of digitalization	A parameter indicating the level of automation and digitization within an organization. A higher degree of this parameter facilitates the faster transition of employees to hybrid or remote work modes, while also considering the employee's level of computer literacy.	*DigLev*
Managerr's level of interest	A parameter reflecting the interest of the	*ManLev*

	organization's (or department's) leader in transitioning employees to remote or hybrid work arrangements.	

Based on the data presented in Table 3, a parametric model has been developed, which serves as the foundation for the employed area in the system dynamics model:

$$\frac{dEMP}{dt} = NWE \cdot i_{NWE} + UNEMP_1 \cdot i_{UNEMP_1} - UNEMP_2 \cdot i_{UNEMP_2} - Sic \cdot i_{Sic} - Dea_{EMP} \cdot i_{Dea_{EMP}} - Pens_{EMP} \cdot i_{Pen_{EMP}} - Stu_{EMP} \cdot i_{Stu_{EMP}},$$

where t – simulation time interval,

i_{NWE} – the *NWE* storage device change rate coefficient, равный *ComLev*(*t*);

i_{UNEMP_1} – the $UNEMP_1$ (increases the number of employed) storage device change rate coefficient, равный *ComLev*(*t*) · *PerCha*(*t*) · *SupLev*(*t*) · *StaReq*(*t*) · *ComPol*(*t*);

i_{UNEMP_2} – the $UNEMP_2$ (reduces the number of employees) storage device change rate coefficient, equal to *DisLev*(*t*) · *RecLev*(*t*) · *ComPol*(*t*);

i_{Sic} – the *Sic* storage device change rate coefficient, equal to *SocLev*(*t*) · *SeaSon*(*t*);

$i_{Dea_{EMP}}$ – the Dea_{EMP} storage device change rate coefficient, equal to *DisLev*(*t*) · *DanLev*(*t*);

$i_{Pen_{EMP}}$ – the Pen_{EMP} storage device change rate coefficient, equal to *SocLev*(*t*) · *ComLev*(*t*) · *AgeRes*(*t*);

$i_{Stu_{EMP}}$ – the Stu_{EMP} storage device change rate coefficient, equal to *SeaSon*(*t*) · *ReqLew*(*t*).

The parametric model for determining the number of workers engaged in labor activities based on their location is as follows:

$$\begin{cases} \frac{dWWO}{dt} = i_{WW}(EMP - WWG - WWR), \\ \frac{dWWG}{dt} = i_{WW}(EMP - WWO - WWR), \\ \frac{dWWR}{dt} = i_{WW}(EMP - WWO - WWG), \end{cases}$$

where i_{WW} – process change rate coefficient, equal to *ProLev*(*t*) · *EpiLev*(*t*) · *DigLev*(*t*) · *ManLev*(*t*).

The analysis confirmed that the current crisis has a heterogeneous impact on various industries and socio-economic groups. Sectors severely affected include those impacted by isolation measures and disrupted value chains, such as hospitality, tourism, cultural events, retail trade, and logistics.

The study identified a trend towards global changes in labor force requirements, with an emphasis on increased mobility and temporary employment. This leads to the marginalization of full-time permanent employment and the development of new labor market institutions associated with temporary or part-time employment.

Special attention is given to the impact of the digital economy on the fragmentation and modularization of work. Technological capabilities allow for effective outsourcing through digital platforms, altering the nature of labor relations.

The need to develop social protection mechanisms for self-employed individuals and workers on short-term contracts is identified, in light of increasing informal norms of labor relations on platforms.

It is shown that institutional models and regulations are not keeping pace with rapidly and profoundly changing business models and forms of labor relations, necessitating flexible and adaptive regulatory approaches.

The pandemic has accelerated digitalization and structural changes, forcing companies to utilize digital tools to enhance resilience to external shocks.

It is noted that young workers and immigrants are particularly vulnerable in the current crisis, requiring special measures for support and integration.

Unprecedented state intervention in the economy is observed, aimed at stabilizing income and employment, with a focus on digital transformation and the development of new legal models for adaptation to changing conditions.

The research emphasizes that the current crisis and associated digitalization processes are leading to the formation of hybrid and dynamic labor market models, requiring a comprehensive approach to analysis and regulation.

4 DISCUSSION

Simulation modeling, as a tool for creating digital twins, has been widely used across various scientific fields including transportation (Krasnikov et al., 2022; Nikishina et al., 2023), sustainable development (Kolodochkin et al., 2023), and ecology (Cressie & Wikle, 2015; Ji, 2017). This approach helps accurately model the characteristics influencing changes in states of various systems. Our study utilized this method to analyze the labor market's response to economic and epidemiological shifts, technological advancements, and varying forms of labor activity (Nikitina et al., 2017; Chernikova et al.

2020). The model developed can guide sustainable economic development and inform practice-oriented education in state and municipal administration, labor economics, and statistics.

The COVID-19 pandemic has accelerated the shift towards more flexible business operations and affected migrant labor markets (Ranjan & Bisht, 2020), emphasizing the need for effective succession planning (Barton, 2019). The study identifies a new form of institutional inequality, dividing employers into innovators and conservatives based on their approach to skills and work modalities (Seymour-Walsh et al., 2020; Zainuddin et al., 2019; Foo et al., 2020; Rangachari & Woods, 2020). Additionally, it highlights the growing gap between existing labor market institutions and rapidly changing business models due to digitalization. This shift is leading to a rise in project-based, temporary jobs requiring specialized competencies, challenging traditional employment and education systems. The study suggests that states must adopt hybrid, fragmented, and imperfect regulatory policies in response to these disruptions, accepting that a universal approach to labor market institution redesign is impractical.

5 CONCLUSION

The simulation modeling of labor market institution transformations in the COVID-19 era reveals a nuanced landscape marked by the interplay of digitalization and pandemic-induced changes. Our analysis suggests a departure from traditional labor market structures towards a new paradigm characterized by hybrid institutions that blend elements of pre-digital and digital models. A key feature of this transition is the technological facilitation of modular work, leading to the marginalization of full-time permanent employment and the rise of flexible, short-term employment models. The COVID-19 pandemic has notably accelerated these changes, underscoring the lag in regulatory institutions' ability to keep pace with rapid shifts in labor relations and business models. This reality points towards a future where fragmented and adaptive regulatory policies become the norm, requiring continuous monitoring and dynamic policy adjustments by public authorities. This study highlights the critical need for flexible, informed approaches to labor market regulation that can effectively respond to the evolving landscape of work in a post-pandemic, digitally-transformed world.

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